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Determinants of market uptake of innovation in a situation of uncertainty about environmental and health risks: From BPA to nanotechnology

Mariia Ostapchuk

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THÈSE DE DOCTORAT

de l'Université de recherche Paris Sciences et Lettres
PSL Research University

Préparée à l'Université Paris-Dauphine

Determinants of market uptake of innovation in a situation
of uncertainty about environmental and health risks:
From BPA to nanotechnology

École Doctorale de Dauphine — ED 543

Spécialité **Sciences de gestion**

**Soutenue le 28.11.2017
par Mariia OSTAPCHUK**

Dirigée par **Claire AUPLAT**

COMPOSITION DU JURY :

Mme Claire AUPLAT
Université Paris-Dauphine
Directrice de thèse

M. Albert DAVID
Université Paris-Dauphine
Président du jury

M. Jean-Yves BOTTERO
CNRS (émérite)
Rapporteur

Mme Sylvie LUPTON
UniLaSalle
Rapporteure

Mme Myriam MERAD
Université Nice Sophia Antipolis
Rapporteure

M. Pascal LE MASSON
MINES ParisTech
Membre du jury

M. Mark WIESNER
Duke University
Membre du jury

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Chapter 1. Background of the thesis

Recent advances in analytical and imaging technologies made it possible to manufacture nanomaterials which have led to nanotechnology innovations (Mark R. Wiesner, Lowry, Alvarez, Dionysiou, & Biswas, 2006). Nowadays the physical and chemical properties of nanoparticles can be controlled and adapted for particular applications (Mark R. Wiesner & Bottero, 2007). Uncertainty about environmental and health risks that surrounds nanotechnology raises the questions of innovation success. As the market for nanotechnology expands, managerial interest in understanding the drivers of uptake of nanomaterials grows. Due in part to a lack of consistent data, there is limited empirical literature on determinants of diffusion of nanotechnology. We attempt to address the following general question about the diffusion of innovation: What are the main factors that influence the uptake of innovation in a situation of uncertainty about environmental and health risks?

This chapter is organized as follows. First, it establishes the context and importance of our research. Second, we provide our main working hypothesis. Third, this chapter lists the specific research questions and it gives a brief overview of the research structure.

1.1. Introduction

In 2000, the National Nanotechnology Initiative (NNI) was established by President Clinton in the United States of America (USA). The initiative was started with the goal of developing a nanotechnology research, promoting the process for conceiving of new products based on new technologies, training a highly skilled workforce, developing an infrastructure for nanotechnology and advocating responsible nano-development¹. The Nanotechnology Research Directions report (IWGN, 1999) had recommended launching this initiative and

¹ <https://www.nano.gov/about-nni/what/vision-goals>, accessed in April 2017

providing government funding in the amount of about \$500 million dollars (twice as high as in 1999) to support nanotechnology. With the help and support of this initiative more than \$23 billion have been invested in nanotechnology since 2001 (National Science and Technology Council Committee on Technology, 2016). In Europe, public funding has increased from around €200 million in 1997 to around €1 billion in 2004 (European Commission, 2004). Nanotechnology is funded by the European Commission through the Seventh Framework Programme (2007-2013) and Horizon 2020 (2014-2020) (European Commission, 2013). These are some examples of funding of nanotechnology research. In comparison to nanotechnology, the budget for EU²-funded satellite program Galileo (for satellite navigation) is limited to €100 million for 2014-2020 with the funding for space research programs in the amount of €13.5 billion³. Space research and innovation activities are funded by the European Commission through Horizon 2020 (Reillon, 2015, 2017). What is nanotechnology and why it has been included in research and innovation programs all over the world?

“Nanotechnology encompasses science, engineering, and technology at the nanoscale, which is about 1 to 100 nanometers. Just how small is that? A nanometer is one-billionth of a meter. For reference, a sheet of paper is about 100,000 nanometers thick. Nanoscale matter can behave differently than the same bulk material. For example, a material’s melting point, color, strength, chemical reactivity, and more may change at the nanoscale” (National Science and Technology Council Committee on Technology, 2016, p. 1). There is no agreed definition of nanotechnology. In 2011, the European Commission (Commission recommendation of 18 October 2011 on the definition of nanomaterial, 2011) gave a definition of a nanomaterial: “a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm-100 nm. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness, the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50 %”. However, the Recommendation on the definition of a nanomaterial (2011/696/EU) imposes no binding legal obligations. The discussion about a definition that can be applied to all regulatory documents is ongoing (Bernard, 2016a).

² European Union

³ https://europa.eu/european-union/topics/space_en, accessed in April 2017

Expected economic impact of nanotechnology is huge. Commercialization of nanotechnology is one of the main goals of the NNI. The NNI Strategic plan states “Facilitate transfer of new technologies into products for economic growth, jobs, and other public benefit” (as cited in Bozeman, Hardin, & Link, 2008, p. 753). The European Commission highlights the importance of key enabling technologies (KETs) which include nanotechnology to European sustainable growth and its competitiveness in world markets. For example, nanotechnology is expected to benefit the following sectors: energy, health care and environment. Nanotechnology was chosen not only because of its economic potential, but also its potential societal impact, its knowledge intensity and a pervasive effect on different types of innovation. Besides, key enabling technologies can make regional comparative advantage stronger. “KETs are supposed to have great potential for the exploitation and eventual transformation of the competencies accumulated at the local level over time” (Evangelista et al., 2017, p. 4). Nanotechnology innovation might help to address issues related to environmental contamination including air pollution, clean drinking water, waste, food safety, etc. (O’Rourke, Winans, Pasanen, Werner, & Brand, 2001). It is currently used in various areas: medicine, information technology, energy production and storage, security, food, electronics, etc (European Commission, 2004; Nowack, Krug, & Height, 2011; Pulit-Prociak & Banach, 2016). While cancer is one of the principal causes of death worldwide, a technological innovation is needed to decrease cancer mortality rates. A cancer treatment is one of the research areas of nanotechnology including a cancer diagnosis and it might offer promising solutions to this problem (Gmeiner & Ghosh, 2014).

Meanwhile, several working groups on nanotechnology have been established all over the world. For example, the Organisation for Economic Co-operation and Development, OECD established the Working Party on Manufactured Nanomaterials (WPMN) in 2006. OECD prepared guidelines related to exposure to nanomaterials in laboratories and for the testing of nanomaterials over the period of 2008-2009 and published a large quantity of reports related to exposure assessment of nanomaterials in 2016. Numerous international and national workshops, conferences and summer schools related to nanotechnology are also organized all over the world to discuss health and environmental issues related to nanomaterials. Why is there so much attention surrounding health and environmental issues? Nanotechnology has become the subject of considerable debate due to uncertainty about environmental and health risks associated with the production and use of nanotechnology

innovations. This uncertainty adds to different uncertainties inherent in every innovation. The uncertainty about environmental and health risks is a consequence of a lack of knowledge on exposure and hazards level. For instance, since the early 2000s, concerns over potential risks from exposure to carbon nanotubes have been raised. Several studies have shown that the use of some carbon nanotubes may lead to “asbestos-like effects”. As a result, the United States National Institute for Occupational Safety and Health recommended an exposure limit (WHO⁴ Regional Office for Europe, 2013). At the present time, the exposure level to different nanomaterials is difficult to define as nanomaterials are not often indicated as components (Scientific Committee on Emerging and Newly Identified Health Risks, 2014). Besides, production data (methods, volume and capacity) is rarely disclosed (Hendren, Mesnard, Dröge, & Wiesner, 2011). In addition to define the level of exposure, the other factors should be considered, for example, form and size of particles and their concentration. The occupational exposure to nanomaterials has not been completely examined. Further investigation is required to better understand genotoxicity of nanomaterials (Scientific Committee on Emerging and Newly Identified Health Risks, 2014).

Previous experience with Genetically Modified Organisms (GMOs) in food suggests that these types of risk and related uncertainty may lead to the rejection of innovation (Paddock, 2010; Steenis & Fischer, 2016). Besides, some applications of nanomaterials related to food are frequently compared to genetically modified organisms in terms of societal acceptance (Gupta, Fischer, George, & Frewer, 2013)⁵.

This short discussion on pledges and perils related to nanotechnology has led to questions on a capacity for successful diffusion of nanotechnology. What makes diffusion of nanotechnology innovation possible? An exploration of the determinants of adoption and rejection of innovation in a situation of uncertainty about environmental and health risks may help to answer this question. We will see that recent studies have identified some patterns of the diffusion of nanotechnology in a situation of uncertainty, they have not fully explored it. The literature on the diffusion of innovation studies the factors that influence the adoption and diffusion of innovation (Tidd & Bessant, 2013). A large number of different factors have

⁴ World Health Organization

⁵ However, certain risks related to genetically modified crops was brought to public attention by nonexperts (Auplat, 2008) which one of the differences between genetically modified food and nano-food.

been identified in the literature (we will discuss them in later chapters). It is not clear whether or how “conventional” factors, that have been shown to influence the diffusion of innovation, impact the diffusion of nanomaterials in a situation of uncertainty about environmental and health risks.

Previous work on the diffusion of innovation has found, that in most cases, a cumulative number of adopters presented over time results in an S-shaped curve presented in Figure 1 (Rogers, 2003).

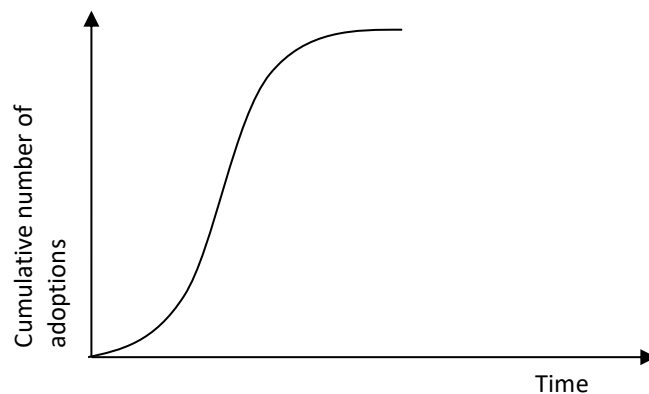


Figure 1. S-curve

Source: Reproduced from Rogers (2003)

This curve describes mostly a growth phase of the product’s life cycle. Besides, it depicts a successful innovation which is first adopted by a few actors, which belongs to innovators category. Then, the number of adopters increases rapidly resulting in a fast rate of growth, but then it continues increasing at a decreasing rate again until the end of process (Rogers, 2003). While it can be assumed that an adoption of nanotechnology follows an S-shaped curve (Working Party on Nanotechnology Organisation for Economic Co-operation and Development, 2012), what are the reasons for successful diffusion of nanotechnology? This leads to several general questions: what factors influence the diffusion of innovation in a situation of uncertainty about environmental and health risks? What (conventional) factors have a specific influence on the uptake of an industrial good in the context?

The quantity of scientific articles examining toxicity of nanomaterials such as nanosilver is constantly growing (see Figure 2). Increasing scientific evidence of potential undesirable effects of a new product might have an important effect on the rise of scientific controversy

surrounding nanosilver and public concern. **This controversy is fueled by the rapidly expanding quantity of new scientific knowledge related to risk which might lead to decrease in its (uptake) consumption.** The conclusions of research papers on risk might diverge significantly. Some papers conclude that there is a potential risk to health and environment associated with nanosilver, the others conclude that there is no potential risk. Sometimes, the findings of the research are unclear (for example, if they state some effects without indicating whether they are harmful or not) or the author(s) could not reach a conclusion. The ongoing divergence of conclusions is also likely to spark more controversy.

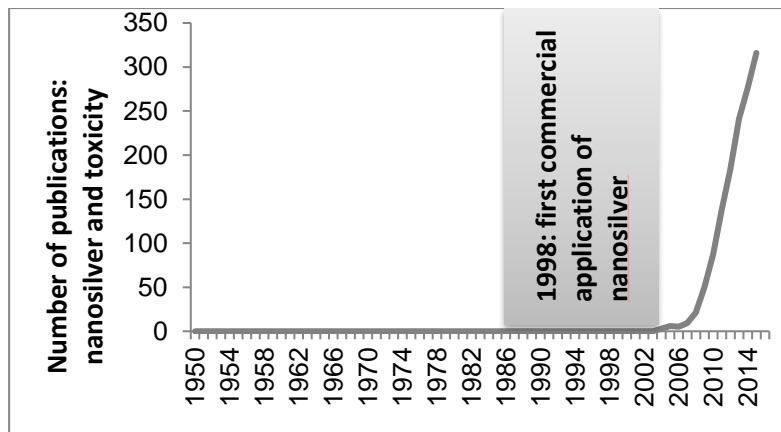


Figure 2. *Number of publications: nanosilver and toxicity*
Source: Ostapchuk, based on PubMed

Our **main working hypothesis** is about new scientific knowledge about risk. Drawing upon the precautionary principle (PP) and a model of impact for unfortunate event (which are discussed in more detail in Chapter 2 and Chapter 4), we hypothesize that the increasing quantity of new scientific knowledge about risk impacts negatively the diffusion of innovation in a situation of uncertainty about environmental and health risks. The higher the quantity of scientific knowledge about risk related to a product, the lower the sales of this product.

Indeed, Godard (2003) sheds light on the importance of scientific knowledge in the case of decisions under uncertainty. The quantity of scientific knowledge is one of the dimensions of plausibility. Scientific plausibility is an important element of the principle of proportionality, which is a part of the precautionary principle (Godard, 2003). The PP applies where there is a lack of scientific certainty about characterization and assessment of risks (Sunstein, 2005). The PP underpins most EU regulations. Besides, the European Commission recommends to adopt a Code of Conduct for Responsible Nanoscience and Nanotechnologies Researches which invokes the PP. A variety of definitions exist. The definition in the Rio Declaration adopted

during the 1992 Rio Conference on the Environment and Development states “In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation” (*Report of the United Nations conference on the environment and development A/CONF.151/26 (Vol. I)*, 1992).

The Communication from the European Commission on the precautionary principle (2000)⁶ states:

“The precautionary principle should be considered within a structured approach to the analysis of risk which comprises three elements: risk assessment, risk management, risk communication. The precautionary principle is particularly relevant to the management of risk. ... **The implementation of an approach based on the precautionary principle should start with a scientific evaluation, as complete as possible, and where possible, identifying at each stage the degree of scientific uncertainty...** the Commission considers that the precautionary principle is a general one which should in particular be taken into consideration in the fields of environmental protection and human, animal and plant health”.

The basic idea behind the Precautionary Principle (PP): “regulation should take steps to protect against potential harms, even if causal chains are unclear and even if we do know that those harms will come to fruition” (Sunstein, 2005, p. 4). According to the PP, a variety of regulatory tools exist (research funding, information disclosure, provisional suspension, ban, etc). While some of the existing interpretations of PP recommend not to take risk, the official ones recommend to act based on proportionality of seriousness of the potential risk and scientific consistency of hypothesis about risk. We will discuss some of the interpretations in later chapters. The PP adds an incentive for further research. Reasons for acting/not acting in a certain way should be based on available knowledge while research is one of the available tools. We might expect that ordinary people follow the logic of PP which can be presented as “better safe than sorry” (Sunstein, 2005, p. 13). The French approach can be reflected in “the more we know, the better we decide”. The precautionary principle applies to nanosilver as it is in the situation of uncertainty about environmental and health risks. This allows us to construct our own working hypothesis based on the PP. Besides, we draw on a model of

⁶ <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52000DC0001>, accessed in April 2017

impact for unfortunate event. According to this model, the public response to unfortunate event depends on the spread of impacts which in turn depends, among other things, on such characteristics related to risk as perceived lack of control, novelty, etc (Slovic, 1987).

A discovery of potential risk can be considered as an unfortunate event which might lead to loss of sales, community opposition, etc. It can be argued that not all scientific knowledge are unfortunate events. New scientific discoveries are made all the time. Some of them are less/more important than others. We do not posit that different improvements in technology or such discoveries as, for example, the double-helix structure of DNA⁷ are unfortunate events. We do posit that a new scientific evidence for potential harm to the environment and/or health can be an unfortunate event. Side-effects of new products might be unknown in the early stages of the product life cycle. Moreover, safety aspects do not appear to be often integrated from the design stage of (nano)products. Discovery of scientific evidence of potential undesirable effects of a new product might lead to serious consequences for the diffusion of this new product. It could be argued that the initial discovery of potential risk might impact sales of new products. However, the ongoing scientific controversies can be fueled by the increasing number of scientific reports with divergent conclusions. Scientific reports are being accumulated⁸. This does not help to resolve a controversy. As soon as the issue appears again, it reminds about the existing controversy.

On the basis of these arguments, we expect that the increasing quantity of new scientific knowledge related to risk which adds to controversy is likely to have important economic consequence. The introduction of new scientific knowledge about risk is likely to decrease the sales of innovation such as nanomaterials (in a situation of uncertainty about environmental and health risks). This hypothesis is one of hypotheses that we will test.

As part of a research program on nanotechnology and in order to design a benchmark for the study of nanotechnology, **the objective of this research is to explore determinants of market uptake of innovation in a situation of uncertainty about environmental and health risks.** We will apply different econometric methods in order to test the effect of new scientific knowledge and other variables on the diffusion of innovation in a situation of uncertainty about environmental and health risks. Several nanomaterials can be currently considered to

⁷ Deoxyribonucleic acid

⁸ We will use the term "new scientific knowledge" to refer to scientific articles which have been published since the first discovery

be in the transition from the introduction to growth stage of the product life cycle and there is a lack of historical sales data on nanomaterials. In order to have historical data that we could use, we have searched for an example of innovation in a situation of uncertainty about environmental and health risks that has been on the market for a long time.

Specifically, we have **two goals**. The **first one** is to provide better understanding of the diffusion process of an intermediate good in a situation of uncertainty about environmental and health risks. We focus on an innovation that can be defined as successful in terms of its longevity on the market since its first introduction. The **second goal** is to compare these results to nanosilver.

We have chosen a chemical bisphenol A (BPA) as a possible model for a nano-based intermediate good for several reasons: (1) both nanosilver and bisphenol A face an epistemic uncertainty about environmental and health risks due to incomplete scientific knowledge, (2) similar time sequences of diffusion of scientific knowledge related to environmental and health risks, (3) similar positions of BPA and nanosilver in their value chains, (4) similarities in their perceived psychological distance (these issues are discussed in later chapters). These similarities between bisphenol A and nanosilver make bisphenol A a suitable candidate for our analysis. It appears that the case of BPA is particularly relevant to illustrate the relationship between new scientific knowledge about risk and diffusion of innovation. This case meets methodological challenge of data collection as statistical data on consumption of bisphenol A is available for several regions in the world in contrast to nanosilver.

A large number of nano-enabled consumer products have been marketed since the early 2000s, for instance, clear sunscreens, antibacterial socks and stiff tennis rackets⁹. The scope of applications of nanomaterials is very large. Different applications of nanomaterials might have different reasons behind their usage. We have decided to focus on nanosilver because it has one of the highest numbers of consumer product applications among nanomaterials (Hendren et al., 2011; Tran, Nguyen, & Le, 2013). Nanosilver has found many applications in medicine, textile, cosmetics, water purification, packaging and electronic industries because of its antibacterial property and/or anti odor effect (Cantuarias-Villessuzanne et al., 2016; Köhler & Som, 2014; Scientific Committee on Emerging and Newly Identified Health Risks, 2014; Tran et al., 2013). An antimicrobial wound dressing with silver nanoparticles is

⁹ <https://www.nano.gov/timeline>, accessed in April 2017

considered to be “the first commercial application of nanotechnology” (Burell, 2009, p. 24). It is called Acticoat. It is also the first commercial application of nanosilver. Nanosilver has an additional advantage to speed the healing because of its anti-inflammatory properties (Burell, 2009, p. 24).

As of 2015, the global quantity of manufactured nanomaterials worldwide is about 11.5 million of tonnes with market value about 20 billion per year (as cited in Pulit-Prociak & Banach, 2016). The global market for nanosilver is presented in Figure 3 which shows that it is continually growing.

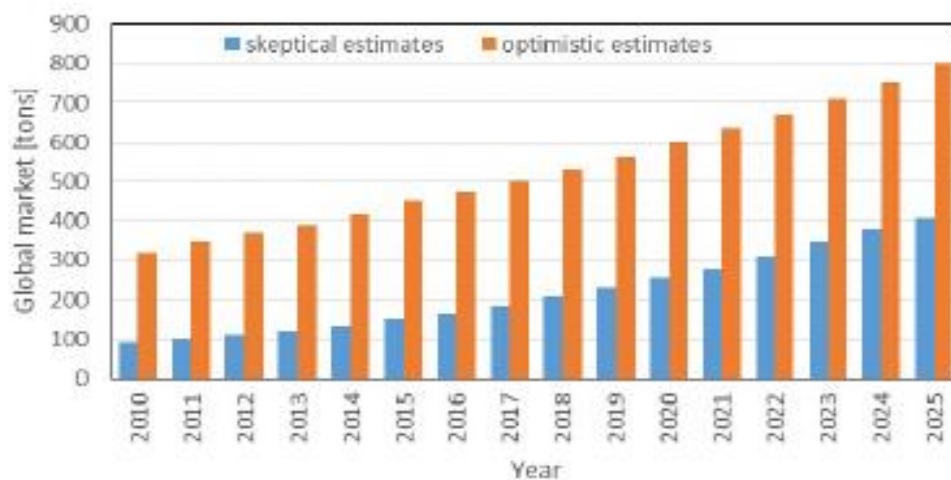


Figure 3. Global market for nanosilver

Source: Reproduced from Pulit-Prociak & Banach (2016)

According to the Ministry of the Environment, Energy and Marine Affairs (2015) the volume of home-produced and imported substances in nano-form that was declared in France in 2014 was around 415 thousand tonnes. The volume of nanosilver that was declared in 2014 was extremely low, in the range of 0,1 to 1 kg which is quite similar to the volume reported in 2013. One of the possible explanations of this phenomenon was that nanosilver had been integrated in products before arriving in France (Avicenn). This reasoning might be still valid for the level of nanosilver that was declared in France in 2015.

Concerning nanosilver, scientists state that the its employment could have adverse effects while the toxicity of silver is well known (Pulit, Banach, & Kowalski, 2011). One of the adverse effects of silver, a bluish-grey discoloration, is a result of chronic exposure. A number of studies suggest a liver toxicity as a result of silver nanoparticle intake. In vivo, it is demonstrated that the immune system can be affected by nanosilver. The genotoxic effect

has been shown in vitro. However, more data is required to reach a conclusion. Potential exposure routes are inhalation, dermal, oral or combined administration. As we have mentioned, the exposure level is difficult to define as nanomaterials are not often indicated as components (Scientific Committee on Emerging and Newly Identified Health Risks, 2014). Additionally, the following factors should be considered: form and size of particles, their concentration and the probability of silver particles or silver ions release. Further research is needed to better understand genotoxicity of nanosilver in vivo, response of bacterial flora to nanosilver exposure and mechanism of bacterial resistance to nanosilver (Scientific Committee on Emerging and Newly Identified Health Risks, 2014). Silver nanoparticles can be released into the environment, for example, through the use of nanotextile, soap, cosmetics or building materials (Pulit-Prociak, Stokłosa, & Banach, 2015). Then, they can enter surface and ground water and/or soil. They can get into the sediments, where then they can be accumulated, transformed or resuspended. There is an ongoing debate among scientists over adverse effects of nanosilver on the environment. However, experiments show that the proportion of nanosilver particles released from sewage sludge into water is very small (Pulit-Prociak et al., 2015; Scientific Committee on Emerging and Newly Identified Health Risks, 2014).

In order to conduct an empirical analysis, data on BPA consumption and explanatory variables, which potentially affect consumption of bisphenol A, data has been collected from different sources. We use the data on bisphenol A to get insights on the relationship between consumption, new scientific knowledge and other variables in a situation of uncertainty about environmental and health risks.

In this context, our general research question:

- **What are the main factors that influence the uptake of innovation in a situation of uncertainty about environmental and health risks?**

The first two specific research questions that we address:

- **What are the key determinants of international uptake of innovation in a situation of uncertainty about environmental and health risks?**
- **Does the number of risk-related scientific publications impact consumption?**

BPA is an example of innovation that has been on the market for more than 60 years. In our study, we focus on the period between the end of the growth state and the beginning of the

decline stage. Most of the work on the diffusion of innovation explores mainly the growth stage of the product life cycle. Studies on the factors that influence a time to takeoff are not widespread. There is even less work on the determinants of a time of slowdown. The term takeoff is defined by Chandrasekaran & Tellis (2007a) to refer to “the first dramatic and sustained increase in a new product’s sales” (Chandrasekaran & Tellis, 2007, p. 40). Slowdown is identified as “the beginning of a period of level, slowly increasing, or temporarily decreasing product sales after takeoff” (Chandrasekaran & Tellis, 2007, p. 40).

The takeoff and slowdown of new products are important points in the product life cycle (PLC) to the managers of new products. Given that “products are not organisms ..., they have no natural cycle of development to follow” (Enis, La Grace, & Prell, 1977, p. 48). The PLC can be considered as an enabling factor that provides new threats or chances of sales growth and/or cycle alteration (Enis et al., 1977; Scheuing, 1989). It can be helpful in marketing planning and in developing strategies with respect to the phase of the product life cycle.

Knowing how different factors influence sales growth at different phases across countries and the current stage of the PLC allows adjusting marketing decisions. As a result of introduction of scientific knowledge about potential risk of an industrial good under conditions of uncertainty, can we observe that the shape of product life cycle depicts substitution, extension or other strategies?

Streams of research on theories of communication and diffusion of innovation contribute to understanding of factors that impact the uptake of BPA but leave gaps that this thesis seeks to fill. With respect to contributions to theory, our objective with this thesis is to shed light on a set of factors which are likely to influence the diffusion of innovation, in particular the maturity stage and how they are related to innovation in a situation of uncertainty about environmental and health risks. We aim to use the results of this thesis to close the loop in connection with the literature as they have important implications for understanding the uptake of nanosilver. Besides, one objective of the PhD is to provide fresh insights into the potential role of new scientific knowledge in the uptake of innovation and into the literature devoted to rejection of innovation.

We will conduct a qualitative study to verify how our results connect with actions of stakeholders who may contribute in some way to new scientific knowledge and/or who are involved in exchange of expertise. We make an attempt to clarify the link between different stakeholders and new scientific knowledge.

This involves the third research question:

- **What is the link between new scientific knowledge and stakeholders in a situation of uncertainty about environmental and health risks?**

1.2. Thesis outline

The PhD thesis contains 9 chapters. This chapter is introductory and defines the scope of the study. **Chapter 2** reviews existing literature on the diffusion of innovation. It presents a selective review that contains different works existing in several fields connected with our topic. These elements serve as a starting point for our analysis and they help to comprehend a further discussion. Our work draws mainly on the theory of diffusion of innovation from a marketing prospective and the literature on product life cycle. Besides, we briefly review the literature that helps us to understand the role of new scientific knowledge about risk in the diffusion of innovation (negative information and marketing, science and uncertainty, the precautionary principle).

Besides, we review empirical studies that focus on the cross-country diffusion of innovations and its drivers given the scope of our study. There is a large quantity of different sets of explanatory variables that might impact the diffusion of innovation. We present these factors in Chapter 2. We note that controversies have arisen over the impact of different factors on the diffusion of innovation across stages, we discuss these controversies and we will underline several gaps existing in literature in Chapter 2.

Chapter 3 gives an overview of different factors which might be associated with consumption of bisphenol A. Besides, a research approach, data sources and methods of data analysis are presented in Chapter 3. A relatively short data sample does not allow to deal with every single determinant of the diffusion of innovation. We will explain how we have chosen the relevant factors in this chapter. To explore one of the drivers, an original variable is constructed. This variable is new scientific knowledge about potential risk. We discuss a potential process of scientific knowledge dissemination and its role in the diffusion of innovation. The effect of scientific information about risk on the consumption in a situation of uncertainty about environmental and health risks is still not well understood.

In order to answer our research questions, we use mixed methods. To answer first two research questions, quantitative data is obtained from different sources. In order to answer

the third research question, a qualitative study is carried out. Primary and secondary sources of data have been collected. More details on this are given in Chapter 3.

Chapter 4 presents a descriptive comparison between the history of BPA and the beginning history of nanosilver. First, we determine the positions of BPA and nanosilver in the product life cycle over the studied period. We have identified that BPA is in the transition from the growth to decline stage and nanosilver is in the transition from the introduction to the growth stage. We list different stakeholders related to BPA and nanosilver and assign them to different categories. Then we report general facts and regulatory framework related to BPA and nanosilver followed by different activities which can be classified as responsible development undertaken by different actors. Finally, we present companies' reactions to new scientific knowledge followed by non-governmental organizations' (NGOs) activities related to new scientific knowledge about environmental and health risks. The data has been collected through interviews with experts and secondary sources.

The construction of variables together with data collection difficulties related to BPA are described in **Chapter 5**. This chapter attempts to propose a classification of new scientific knowledge about potential health and environmental risks based on conclusions of scientific articles related to potential risks of BPA. Besides, background information about bisphenol A use, health and environmental concerns about BPA is discussed and bisphenol A consumption pattern is presented.

Then, we conduct a research taking account of the volume of scientific articles related to potential risks all together in **Chapter 6 and Chapter 7**. These chapters seek to shed light on drivers of slowdown of some products in a situation of uncertainty about environmental and health risks using appropriate data. In this context, the goal of Chapter 6 is to explore changes in consumption of bisphenol A (BPA). The literature on the Environmental Kuznets Curve (EKC) is additionally reviewed to shed light on the relationship between economic growth and consumption of BPA. The EKC represents an inverted U-type link between economic growth and environmental degradation. We use material consumption instead of pollution indicators to test the EKC. We will test the hypothesis that BPA use might first increase as income increases, and then decrease with a rise in income per capita (together with scientific evidence of potential risks of BPA and health/environmental concerns). Then, we assess if and to what extent the process is influenced by new scientific knowledge about risks in addition to other variables in a situation of uncertainty regarding these risks. In Chapter 7, we carry out analysis

for polycarbonate sales in Japan. We analyze if sales of a secondary intermediate good, namely polycarbonate, are affected by information shocks related to BPA.

In **Chapter 8**, we state the main findings of the study by answering our research questions. Then, we discuss to what extent bisphenol A is an appropriate candidate for the analysis of the relationship between new scientific knowledge about risk and uptake of innovation. Third, we make an attempt to discuss the relationship between new scientific knowledge and stakeholders based on the data presented in Chapter 4. Then, we focus on the role of a prescriber in this relationship. Then, we relate this study to other streams of literature (Chapter 9). This discussion is followed by suggestions for further research. Our conclusions are drawn in the final chapter (Figure 4).

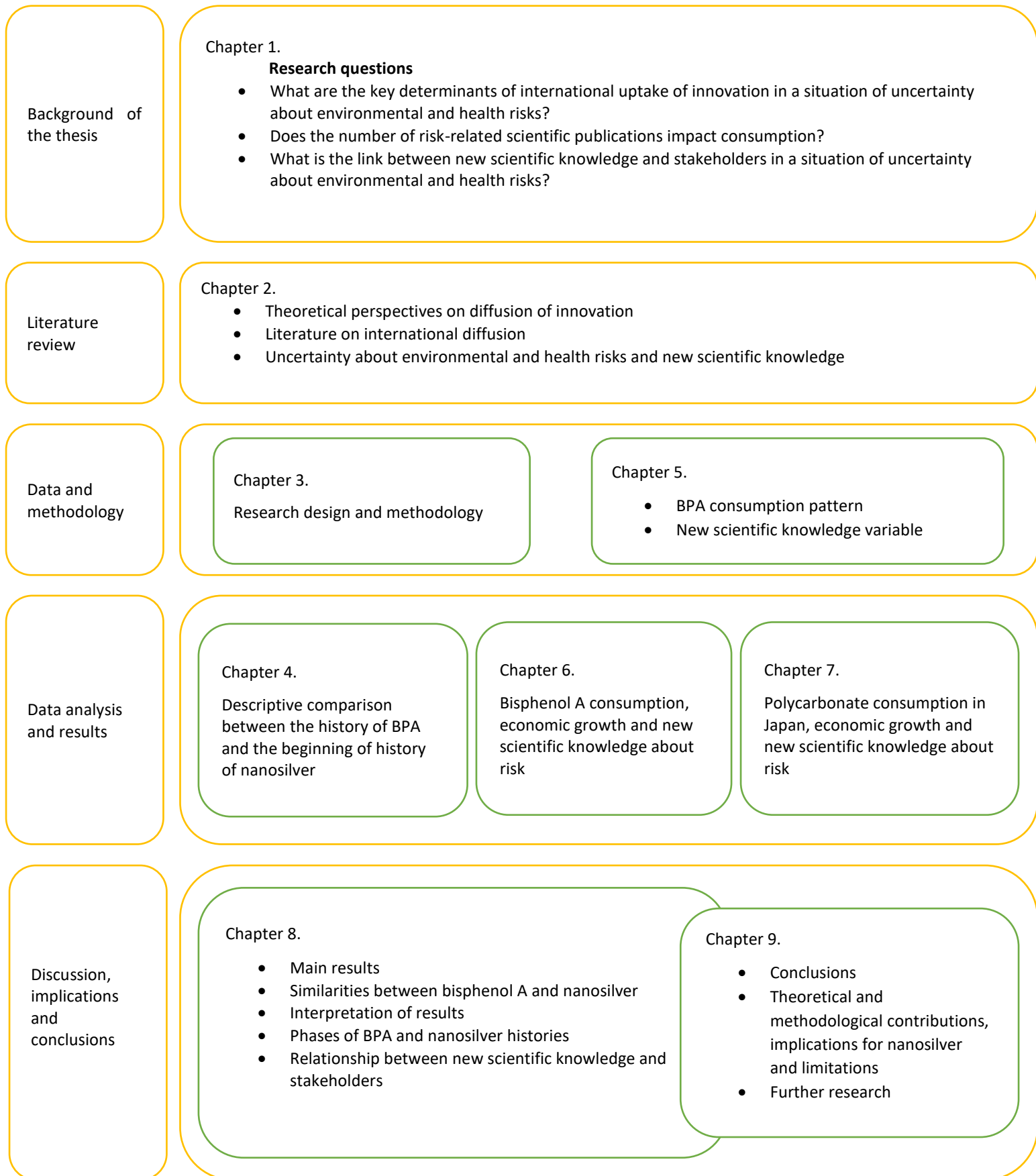


Figure 4. Thesis structure

Source: Ostapchuk

Chapter 2. Literature review

This chapter focuses on the diffusion of innovation, a subject studied by multiple disciplines: sociology, management, economics, agriculture, medicine, geography, anthropology and information systems (Chandrasekaran & Tellis, 2007). This chapter presents a selective review that contains classic works and seminal papers existing in several fields connected with our topic. It will provide a basis for the current research.

The goal of this literature review is twofold. Its first objective is to describe dominant theoretical perspectives which help to understand main elements of diffusion of innovation. These elements serve as a starting point for our analysis and they help to comprehend a further discussion. Its second objective is to explore if the literature on diffusion of innovation provides us with an appropriate explanation of factors affecting the diffusion of innovation in a situation of uncertainty about environmental and health risks. To pursue the second goal, we mainly review the literature at international level falling within the scope of our study. Most of the studies on innovation in a situation of uncertainty have centered on a single geographical unit¹⁰. Moreover, prior literature on the diffusion of innovation in Marketing has mainly focused on consumer market rather than industrial market. Our review mainly includes studies on the diffusion of consumer products. Given that the main purpose of this literature review is to examine the literature that is relevant to develop a conceptual framework for diffusion of an industrial good (that is used in production of consumer goods), some potential differences in the diffusion of innovations between consumer and industrial markets are pointed out. Finally, we will present the literature on uncertainty about environmental and health risks which is used to formulate our main working hypothesis about new scientific knowledge about risk. We will review the studies on risk management principles including the precautionary principle and its interpretation, few studies on the sociology of perception and the literature that helps to characterize new scientific knowledge about risk.

¹⁰ Earlier studies focused on the United States and Europe (Rogers, 2003). More recent studies were conducted in a larger number of countries.

This chapter is arranged as follows. First, definitions of key concepts are presented. Second, a diffusion of innovation theory from the perspectives of sociology and management is discussed. Next, a review of empirical studies that focus on the cross-country diffusion of innovations is presented. These studies examine factors that influence the whole process of diffusion and main drivers at different stages of the product life cycle at international level which are at the core of our study. Then, a review of the limited empirical literature on diffusion of innovation in a situation of uncertainty about environmental and health risks and a brief comparison of identified determinants of diffusion of innovations at different levels of aggregation in different situations regarding uncertainty about environmental and health risk are given.

2.1. Definition of innovation

Before the issue of diffusion of innovation can be studied, it is necessary to give definitions of several key concepts and how they are integrated in the current research.

Innovation can be defined in many ways. According to Rogers (2003) *“Innovation is an idea, practice, or object that is perceived as new by an individual or other unit of adoption”*. A subject’s recognition of something as new identifies his/her attitude towards it. If it appears to be new to him/her, it is defined as innovation. Besides, new can be referred to awareness about idea (practice or object), position on it or a choice to use/buy it (Rogers, 2003, Chapter 1).

Drucker defines innovation as *“an economic or social rather than a technical term...Or, as a modern economist would tend to do, it can be defined in demand terms rather than in supply terms, that is, as changing the value and satisfaction obtained from resources by the consumer”*. In supply terms, he describes it as *“the specific instrument of entrepreneurship. It is the act that endows resources with a new capacity to create wealth”* (Drucker, 1985: p. 33, p.30).

The terms innovation and new technology can be used interchangeably in the literature given the fact that studies on diffusion of innovation often deal with technologies (Rogers, 2003). This change can be separated in 3 phases outlined by Stoneman (1995) who refers to the Schumpeterian trilogy: invention, innovation and diffusion. The former is about creation of a new concept, the second phase concerns its conversion into marketable good, and the latter is about its dissemination across market. Here, innovation is a part of technological change

(Stoneman, 1995). Furthermore, innovation is often confused with an invention. Whereas Stoneman (1995) makes it clear that that these two notions are closely related, following the 1970 annual IRI¹¹ spring meeting Roberts (2007) clarifies that innovation is an invention that is brought to a business. Besides, the Oslo Manual, 2005, states “An innovation is the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations” (OECD & Eurostat, 2005, p. 46).

Since the terms new product, process, service, idea, method and technology are used interchangeably with innovation in the literature, we decide to adopt the following definition: An innovation is a product that is (1) perceived to be new, and (2) brought to the market.

The following question may arise: When does a product starts being new? Le Masson, Weil, & Hatchuel (2010) identify 3 characteristics of “new” product which are not necessarily mutually exclusive: (1) a renewal of the recent version, (2) a completely new product that did not exist before the launch of this product (3) a new product presents a problem of identity. These characteristics help to identify a new product.

2.2. Theoretical perspectives on diffusion of innovation

2.2.1. Sociological perspective on diffusion of innovation¹²

In the following section, the phenomenon of diffusion from a sociological theoretical perspective is mainly discussed. Relevant general facts about the perceived features of innovation and the phases of innovation-decision process, the shape, characteristics, and important points of the diffusion curve are presented.

According to Rogers (2003)¹³, one of the seminal authors in the diffusion of innovation field, “*diffusion is the process in which an innovation is communicated through certain channels over time among the members of a social system*” with new ideas as the main thesis of communication. He defines communication as a process where actors generate and exchange information with each other to come to a reciprocal agreement. He refers to diffusion

¹¹ Industrial Research Institute

¹² This subsection mainly covers Rogers’ (2003) seminal text. We classify the perspectives discussed in this subsection as sociological. However, “it is becoming increasingly difficult to categorize the authors in the most recent work, which seems to move easily from economics or sociology to management” (Le Masson et al., 2010, p. 21).

¹³ The book “Diffusion of innovation” by Rogers (1962) was first published in 1962 and is now in its 5th edition. It remains “the best overview of this subject” (Tidd & Bessant, 2013, p. 399). The author has revised the theoretical framework and empirical evidence by reviewing new studies. While the author introduced slight modifications to the diffusion model in line with recent findings, the structure of the basic model remains unchanged. In the 5th edition, he emphasizes the role of communication and communication technologies in the diffusion of innovation (Rogers, 2003).

phenomenon as a type of social change that may happen. It might involve an invention of new idea, its diffusion and eventually its adoption or rejection. The definition suggests that each process of diffusion consists of 4 components, namely “innovation, communication channels, time and the social system”. In his work, he describes diffusion of innovation through the characteristics of all these elements (Rogers, 2003, Chapter 1).

Rogers (2003) considers communication channel as a way of transferring information about a new product from one person to another. According to Rogers’ definition of diffusion process, a new product is communicated between people or organizations. At the same time communication itself can be considered to be very closely connected with drivers of diffusion. We mainly stick to the definition of diffusion suggested by Chandrasekaran & Tellis (2007a) which states that “diffusion is the spread of an innovation across markets” (Chandrasekaran & Tellis, 2007, p. 40). However, we add one of the aspects defined by Rogers (2003), that deals with time as the diffusion process occurs over time. Therefore, we define diffusion as the spread of an innovation across markets over time. This definition is more appropriate for our research as it allows us to separate the phenomenon of diffusion with its determinants.

While there are several definitions of diffusion of innovation which are generally used, there are no widely accepted definitions of the terms adoption and implementation (Tidd & Bessant, 2013). According to Rogers (2003) these terms are a part of the “*innovation-decision process*” which consists of 5 phases: “*knowledge*” is when an actor becomes aware of the innovation, “*persuasion*” is when the actor forms an opinion about it, “*decision*” is when he/she takes a decision to adopt or to reject the innovation, “*implementation*” is when the actor begins using it and “*confirmation*” is when he/she continues using it or she changes the decision to the opposite of the one made before. The result of innovation-decision process is adoption that is a choice of exploitation of an innovation, or its rejection. However, some decisions can be overturned afterwards. The author highlights the importance of recognition of a true decision maker to analyze correctly the phenomena of the “*innovation-decision process*” (Figure 5). Tidd & Bessant (2013) define “adoption” as “the decision to acquire something” and “implementation” is the term for “some action and adaptation” which is roughly similar to definitions of Rogers (2003).

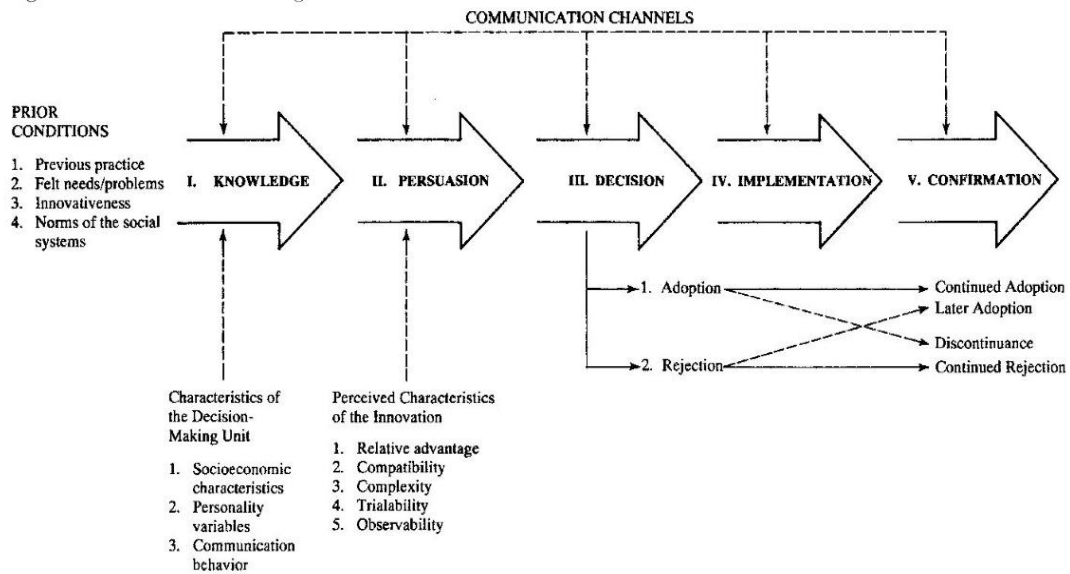


Figure 5. Five Stages in the Innovation-Decision Process

Source: Reproduced from Rogers (2003)

2.2.1.1. Adoption rate

The literature on the diffusion of innovation aims to define factors that influence the diffusion (Tidd & Bessant, 2013). Tidd & Bessant (2013) state that a large number of variables are identified as influencing the diffusion process. These variables can be classified under 3 groups: characteristics of new product, characteristics of the environment and characteristics of adopters. These groups will be discussed in more detail in Subsection 2.2.1.2 - 2.2.1.4. The factors affecting the diffusion of innovation at international level will be discussed in Chapter 2.3. However, it is worth mentioning that there is no agreement in the literature of diffusion of innovation on the magnitude of effect of various factors and there are some contradictions concerning the directions of effect of some variables under certain conditions. The process of diffusion can be characterized in terms of an adoption rate¹⁴. The rate of adoption is related to one of the time aspects that characterize the process of diffusion (Rogers, 2003). It can be measured as the quantity of individuals who adopt a new idea over the given period of time (Rogers, 2003). Alternatively, it can be measured as sales growth rate for the time until a sales peak, time to takeoff/slowdown or for the entire process (Chandrasekaran & Tellis, 2007; Kuester, Gatignon, & Robertson, 2000).

¹⁴ Sometimes called a diffusion rate.

In most cases, a cumulative number of adopters presented over time leads to an S-shaped curve (Figure 6). It describes mostly a growth phase of the product's life cycle. Besides, it depicts a successful innovation which is first adopted by a few actors, which belongs to innovators category. Then, the number of adopters increases rapidly resulting in a fast rate of growth, but then it continues increasing at a decreasing rate again until the end of the process. However, the slope of the curve varies depending on innovation (Rogers, 2003).

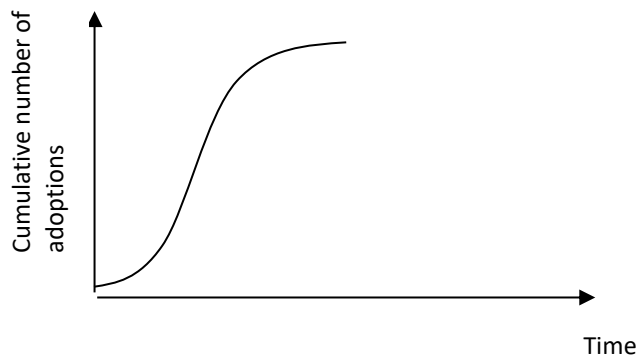


Figure 6. S-curve
(Figure 2 from Chapter 1) Source: Reproduced from Rogers (2003)

2.2.1.2. Perceived characteristics of innovations

Rogers (2003) defines the following innovation's perceived features:

First, "*relative advantage*" is the level of perceived superiority of innovation over existing goods or services. The higher the level, the faster the adoption rate. A concept of relative advantage may deal with economic and social factors, time efficiency, convenience, and immediacy of reward. For example, for most of preventive innovations¹⁵, the period of waiting for a reward is relatively long that explains slower rates of diffusion.

Second, "*compatibility*" is the level of perceived coherence of innovation and such factors as social norms, ethnic, education or family background of an individual. Previous experience might have an impact on diffusion of new ideas depending on the level of difference or similarity with individuals' experience. If an innovation differs from what is expected or what has existed before, it can be easily rejected. An innovation that is highly compatible with a previously rejected product might be rejected as well (which is one of the consequences of compatibility). On the other hand, a large compatibility gap might entail a long transformation

¹⁵ Preventive innovation is a new product/idea that is introduced to decrease the probability of a specific undesired event that might occur to its (potential) adopter (Rogers, 2003).

process of individuals' values. This might slow down the speed of adoption rate. A wrong belief about incompatibility of innovation can potentially lead to a complicated process of adoption. Third, "*complexity*" of innovation is the level of perceived easiness of dealing with it. Sometimes it might require gaining new competence or new knowledge to adopt it. The author states that this characteristic is relatively less important than relative advantage and compatibility. Nevertheless, it might prevent actors from adopting an innovation.

Fourth, "*trialability*" refers to possibility of testing an innovation prior to its adoption. Fifth, "*observability*" of innovation stands for the level of noticeability of outcomes of the innovation or its presence (Rogers, 2003).

Another attribute of innovation which is particularly relevant to industrial market and which can be added to Rogers' list defined earlier is "*essentiality*". It can be defined as the level of importance of a new industrial good to continued operation of an industry or a firm. Essentiality is connected to the extent to which a decision of adoption/rejection can be delayed (Day & Herbig, 1990).

2.2.1.3. Characteristics of the environment

One of the sociological characteristics of the environment is communication channel. Communication channels can be referred to mass media or interpersonal communications. Beginning with Katz & Lazarsfeld (1955)¹⁶, the influence of endogenous word-of-mouth¹⁷ (WOM) on the innovation decision process (see next paragraph) has been studied. The literature has shown that these means of communication serve different purposes. While mass media channel is useful to increase awareness about a product or process, interpersonal communication might be more efficient in convincing someone to adopt an innovation (Rogers, 2003). More recently, a study of Godes & Mayzlin (2009) shows that company-generated word-of-mouth, that is arranged by company and performed by involved customers, can be a powerful tool to increase sales. In industrial market a word-of-mouth communication is relatively rare due to very few interpersonal contacts among potential adopters. However, industry associations, conferences, online discussion (forums) and purchasing/sales agents (which can prove information on adoption by a leading firm) can

¹⁶ Their communication theory explains the flow of information from mass media to most people via opinion leaders who receive it and who might add their own impact while transmitting the information. Thereafter the notions of word of mouth effect and influentials were integrated in the diffusion of innovation theory.

¹⁷ Word-of-mouth can be defined as an informal oral communication ("Random House Kernerman Webster's College Dictionary," 2010).

encourage the spread of information by word-of-mouth communication (Day & Herbig, 1990). Given our interest in an industrial good, we will not review the studies from a consumer perspective which deal mainly with WOM effect (except for benchmark studies). Economic factors can be included in this category. If we conduct an analysis at international level, economic factors can be classified under country variables which are related to characteristics of adopters (in this case, a country can be considered as an adopter).

2.2.1.4. Characteristics of adopters

Time plays a prominent role in defining categories of adopters with regard to Rogers's classification. Rogers (2003) introduces a classification based on a notion of innovativeness which is determined by the time of adoption. Innovativeness indicates the time of adoption of a new product by an individual or a firm or another unit compared to others.

Rogers (2003) determines the following categories: innovators, early adopters, early majority, late majority and laggards. As to the "*innovators*", they are searching for information on innovation; they are highly exposed to the media and following Rogers (2003), they are able to deal with greater uncertainty regarding innovation than others (for instance, uncertainty about profitability) and they are responsible for the takeoff of innovation. Besides, they are fascinated by new ideas and they are often able to deal with complex ideas or processes. This category is essential for transferring awareness about innovation further. Innovators represent about 2.5 percent of adopters, on average (Figure 7). Early adopters represent approximately 13.5 percent. This category includes many opinion leaders. According to Rogers (2003), a fragment between 10 and 20 percent of diffusion curve is the most important part of the process as it is difficult to stop future adoption of innovation afterwards, the process begins to be self-sustaining. "*Early adopters help trigger the critical mass*" (Rogers, 2003: Chapter 7). While the role of opinion leaders is highly recognized in the diffusion of innovation in consumer markets, its role is considered to be less important in industrial markets. Different associations, consulting companies or sales agents usually spread information about a new product throughout an industry. In this way, they increase awareness about innovation. Moreover, peer pressure that might influence an adoption decision is replaced by competitive pressure (Day & Herbig, 1990). This discussion is partly related to the fashion and fad perspectives of Abrahamson's (1991) which are described in Subsection 2.2.2.

The next two categories defined by Rogers (2003) represent two third of all adopters. Early majority represents one third of all adopters. Innovators, early adopters and early majority are located to the left of mean, late majority and laggards are located to the right of the mean (Figure 7). The representation of late majority and laggards are 34 and 16 percent, correspondingly. The last two categories adopt the innovation when it is brought into conformity with social standards. The non-symmetry of classification can be avoided by dividing late majority by two categories. Although, the author claims that adopters within these categories possess common characteristics. Otherwise, early majority and early adopters can be grouped together, but they possess different qualities. Even though this classification is exhaustive, mutually exclusive and based on one criterion, certain innovations might deviate from this path. For instance, several authors (Mahajan, Muller, & Wind, 2000; Moore, 2009; Van den Bulte & Joshi, 2007) state that “market chasm” can occur between early adopters and further categories of adopters due to different needs.

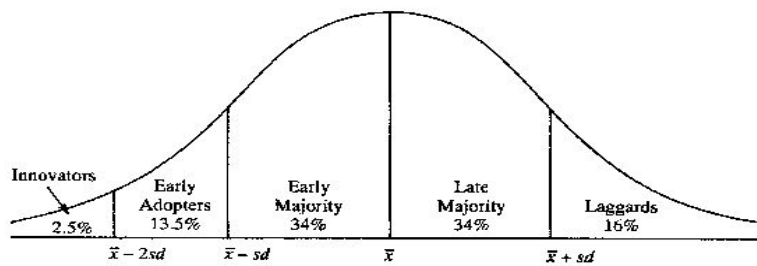


Figure 7. *Categories of adopters*
 Source: Reproduced from Rogers (2003)

We have already discussed 3 out of 4 components of the diffusion process defined by Rogers (2003), namely innovation, communication and time. The last component of diffusion process defined by Rogers (2003) is a social system that is “a set of interrelated units that are engaged in joint problem solving to accomplish a common goal” which have a particular structure. It can be identified as a regularly repeated process or result of organization of actors belonging to this social system. Scholars who study the diffusion of innovation attempt to analyze an impact of this structure on diffusion or an influence of cultural and ethnic norms on the diffusion process or how important are opinion leaders in the diffusion of innovation. We discuss briefly the studies which explore the impact of culture and opinion leaders at international level in Chapter 2.3.

2.2.2. Overview of the Bass model

This subsection is a part of a brief historical overview of the research on the diffusion of innovation. We will present the Bass (1969) model which is a benchmark diffusion model for successful products in marketing. It is worth presenting in the literature review. It is an aggregate level demand-side model for consumer durable goods¹⁸. It describes sales growth of a new product over time. It deals with first purchases which are considered as adoptions. Bass defines the first consumers of a new product as innovators as they are autonomous of other consumers, which corresponds to Rogers' (2003) definition of innovators. The second type of consumers is called imitators and it includes the other four types of adopters suggested by Rogers' (2003) (Figure 7). Imitators are dependent upon the choices made by others over time.

Following Bass (1969), the likelihood of adoption given that adoption has not occurred at time t (it can be also presented as a hazard rate¹⁹):

$$P(t) = \frac{f(t)}{1 - F(t)} = p + q/mY(t) = p + qF(t), \text{ where } f(t) = \frac{dF(t)}{dt}$$

$$Y(t) = \int_0^t S(t)dt = m \int_0^t f(t)dt = mF(t)$$

where $f(t)$ is the probability density function and $F(t)$ is the cumulative distribution function (probability of adoption at t or before), p is a coefficient of innovation (coefficient of external influence) and q is a coefficient of imitation (coefficient of internal influence). m states for fixed market potential, $Y(t)$ is used to refer to total sales over $(0, t)$ period and $S(t)$ is sales at t . We can write the following differential equation:

$$dt = dF / (p + (q - p)F - qF^2)$$

The solution to this equation together with the discussion of a sales peak is presented in

Appendix A.

A discrete version of the Bass model is $S(t) = a + bY_{t-1} + cY_{t-1}^2$,

¹⁸ Durable good is a good that does not wear out immediately (for example, a washing machine or a freezer) (O'Sullivan & Sheffrin, 2003)

¹⁹ The likelihood of adoption at time t can be also presented as hazard rate given that the purchase has not occurred: $h(t) = p + qF(t)$ where $h(t)$ is a hazard rate and it is a non-decreasing function in t . Kauffman & Techatassanasoontorn (2005, p. 267) define hazard rate as "the instantaneous risk that an event will occur at time assuming that a subject has survived to time t ". In the Bass model hazard rate is presented in a linear form. However, other form of likelihood of adoption at time t is possible, which includes Gompertz, exponential, etc. A Cox proportional-hazards model is especially useful as it allows including time-varying covariates in the model. Hazard rate modeling is also associated with an event history analysis. Hazard rate models are often applied to analyze duration data, for example, the duration of a particular state of the product life cycle, time to takeoff or time to slowdown (Chandrasekaran et al., 2013; Kauffman & Techatassanasoontorn, 2005; Tellis et al., 2003).

where $a = pm$, $b = q - p$ and $c = \frac{q}{m}$,

$S(t)$ is sales at T and Y_{t-1} is cumulative sales at $t - 1$.

As several researchers (Bass, 1969; Bass, Krishnan, & Jain, 1994; Chandrasekaran & Tellis, 2007; Mahajan et al., 2000; Mahajan & Peterson, 1985; Toubia, Goldenberg, & Garcia, 2008) have highlighted a number of limitations of the original Bass model. The main limitations are:

- One of the major limitations of Bass model is the homogeneity of consumers²⁰, which is eventually relaxed by Van den Bulte & Joshi (2007). The authors introduce two fractions of populations: *influentials* and *imitators* which are different from the initial Bass model in the sense that these types depend on the characteristics of adopters rather than time of adoption. The former includes adopters who are well-informed about new products or improvements and who impact the imitators, the latter represents those who do not influence the influentials. The authors support the existence of “two-segment structure” by discussing several sociological arguments, communication theory and market chasm issue.
- Price and/or advertising are not directly included in the original model. It can be an important drawback as these two variables can be of interest to managers and they can be considered as vital marketing tools. Other explanatory variables which might influence the diffusion process are not included in the model either (for example, sales of complementary products or substitutes).
- Sales over the introduction and growth stages are needed to provide accurate forecasts. However, the model describes well the process a posteriori and therefore its descriptive capabilities can be employed by managers (Mahajan et al., 2000). Nevertheless, the Bass (1969) model is one of the most frequently cited articles in the diffusion of innovation literature.
- Despite its limited predicted capacity, it deals with first purchases of consumer durables. Although, the majority of sales data sets do not distinguish between first purchase and subsequent purchases.

A large quantity of extensions to Bass (1969) model along with alternative aggregate diffusion and disaggregate-level (individual level) models have been introduced since the original model was published to incorporate marketing-mix variables, repeated (replacement, multiple)

²⁰ Bass classifies consumers according to the time of adoption.

purchases, multi-market adoptions (complementary and substitutes product diffusion, global diffusion, and multi-stage diffusion including awareness stage) and various drivers of diffusion²¹.

2.2.3. Managerial perspective on adoption/rejection of innovation

Abrahamson (1991) proposes four theoretical perspectives to interpret the phenomena of adoption and rejection of innovation examining the diffusion process of administrative technologies²². While he explains the diffusion of administrative technologies, the same perspectives can be easily applied to other types of innovations. The author addresses the following question: “*When and by what process are technically inefficient innovations diffused or efficient innovations rejected?*” (Abrahamson, 1991: p. 587). The author argues that the prevailing conception, that is the efficient-choice perspective, fails in giving a full answer to the mentioned above question. Its fundamental assumptions are that institutions which belong to a particular group are able to decide easily for themselves which administrative technology to use. Besides, institutions are relatively confident about their aims and their preferences for administrative technologies taking into account their performance. On the contrary, institutions which do not belong to a group, including powerful organizations and regulators, might have impact on the decisions of organizations to adopt or not in spite of efficiency or inefficiency of innovation. Besides, institutions might not have well defined aims and they might have no certainty regarding efficiency of innovation. Under these circumstances, institutions copy the adoption/rejection behavior of others. These counter assumptions allow to introduce the other conceptions in order to explain the decision of potential adopters: “forced-selection perspective”, “fashion perspective” and “fad perspective” (Abrahamson, 1991). Table 1 presents the description of adoption and rejection based on the mentioned above perspectives. Sometimes several perspectives are needed to explain the diffusion of one innovation. Although, a “contingency resolution” suggests that a certain aspect of adoption or rejection should be interpreted using only one perspective which corresponds closely to one of the types²³.

²¹ A brief discussion of these papers can be found in Appendix A.

²² Abrahamson (1991) defines administrative technologies “as prescriptions for designing organizational structures and cultures. Some of these prescriptions, such as those for designing and running matrix forms, affect the overall structure of organizations; others, such as those pertaining to strategic-planning units, affect only certain organizational subunits” (p. 588).

²³ Additionally to the existing perspectives, Fischer, George, & Hirschheim (2013) introduced two social conceptions to understand the adoption of innovation, namely “the pushed-selection perspective” and “transfer perspective”. The former

Table 1. Managerial perspective on adoption/rejection of innovation

<p>“The efficient-choice perspective”: institutions rationally decide on adoption or rejection of an efficient innovation subject to present constraints</p>	<p>Adoption: Exogenous variation creates a gulf between institution aim and what it can achieve which leads to technology adoption in order to narrow the gap (demand side reasoning); New knowledge development provides institution with innovation that can widen or bridge the gap (supply side reasoning).</p>
	<p>Rejection: Innovations are adopted when they narrow the gap. If the gap is altered, innovations fail (demand side reasoning); Substitutes which are brought into use as a result of new knowledge arrival cause a rejection of previously used administrative technology (supply side reasoning).</p>
<p>“The forced-selection perspective”: regulators or other powerful groups induce an innovation while having their own motivation</p>	<p>Adoption: Technologies are diffused among the institutions if they are supported by powerful groups</p>
	<p>Rejection: Conflict of interests among several powerful groups may result in rejection of the technology if the group which has more power forces the issue</p>
<p>“The fashion perspective”: ambiguous aims of institutions, exogenous forces and uncertainty about efficiency. Under these conditions administrative innovation within a group follow the behavior of “opinion leaders” which do not belong to the group, for instance consulting companies while promotions can be a part of their activities</p>	<p>Adoption: Inefficient/efficient technologies diffuse under the influence of inspiring leaders</p>
	<p>Rejection: Institutions turn down old administrative technologies if mutually exclusive innovations are promoted by inspiring leaders; With time, inspiring leaders’ power and innovations’ benefits might die out, which leads to rejection of innovation previously adopted</p>
<p>“The fad perspective”: explains diffusion of innovation under the same conditions as previous perspective except that inspiring leaders belong to the same group</p>	<p>Adoption: There are several explanations of adoption. First, inspiring leaders provide other institutions with necessary information that reduces uncertainty about innovation. Second, institutions motivation is to act with the existing norms. These organizations imitate others which belong to the same group. Third, institutions follow the behavior of other institution in order to reduce a competitive disadvantage. Besides, the higher the quantity of adopters, the higher the pressure to adopt²⁴</p>
	<p>Rejection: Decision to adopt is overturned due to inefficiency of innovation or reduced competitive advantage</p>

Source: Based on Abrahamson (1991)

To sum up, several theoretical perspectives are discussed in this subsection. The first part deals with the innovation diffusion process, its phases and adoption/rejection phase, in

explains adoption as a result of pressure of other institutions. These institutions have more power, or beneficial network externality might arise as a result of adoption. The latter explains the adoption of innovation due to “*the professionalization*” aim which spreads innovation from one group to another. However, it seems that the perspectives suggested by Fischer, George, & Hirschheim (2013) can easily fit into Abrahamson’s (1991) framework. Specifically, «*the pushed-selection perspective*” can be assigned to “*the forced-selection perspective*” and “*the professionalization*” can be associated with “*the fad perspective*”.

²⁴ The threshold model is presented below to support this argument

particular. Rogers (2003) explains the differences in adopters' characteristics and he determines the perceived features of innovations as determinants of variations in diffusion rates. Then, an aggregate level demand-side model for consumer durables developed by Bass (1969) and its limitations have been discussed. The third part is about managerial perspectives on adoption/rejection of innovation defined by Abrahamson (1991). He proposes four different perspectives to explain adoption/rejection decisions, namely the efficient-choice perspective, the forced-selection perspective, the fad and fashion perspectives. Rogers' (2003) diffusion-innovation process together with Abrahamson's (1991) and Bass' papers (1969) are landmarks work in the diffusion of innovation literature and they serve as a basis to other fields where diffusion of innovation is studied. Besides, we will see if our results are consistent with some of the perspectives on adoption/rejection of innovation defined by Abrahamson (1991) in Subsection 8.3.2.

2.2.4. Epidemic, rank, order and stock effect models

Various models that study the diffusion of innovation exist. These models examine different sets of factors which can explain the diffusion. According to the majority of these models, the diffusion of successful innovations can follow an S-shaped curve (discussed in Subsection 2.2.1.1). There is not a thorough and comprehensive model that explains the diffusion of innovation, the existing models can be seen as competing (Camerani, Corrocher, & Fontana, 2016). A large portion of the economic literature focuses on an inter-industry diffusion or a spread of innovation among companies in one industry or an intra firm diffusion of technology with little research conducted on new products diffusion compare to marketing field (Battisti & Stoneman, 2003).

Camerani et al. (2016) distinguishes between aggregate and epidemic models. Aggregate models are "critical mass models such as epidemic models that investigate the diffusion of innovation within a population of potential adopters, paying particular attention to the role of information in explaining the pattern of diffusion". Equilibrium models are "rank and game theoretic models that study the individual behavior towards the adoption of an innovation" (Camerani et al., 2016, p. 732).

a) Epidemic models

One of the first innovation diffusion modeling approach in economics goes back to epidemiology and sometimes called as a SIR modeling that stands for "*susceptible-infected-*

recovered" (Watts & Dodds, 2007) to highlight that adoption is caused by the diffusion of information. A general idea of this type of models: an innovation is adopted as soon as potential adopters get the information about this innovation, the information spreads by word-of-mouth, this innovation is superior to the existing products (ideas or technology).

One of the pioneers in the field of epidemic models is Mansfield. He defines the speed of diffusion as a function of profitability and size of investment. The author states that uncertainty regarding lack of information on the innovation performance decreases as the proportion of adopters increases (Mansfield, 1963, 1989; Stoneman & Karshenas, 1995). Here, the author states that the decreases as the proportion of adopters increases as they share their experience. However, it seems that this statement does not hold in the situation about environmental and health risks as the uncertainty regarding environmental and health risks is an exogenous factor.

We have already discussed the Bass model which can be categorized as a communication model (Le Masson et al., 2010). One of the reasons why the Bass model is different from epidemic models is it envisages that the information can be disseminated by mass media channels in addition to word-of-mouth channel. Information and communication can be used interchangeably in relation to the diffusion of innovation in marketing, sociology and communication. The theory of information deals with the transmission of information and its processing (Le Masson et al., 2010). From the marketing point of view, it is crucial to understand how information impacts the adoption of a new product, and as a result its diffusion (Delre, Jager, Bijmolt, & Janssen, 2010). The communication theory explains the flow of information from mass media to most people via opinion leaders who receive it and who might add their own impact while transmitting the information (E. Katz & Lazarsfeld, 1955). The diffusion of innovations theory seeks to explain what factors affect the communication (spread) of an innovation through a society or a well-defined network structure (Chandrasekaran & Tellis, 2007; Delre et al., 2010; Rogers, 2003). However, communication can be considered as a driver of diffusion (Chandrasekaran & Tellis, 2007). Some diffusion models can be called communication, e.g., the Bass model (Le Masson et al., 2010). The distinction between information and knowledge can be drawn in connection with knowledge complexity which is needed to deal with a technology. Scholars seek to understand how this knowledge can propagate through an information network (Le Masson et al., 2010).

b) Rank, order and stock effects models

Rank, order and stock effects models can be considered as equilibrium models which assume perfect information, rational behavior and welfare/profit maximization. Rank models focus on heterogenous adopters, order and stock models consider possible strategic interactions among potential adopters. According to the rank models, adopter characteristics explain the benefits from adoption and the time of adoption for particular firm or individual. According to the stock effect models, the higher is the number of adopters, the smaller are the benefits from new technology. This can be compared to “snob effect”, a need to be unique (Camerani et al., 2016). However, for some technologies benefit can be larger as the quantity of adopters rises (Stoneman & Karshenas, 1995). For instance, diffusion in one country might influence a pattern in other countries (Stoneman & Battisti, 2010). The order effects model states the a location of a firm or an individual in the sequence of adoption matters and it influences benefits gained from adopting innovation (Stoneman & Battisti, 2010). “Higher-order adopters experience a higher return than lower-order adopters”. This can be compared to an opinion leader advantage, the ability to influence the subsequent adopters (Camerani et al., 2016, p. 735).

This subsection presents the aspects of diffusion of innovation studied in the field of economics and different models are used to develop a broader picture of the process, namely epidemic, rank, order and stock effects models. The majority of these models focus on different set of determinants of diffusion in the early stages of the product life cycle²⁵. Despite a large number of models which study the diffusion of innovations, these models do not capture the impact of new scientific knowledge about risk explicitly.

2.3. Literature on international diffusion

There is a sizable literature on the diffusion of innovation. This subsection reviews empirical studies that focus on the cross-country diffusion of innovations and its drivers given the scope of our study. The goal of this part is to shed light on the wide range of different factors and their measures that influence the entire diffusion process and specific stages of the product’s life cycle at international level. Our specific questions:

- What factors influence diffusion of innovation at international level?
- What are key drivers at different stages of the product life cycle at international level?

²⁵ We are interested in a model that captures the maturity and decline stages of the product life cycle. Better understanding of these stages can help define possible causes of rejection of innovation.

Different patterns of diffusion across products and countries are observed. Some early studies use the Bass model to study differences in diffusion rates across products and countries (Dwyer, Mesak, & Hsu, 2005; Ganesh & Kumar, 1996; Takada & Jain, 1991; Tellefsen & Takada, 1999). Scholars compare the coefficients of internal and external influence across countries. The authors explain similarities in diffusion rates by country-characteristics which might be related to homogenous populations and alike cultural and socioeconomic backgrounds (Dwyer et al., 2005; Takada & Jain, 1991), the time since introduction (Ganesh & Kumar, 1996; Takada & Jain, 1991), cultural dimensions (Dwyer et al., 2005) and/or availability of the mass media (Tellefsen & Takada, 1999). These studies mainly explore the growth stage of the product life cycle. Subsequent studies also examine other stages of the product life cycle and additional drivers of diffusion of different products and services. Table 2 shows international diffusion studies which explore different factors influencing the diffusion rates of various services, consumer and industrial products at international level together with main findings and existing contradictions.

2.3.1. Factors influencing diffusion of innovation at international level

The empirical literature on international diffusion of innovation uses a large quantity of different sets of explanatory variables that might affect the diffusion. Most of the factors can be grouped under the following headings: cross- and intra-country interactions, socio-economic, cultural, demographical, geographical, media intensity and political variables.

a) Cross-country interactions

Takada & Jain (1991) are among the first scholars to study cross-country interactions. The authors explore a lead-lag phenomenon. They conclude that countries with a later product introduction (lag countries) tend to have faster diffusion rate (imitation coefficient) than those which have introduced the product earlier (lead countries). Ganesh & Kumar (1996) explain faster diffusion rate by a learning effect²⁶ that occurs as a result of sharing experience of the lead country. However, at a certain level the learning effect may decrease. In contrast to these findings, prior takeoffs in other countries²⁷ rather than prior introductions in other countries²⁸ have a positive impact on the probability of takeoff (Chandrasekaran, Arts, Tellis, & Frambach,

²⁶ "The influence of the adopters in the lead country on the potential adopters in the lag countries" (Ganesh & Kumar, 1996, p. 329).

²⁷ The countries where a takeoff has occurred before

²⁸ The countries where an innovation is introduced first

2013; Tellis, Stremersch, & Yin, 2003; van Everdingen, Fok, & Stremersch, 2009). International experience can be also measured by the total number of countries which tried an innovation. According to Dekimpe et al. (2000a) the probability of a new product implementation increases with the number of countries which have tried an innovation. This conclusion is in line with Rogers' (2003) notion of triability.

b) Intra-country interactions

In addition to inter-country interactions, intra-country communication occurs which can be compared to a contagion effect. Intra-country interaction can be measured by cumulative sales within a country and prior introduction in a country (Chandrasekaran et al., 2013; van Everdingen et al., 2009). Chandrasekaran et al. (2013) conclude that intra-country interactions²⁹ have positive effect on the probability of takeoff. However, whether the learning and contagion effects and their direction hold for slowdown has not been analyzed directly yet. Industrial goods might exhibit different patterns due to a longer time lag of sharing experience and a potentially complex and costly procedure of input-mix or equipment replacement.

c) Country characteristics

Country's socio-economic characteristics can be measured by gross domestic product (GDP) per capita or gross national product, GNP, per capita, GINI index, percentage of economically active women, country's infrastructure development (for example, number of fixed line telephones), literacy rates, openness³⁰, economic progressiveness³¹ etc. It is hypothesized that a country's time of adoption and diffusion is positively related to GDP per capita. This is in line with Rogers' (2003) claim that earlier adopters have higher income and literacy rate. One of the explanations is that wealthier societies have greater ability to take a risk (for example, performance risk³²) (Dekimpe, Parker, & Sarvary, 2000a; Tellis et al., 2003) and thus wealthier countries may adopt faster. A rate of economically active women may suggest that there is a need for time-saving consumer products (for example, a washing machine). Openness can facilitate the spread of new products and experience sharing among countries. Besides, it might increase competition which may result in lower prices. (Chandrasekaran et

²⁹ The authors use as one period lag of cumulative sales for a particular product in a particular country as a measure of intra-country contagion effects.

³⁰ International trade involvement

³¹ Economic progressiveness deals with distribution of wealth within country and affordability.

³² Oren & Schwartz (1988) state that "the 'newness' of the product, implying a lack of information about its effectiveness, and variation in the product's effectiveness for different consumers" may raise doubts about an innovation performance (p. 274).

al., 2013; Dekimpe et al., 2000a; Golder & Tellis, 2004; Tellis et al., 2003; van Everdingen et al., 2009). Additionally, Golder and Tellis (2004) suggest that a recession might make several consumers to delay buying a new product. These decisions may trigger the responses of other consumers which in turn might result in a product's slowdown (these change in sales is not proportional to a decrease in GDP). Concerning new industrial products, companies might require an investment in additional means of production and wealthier countries might benefit from access to capital and, thus, adopt new products faster.

The studies on the international diffusion provide controversial evidence of the impact of wealth on diffusion rates. While several authors have found positive impact of wealth on time of adoption and diffusion rates (Chandrasekaran & Tellis, 2008; Dekimpe et al., 2000a, 2000b; Kauffman & Techatassanasoontorn, 2005; Putsis Jr. & Srinivasan, 2000; van Everdingen et al., 2009), other scholars have found no statistically significant effect of wealth on time to takeoff and diffusion rates (Dekimpe, Parker, & Sarvary, 1998; Tellis et al., 2003). Besides, Yeniyurt and Townsend (2003) have found that higher uncertainty averse countries with higher GDP are likely to have lower penetration rates. Deepa Chandrasekaran et al. (2013) have found that wealth has a moderating effect on the impact of price volatility on the probability of takeoff. Regarding a time to slowdown, Golder & Tellis (2004) have found that a decrease in GDP affects positively the probability of slowdown.

Dwyer et al. (2005) are one of the first to study the impact of national culture on diffusion of innovation across countries. Differences in cultural characteristics are often measured by cultural dimensions suggested by Hofstede et al. (2004, 2010). Cultural difference can be also measured by religiosity and quantity of ethnic groups. Initially, cultural dimensions have included 4 different indexes: Power Distance Index, Masculinity (vs Femininity), Individualism (vs Collectivism) and Uncertainty Avoidance Index. Recently, two other dimensions have been added: Long Term Orientation and Indulgence. Power distance is "the extent to which the less powerful members of institutions and organizations within a country expect and accept that power is distributed unequally". Individualism is "the degree of interdependence a society maintains among its members". Masculinity is related to "what motivates people, wanting to be the best (Masculine) or liking what you do (Feminine)". Uncertainty avoidance reflects to "the extent to which the members of a culture feel threatened by ambiguous or unknown situations and have created beliefs and institutions that try to avoid these". Long term orientation addresses "how every society has to maintain some links with its own past

while dealing with the challenges of the present and future". Indulgence deals with "the extent to which people try to control their desires and impulses". These dimensions reflect differences in people's convictions, attitudes and behavior across cultures. Uncertainty avoidance index is the most frequently used dimension among these dimensions (Chandrasekaran et al., 2013; Dwyer et al., 2005; Tellis et al., 2003; van Everdingen & Waarts, 2003; Yenyurt & Townsend, 2003). According to Hofstede et al. (2010), Japan is considered to be one of the countries with the highest uncertainty avoidance index (it equals 92 out of 120). The authors explain this fact among other things by frequent natural disasters and the existence of associated precautions and emergency plans³³. It is hypothesized that countries with higher uncertainty avoidance are likely to have a negative influence on time to takeoff and other diffusion rates. It can be explained by the delay in new product purchase due to lack of understanding of its benefits and unwillingness to take risks (Dwyer et al., 2005; Tellis et al., 2003). Several scholars have found a support for this hypothesis. The authors have found a negative effect of higher uncertainty avoidance on the probability to takeoff and diffusion rates (Chandrasekaran et al., 2013; Tellis et al., 2003; Yenyurt & Townsend, 2003). In contrast to these findings, Dwyer et al. (2005) have not found a statistically significant effect of uncertainty avoidance on diffusion rates across countries.

d) Demographic characteristics

Demographic and geographical dimensions can explain a variation in diffusion pattern through population growth, number of population centers, urbanization etc (Dekimpe et al., 1998). Additionally, countries located near each other might have similar pattern of diffusion compared to countries which are located far away from each other (Kuester et al., 2000). These dimensions capture the idea of increased interpersonal communication which might result in higher awareness rate (Tellis et al., 2003). However, Rogers (2003) states that a spatial distance is relatively less important due to new technologies of communication. Access to information is another dimension that influences awareness about a new product. Information access dimension include media intensity, mobility and education (education serves as a proxy of receptiveness of new ideas and new products). It is hypothesized that

³³ "From cradle to grave, life is highly ritualized and you have a lot of ceremonies... At weddings, funerals and other important social events, what people wear and how people should behave are prescribed in great detail in etiquette books. In corporate Japan, a lot of time and effort is put into feasibility studies and all the risk factors must be worked out before any project can start. Managers ask for all the detailed facts and figures before taking any decision. This high need for Uncertainty Avoidance is one of the reasons why changes are so difficult to realize in Japan" (Hofstede, 2001; Hofstede et al., 2010)³³.

countries with higher number of large cities and higher information access have faster takeoff and diffusion rates. Dekimpe et al. (1998, 2000b) have found that countries with higher level of urbanization are likely to adopt new products faster. Media intensity emerges as a significant driver of the diffusion of innovation (Putsis Jr., Balasubramanian, Kaplan, & Sen, 1997; Tellefsen & Takada, 1999; Tellis et al., 2003).

e) Political dimension

Political dimension includes such measures as a membership of the EU, Former East-bloc or other unions and different regulations which are related to the diffusion of innovation. Membership of one of the unions suggests the existence of similarities among members which ease the experience sharing and as a result a membership might have a positive effect on adoption rate (Dekimpe et al., 1998, 2000b). Regarding regulatory policies, a standardization that involves a policy might have an impact on the diffusion of innovation. Regulators might decide on standards and other regulations before consumers purchase a new product (for example, telecommunication services, medical products or chemicals can be subject to different policies). A unified standard can increase an adoption of innovation and the existing multiple standards might slowdown diffusion rates (Kauffman & Techatassanasoontorn, 2005).

f) Other dimensions

Other dimensions included in the studies at international level are market and industry dimensions. For example, a study on digital mobile devices define indicators which are related to digital mobile phone industry and its previous generation : quantity of existing analog mobile phone users, digital mobile phone services price, quantity of digital mobile operators and standards, quantity of existing analog phone users, analog mobile phone services price and quantity of analog phone operators and standards (Kauffman & Techatassanasoontorn, 2005).

To sum up, we note that controversies have arisen over the impact of different factors on the diffusion of innovation across stages. First, most studies have found that prior introduction of innovation compared to other countries influences the diffusion of innovation. However, the other studies define prior takeoffs in other countries rather than prior introduction as important determinants. Second, the role of wealth in diffusion of innovation is not obvious. The reviewed research in Marketing provides some contradictory evidence regarding this factor. These findings highlight the need to review studies from related disciplines. Third, the

influence of cultural variables can be further studied as the evidence is mixed regarding the uncertainty avoidance index in the diffusion of innovation as one of the studies has not found its effect on diffusion rates at international level statistically significant. Moreover, it is unclear whether similar drivers of diffusion and the pattern of their influence hold for a new product under conditions of uncertainty given the lack of literature on this topic.

2.3.2. Key drivers at different stages of the product life cycle at international level

Subsection 2.3.1 has presented the different sets of factors which might impact an adoption rate. As we have mentioned in Subsection 2.2.1.1 there are several measures of adoption rate. Broadly speaking, we not distinguished the factors and their effects on takeoff and slowdown from other adoption rates in Subsection 2.3.1. Kauffman and Techatassanasoontorn (2005) state that certain factors influence differently in different phases of the product life cycle. A factor that has a particular effect in one phase might have no effect or opposite effect in the other stages of the product's life cycle. Relatively few studies explore the factors that influence the specific turning points of diffusion. The review of these studies helps us to define what factors influence different stages of the PLC and relates these factors to our cases as potential determinants of diffusion of BPA and nanosilver. To summarize, these studies examine different determinants of takeoff and slowdown. Drawing on these studies, we formulate our hypotheses concerning BPA.

The takeoff and slowdown of new products are important points in the product life cycle (PLC). Knowing how different factors influence sales growth at different phases across countries allows adjusting international marketing decisions and adopting various product policies ranging from improvement in new products to their phasing out. For example, different product introduction strategies can be implemented: a waterfall ³⁴or sprinkler strategy³⁵ (Tellis et al., 2003). To take control of a decline of the sales, two different strategies can be implemented: substitution³⁶ or extension³⁷ (Scheuing, 1989). Moreover, understanding the factors that influence the key turning points of the product life cycle may also help to recognize the need for rapidly increasing or decreasing quantity of good which can help to

³⁴ Sequential products launch across countries (Tellis et al., 2003)

³⁵ Simultaneous products launch across countries (Tellis et al., 2003)

³⁶ Innovation is launched when a recently introduced product is in the phase of growth. The old product is phased out as soon as a new product reaches a certain level (Scheuing, 1989)

³⁷ Sales are pushed upward instead of continuing their pattern (stability or decline). It can be achieved through more frequent and diverse usage among current users, conquering new markets and discovering new uses for the product (Levitt, 1965; Scheuing, 1989)

manage inventories and delivery timing properly. Moreover, pricing policies can be adjusted according to phase and goals of product managers (Scheuing, 1989).

Key determinants of takeoff that are examined are intra- and cross-country, economic characteristics, regulatory policies, industry and market characteristics (Chandrasekaran et al., 2013; Chandrasekaran & Tellis, 2008; Golder & Tellis, 2004; Kauffman & Techatassanasoontorn, 2005; Tellis et al., 2003; van Everdingen et al., 2009). The results of these studies are presented in Table 2 and the existing controversies in the empirical literature (discussed above) hold for takeoff. However, several studies (Dekimpe et al., 2000a; Kauffman & Techatassanasoontorn, 2005) are not directly comparable as they do not adopt the terminology of the product life cycle concept defined by Levitt (1965). Kauffman and Techatassanasoontorn's stages (2005) include introduction, early diffusion, partial diffusion and maturity. It seems that early diffusion and partial diffusion stages represent Levitt's growth stage delineated by two stages. Thus, a takeoff is represented by a transformation rate from introduction to early diffusion.

The study of Golder and Tellis (2004) is one of a few studies investigating determinants of slowdown of a new product. One of the key determinants is country's wealth. The authors provide two explanations of its impact. One explanation is economic. It deals with an affordability concept and a decrease in disposable income as a result of recession which results in lower adoption rate and slowdown. Another explanation is related to the decision of consumers to delay their purchase of a new product triggered by other consumers. As it is mentioned previously, the changes in sales are not proportional to a decline in GDP if the latter occurs. The authors have found that a decrease in GDP affects positively the probability of slowdown. However, the authors have not confirmed their hypothesis about a proportional decline of sales with respect to changes in GDP. This suggests that this decision is triggered by other consumers' behavior as a result of changes in GDP. Moreover, the study of Golder and Tellis (2004) illustrates that the probability of slowdown is higher if market penetration is higher or price reduction is lower. The scholars have concluded that products which have a larger increase in sales at takeoff are likely to have a larger decrease in sales at slowdown.

Besides, we note the following gaps that exist in the literature:

- Many studies of international innovation diffusion focus on consumer products with a few exceptions of studies which explore diffusion of industrial products and services

- Most of the work on the diffusion of innovation explores mainly the growth stage of the product life cycle. Studies on the factors that influence a time to takeoff are not widespread compared to other studies on the diffusion of innovation. There is even less work on the determinants of a time of slowdown.

- To our knowledge, there is still need for literature on the diffusion of innovation in a situation of uncertainty about environmental and health risks at international level in the light of recent events (for example, GMOs). Whether similar findings regarding determinants of innovation hold for a new product in a situation of uncertainty about environmental and health risks needs to be investigated in depth. Therefore, we review single-country studies on the diffusion of innovation under this condition.

Table 2. Summary of international diffusion studies

Reference	Objective	Factors/Variables	Countries/ Product Category	Main findings
Chandrasekaran & Tellis (2008)	To understand how and why time to takeoff differ across countries	<p>Country characteristics: <u>Cultural variables:</u> in-group collectivism, power distance, religiosity (frequency of church attendance), uncertainty avoidance <u>Economic variables:</u> economic development (GDP per capita), economic disparity (GINI index), information access (number of radios, number of TVs, number of telephones and vehicles possession including buses), trade openness Other: Year of first commercialization, number of takeoffs across countries, population density</p>	31 countries, 16 durables and services	Probability of takeoff of fun products (CD player, video camera, etc) is higher in countries with higher economic development and higher in-group collectivism. Fun products which have been commercialized more recently have higher probability of takeoff. Higher level of trade openness impacts positively the probability of takeoff for fun and work products (freezer, washing machine, etc). Higher level of uncertainty avoidance has a negative impact on the probability of takeoff. The average time to takeoff differs between fun and work products, between developing and development countries.
Chandrasekaran et al. (2013)	To explore drivers of takeoff (including price volatility and relative price)	<p>Country characteristic: national wealth, uncertainty avoidance, Market: relative price (relative to the initial price), price volatility (based on the deviation of actual and expected price), innovative activity Intra-country interaction (contagion effect): Cumulative</p>	8 countries, 7 consumer electronic products	Lower relative price impacts positively the probability of takeoff and higher price volatility impacts negatively the probability of takeoff. Wealth, cultural variables and other intra-country characteristics have a moderating effect on the impact of price volatility on the probability of takeoff. Prior takeoffs in other countries, higher intra-country interaction and higher level of innovative activity have a positive impact on takeoff. Higher uncertainty avoidance index

Reference	Objective	Factors/Variables	Countries/ Product Category	Main findings
		sales of a product in a country in the previous period Cross-country interaction: number of takeoffs across countries within a region		or lower wealth strengthens the negative impact of price volatility on the probability of takeoff.
Dekimpe, Parker, & Sarvary (1998)	To study the impact of exogenous/endogenous country characteristics on country-level diffusion patterns	Country characteristics: <u>Economic:</u> GNP per capita, number of competing cellular systems, poverty (crude death rate) <u>Social system factors:</u> Number of ethnic groups Demographic: population growth, number of population centers Other: Number of adopting countries, proportion of World Bank countries	184 countries, cellular phone (service)	Population growth has a positive effect on initial penetration. Number of population centers has a negative effect on initial penetration, but it has a positive effect on penetration growth. GNP, a number of adopting countries, a proportion of World Bank countries have no effect of diffusion parameters. Death rate has a negative effect on diffusion parameters. Number of competing cellular centers has a positive effect on initial penetration. Ethnic heterogeneity has a negative effect on diffusion parameters.
Dekimpe, Parker, & Sarvary (2000a)	To examine the diffusion of a technological innovation over 3 phases: implementation, trial, confirmation while considering the effects of network externalities and installed base of old technology while suggesting a new methodology	Country characteristics: <u>Economic:</u> GNP per capita <u>Social:</u> number of ethnic groups <u>Installed base of old technology:</u> number of telephone lines in a particular year International experience (cross-country interaction):	162 countries, digital phone switches (industrial product)	GNP has a positive effect on the transition rates between stages. The hypothesis about the impact of ethnic heterogeneity is partially supported. Introduction of the new product is not affected by the installed base of old technology. International contagion effect: the wider the international experience, higher the chance of innovation implementation in other countries.

Reference	Objective	Factors/Variables	Countries/ Product Category	Main findings
		total number of countries which tried an innovation, total number of innovations adopted		
Dekimpe et al. (2000b)	To explore the effect of exogenous and endogenous country characteristics on the diffusion process in the context of a new staged estimation procedure	<p>Demographic: population growth, number of population centers</p> <p>Country characteristics:</p> <p><u>Economic:</u> GNP per capita</p> <p><u>Social factors:</u> number of ethnic groups</p> <p>Political factor: former Eastern bloc countries</p> <p><u>Other:</u> proportion of World Bank countries, the time since the introduction</p>	184 countries, cellular phones (service)	The contagion effect is supported by the data. The counties with higher level of urbanization, wealth and heterogeneity are likely to adopt the innovation sooner. And countries which belong to the former Eastern bloc countries are likely to adopt the new products later. The probability of adoption is higher if one fourth of countries which belong to World Bank countries have adopted the innovation.
Dwyer et al. (2005)	To study the effect of cultural dimensions on diffusion rates across countries.	<p>Country characteristics:</p> <p><u>Cultural variables:</u> uncertainty avoidance, individualism, masculinity, power distance and long-term orientation,</p> <p><u>Socio-economic variable:</u> GDP per capita</p>	13 European countries, 7 durables	Individualism and long-term orientation have a negative effect on cross-country diffusion rates. Masculinity and power distance have a positive effect on diffusion rates. The impact of uncertainty avoidance is statistically insignificant.
Ganesh & Kumar (1996)	To study the relationship between the lead ³⁸ and lag countries and their impact on the diffusion rate	Adopters in the lead country, Competition (population per outlet)	European Union, USA and Japan,	The learning effect exists between the lead and lag countries. The later the launch of new

³⁸ If a product is introduced earlier in one country, it is called the lead country. Subsequent countries of product introduction in relation to this country are called the lag countries.

Reference	Objective	Factors/Variables	Countries/ Product Category	Main findings
	(to better understand the learning effect).		retail scanners (industrial product)	product in the lag country, the higher the impact of the lead country.
Ganesh (1998)	To investigate the impact of the unification of Europe on diffusion rates.	None	European Union (12 member states), 10 durables (including VCRs, microwave ovens, home computers, cellular phones and CD players)	The unification is associated with similar rates of diffusion among members. However, the unification does not affect the speed of diffusion rate.
Golder & Tellis (2004)	To examine the impact of different drivers on takeoff and slowdown taking into account the number of prior adopters	Country characteristic: GDP per capita, Product characteristic: product class, Market characteristic: relative price (relative to the price at takeoff), Intra-country interaction: year of takeoff, market penetration (cumulative adopters)	30 consumer durables	Decrease in GDP affects positively the probability of slowdown. However, the authors have not confirmed their hypothesis about a proportional decline of sales with respect to changes in GDP. Besides, higher market penetration and lower price reduction affect positively the probability of slowdown. Products which have larger increase in sales at takeoff are likely to have larger decrease in sales at slowdown. There is a difference in length of the growth stage between leisure-enhancing products and time-saving products.
Helsen, Jedidi, & DeSarbo (1993)	To investigate if segmentation of countries based on macro-level characteristics helps to explain variations in diffusion rates of different products.	Mobility, health, trade, lifestyle, cosmopolitanism	10 European countries, United states and Japan, 3 consumer durables	Differences in diffusion rates cannot be completely attributed to macro-level variables

Reference	Objective	Factors/Variables	Countries/ Product Category	Main findings
Kauffman & Techatassanasoontorn (2005)	To study the impact of factors that affect the diffusion process and different stages (introduction, early diffusion and partial diffusion) as a starting point to understand m-commerce	<p>Country characteristics: <u>Economic factors:</u> wealth (GNP per capita), country's infrastructure development (number of fixed-line telephones) <u>Regulatory policies:</u> standardization policy (market-mediated vs regulated regime), competition policy (regional/national/hybrid licensing policy) Industry characteristics: <u>Analog mobile phone industry characteristics:</u> quantity of existing analog mobile phone users, quantity of analog mobile phone operators and standards, analog mobile phone service prices <u>Digital mobile phone industry characteristics:</u> quantity of existing digital mobile phone users, operators and standards, digital mobile phone service prices</p>	Digital mobile phones	<p>Main determinants that influence the diffusion rates from the introduction to the early diffusion stages: "GNP per capita, digital mobile phone penetration, the number of digital mobile phone standards and analog mobile phone penetration". One of possible reasons of why higher number of analog mobile phone penetrations has a positive effect is the familiarity with mobile phones which eases the adoption of the advanced digital technology. Countries with fewer standards tend to have faster early diffusion. GNP per capita and digital mobile phone penetration rate have positive impact on the probability of the transition from the introduction to the early diffusion stages.</p> <p>Main determinants that influence the transition rate from the early diffusion to the partial diffusion: digital mobile phone penetration, number of digital mobile phone operators, number of digital mobile phone standards, digital mobile phone service process, number of analog mobile phone operators, analog mobile phone service prices and licensing policy. Countries which use regional licensing policy and/or higher quantity of operators in the digital phone market (in contrast to higher quantity of analog phone markets) are likely to have higher probability of transition.</p>

Reference	Objective	Factors/Variables	Countries/ Product Category	Main findings
Putsis Jr., Balasubramanian, Kaplan, & Sen (1997)	To understand how earlier adoption of an innovation in one country influences impacts adoption in another country.	Country characteristics: <u>Media intensity:</u> number of TV sets <u>Economic:</u> GDP per capita	10 EU members, 4 durables (VCRs, microwave ovens home computers and CD players	GDP per capita and the number of TV sets have positive effect of the diffusion process. Moreover, a cross-country interaction is recognized as an important factor in the diffusion of innovation.
Takada & Jain (1991)	To define main determinants that affect the diffusion rates in the Pacific Rim Countries	Country effect Time effect (lead and lag time relationship)	Pacific Rim Countries, 8 durables	Diffusion rates vary across countries which have different communication system. Country with later product introduction tends to have faster diffusion rate (imitation coefficient).
Tellefsen & Takada (1999)	To explore the impact of media availability on diffusion rates	Country characteristics: <u>Media availability:</u> quantity of TVs and radios, kilos of newsprint consumed, and quantity of newspapers consumed Other: Product and country dummies	14 European and 2 Asian countries, durables	Variations in the number of TVs are positively related to the external influence coefficient. This might suggest that TVs raise initial awareness about innovation. Variations in the number of newspapers are negatively related to the internal influence coefficient. This might suggest that newspapers can substitute an interpersonal communication as they provide a detailed description of innovation contrary to TVs.
Tellis et al. (2003)	To study the cross-country differences in time to takeoff.	Country characteristics: <u>Economic variables:</u> GDP per capita, GINI index, participation in the European union, International trade, percentage of economically active women <u>Cultural variables:</u> uncertainty avoidance index, masculinity, need for achievement, industriousness	16 European countries, 10 consumer durables	Prior takeoffs in other countries have positive influence on the probability of takeoff. The probability of takeoff is higher in countries with lower uncertainty avoidance, higher need for achievement and industriousness. Economic wealth does not impact the probability of takeoff.

Reference	Objective	Factors/Variables	Countries/ Product Category	Main findings
		<p><u>Information access:</u> media intensity (number of newspapers, number of radios, number of TVs and number of telephones), mobility (car possession), education</p> <p>Product category: product class, market penetration, year of product introduction, number of takeoffs across countries</p>		
Y. M. van Everdingen & Waarts (2003)	To study the effect of cultural variables on adoption rates across countries	<p>Country characteristics:</p> <p><u>Cultural variables:</u> uncertainty avoidance, individualism, masculinity, power distance and long-term orientation</p> <p>Hal's Cultural Classification: Low-context vs high-context cultures, monochronic vs polychronic cultures</p>	10 European countries, Enterprise Resource Planning software (industrial product)	Cultural dimensions are likely to have a significant effect on differences in adoption rate. Within European countries, substantial differences in cultural variables are present and these differences impact adoption rates of an innovation.
Y. van Everdingen et al. (2009)	To investigate the impact of the cross-country spillover of prior product introduction and takeoffs in other countries and other factors on a time to takeoff	<p>Country characteristics:</p> <p><u>Economic factors:</u> economic wealth, economic trade, income inequality</p> <p><u>Tourism:</u> number of tourist arrivals, tourist expenditures in foreign country.</p>	55 countries, 8 durables	<p>Prior takeoff in other countries (in contrast to introduction in other countries) has a positive impact on a time to takeoff.</p> <p>Geographical and economical proximity has a positive effect on a spill-over effect. The effect of cultural distance on foreign clout, distance between countries and foreign susceptibility is not statistically significant.</p>

Reference	Objective	Factors/Variables	Countries/ Product Category	Main findings
		<p>Demographic variables: population density and size</p> <p>Intra-country interaction: Time of product's introduction in a county</p> <p>Cross-country interaction: Prior introduction across countries together with spill-over effect of one country on another, Prior takeoff together with spill-over effect of one country on another.</p> <p>Spill-over is defined by foreign clout of one country (which is connected to economic, cultural and demographic variables, and expenditures of tourists), distance between two countries (which is connected to geographical distance, economic and cultural variables) and foreign susceptibility of another county (which is connected to economic, cultural and demographic variables, and tourist arrivals).</p>		<p>Direct effects: higher GDP per capita and higher income inequality are likely to have a positive impact on the probability to takeoff, uncertainty avoidance and density of population impacts negatively a time to takeoff.</p>

Reference	Objective	Factors/Variables	Countries/ Product Category	Main findings
		<u>Geographical distance:</u> distance between the capitals, neighbor dummy <u>Economic distance:</u> difference in the GDP per capita between countries <u>Cultural distance:</u> difference in the uncertainty avoidance between two countries		
Yeniyurt & Townsend (2003)	To examine the impact of cultural differences on penetration rates and moderation effects of socioeconomic factors on this relationship.	Country characteristics: <u>Cultural variables:</u> uncertainty avoidance, individualism, masculinity, power distance <u>Socio-economic variables:</u> GDP per capita, urbanization rates, literacy rates, openness rates	56 countries, 2 durables, 1 service	Power distance and uncertainty avoidance have negative impact on penetration rates. Individualism has a positive effect on penetration rates. Moderation effects of GDP per capita, urbanization rates, literacy and openness on the relationship between cultural variables and penetration rates vary across products. Uncertainty avoidance in countries with higher GDP per capita is likely to have negative impact on penetration rates. Contrary to these results, uncertainty avoidance in countries with lower GDP tends to have a positive effect on penetration rates.

Source: Ostapchuk, based on Chandrasekaran & Tellis (2008); Chandrasekaran et al. (2013); Dekimpe, Parker, & Sarvary (1998); Dekimpe, Parker, & Sarvary (2000a); Dekimpe et al. (2000b); Dwyer et al. (2005); Ganesh & Kumar (1996); Ganesh (1998); Golder & Tellis (2004); Helsen, Jedidi, & DeSarbo (1993); Kauffman & Techatassanasoontorn (2005); Putsis Jr., Balasubramanian, Kaplan, & Sen (1997); Takada & Jain (1991); Tellefsen & Takada (1999); Tellis et al. (2003); Y. M. van Everdingen & Waarts (2003); Y. van Everdingen et al. (2009) and Yeniyurt & Townsend (2003)

2.4. Negative information in Marketing

The literature in Marketing studies the impact of negative information. We will briefly review these studies as new scientific knowledge about risk can be compared to negative information and knowledge about the absence of risk can be compared to positive information.

A number of studies (Chang, Tsai, Wong, Wang, & Cho, 2015; Ketelaar, Willemsen, Sleven, & Kerkhof, 2015; Laczniak, DeCarlo, & Ramaswami, 2001; Marc G. Weinberger, Chris T. Allen, 1981; Seo, Jang, Almanza, Miao, & Behnke, 2014; Wallwork, Fortgang, Hashimoto, Weinberger, & Dickinson, 2012; Weinberger & Lepkowska-White, 2000) in Marketing examine the effect of negative information on sales, purchase behavior, company's image, profitability and stock prices. "Hazard or negative information involves experiential contact or non-experiential messages that denigrate a product or company. Often these messages express, or at least imply, some sort of danger or risk in a physical, social or an economic context" (Weinberger & Lepkowska-White, 2000, p. 466).

Negative information is easy to notice as there are more positive events in an individual's environment. This explains why negative information has a significant effect. The term "distinctiveness" is used to refer to the situation where negative information is easy to notice. In addition to distinctiveness, several studies (for example, Laczniak et al. (2001); Parguel, Benoît-Moreau, & Larceneux (2011)) use other two dimensions of information which are used to generate causal attributions, namely consensus and consistency.

Ketelaar et al. (2015) study the effect of online reviews valence (positive, neutral and negative) and receiver expertise on purchase intentions of consumers. The literature on online reviews contain studies on secondary online WOM which can be compared to rumors. The nature of rumors (it can be based on an unreal piece of information) and impossibility to identify the original source make rumors tricky to manage. It can cause serious harm to reputation of a company (Weinberger, Allen, & Dillon, 1981). Contrary to rumors, the primary source of new scientific knowledge about risk can be easily identified. However, company's motives to be engaged in research can be perceived as more intrinsic if this company is involved in an event associated with risk. Its engagement is one of the strategy to deal with negative information. A number of studies in Marketing discuss possible strategies to cope with negative information. According to Tybout et al. (as cited in Weinberger et al. (1981), a denial is not an effective strategy for dealing with rumors compared to storage (relating rumors to another issue) and retrieval strategy (emphasizing the importance of other characteristics which are

not involved in a rumor). Chang et al. (2015) investigates if a reputation of an organization can be influenced by an accommodative (for example, apology or compensation) or defensive strategy to deal with a customer's complaint. The former suggests that an organization admits that there is a problem and the latter means that an organization denies the existence of a problem. Other strategies to overcome negative information include: a product recall, a full refund, new quality measures, comparative advertising, self-denigrating measures as corrective advertising or affirmative disclosure (Seo et al., 2014; Sparks, So, & Bradley, 2016; Weinberger et al., 1981; Weinberger & Lepkowska-White, 2000).

In our analysis, we have chosen not to distinguish between scientific articles concluding that there is a risk /no risk/uncertain in our analysis. This approach is different from studies in Marketing. The studies on negative information in Marketing explore the effect positive, neutral and negative information separately. It seems that this approach is not suitable for our study and we will discuss this in Chapter 3.

2.5. Diffusion of innovation in a situation of uncertainty about environmental and health risks: what does the literature say?

Another aspect that deserves further discussion is uncertainty. This aspect is closely related to the topic of innovation and our study, in particular. Uncertainty is inherent in every innovation and potential side-effects might be unknown in the early stages of product life cycle (Scherer, 2010). Despite a large number of studies on diffusion of innovation, uncertainty is not fully studied (Olson, Birge, & Linton, 2014). However, recent studies (Arora, Foley, Youtie, Shapira, & Wiek, 2014; Köhler & Som, 2014) provide first evidence of determinants of adoption of nanotechnology in a situation of uncertainty about environmental and health risks. These studies represent one of the streams of literature that provides background for this study. These studies permit to draw a comparison of drivers of diffusion of innovations in different situations regarding uncertainty about environmental and health risks.

Arora et al. (2014) explore nanomaterials in the construction sector in the United States. The authors try to capture not only drivers of adoption, but also its barriers. Due to unavailability of quantitative data, they mainly use a qualitative approach to explore whether actors in the constructive industry are willing to consider and adopt nano-enabled products. The authors study the role of absorptive capacity, supply-chain and inter-firm organization together with products availability and awareness. Analyzing patents on manufactured nanotechnology

products, the authors have observed an increasing supply of manufactured nanotechnology products which can find applications in the construction industry.

Absorptive capacity is defined as a degree to which a firm is able to evaluate and incorporate internally the knowledge created exogenously with the goal of commercialization (Arora et al., 2014). The authors argue that the firms in the building construction sector experience difficulty in integrating the innovations in their innovation projects due to lack of absorptive capacity. Otherwise, the lead users which are represented by lead constructions firms might improve other firms' ability to exploit external knowledge through communication. The latter explanation is in line with the Abrahamson's (1991) fad and fashion perspectives. Given that the analysis of Arora et al. (2014) is undertaken at one country level, some findings need to be converted to aggregate international level. Regarding absorptive capacity development, it can be compared to a country's learning effect that happens as a result of experience sharing of the lead country. The authors have concluded that a current level of absorptive capacity does not allow to evaluate extensively different aspects, including health and safety, of manufactured nanotechnology products extensively.

Inter-firm organization is considered as a barrier to innovation adoption. Contractual obligations limit inter-firm interaction and knowledge sharing. The difficulties in communication on new products across a supply chain might extend the length of time needed for experience sharing. Therefore, it might slowdown the diffusion process. However, several respondents confirm their participation in trainings and different workshops organized by universities (Arora et al., 2014) which can be compared to a word of mouth behavior. These results are consistent with Day & Herbig (1990) on the difference between consumer and industrial markets. It is worth mentioning that Day & Herbig (1990) have concluded that the time of diffusion of an industrial product is, on average, longer than a consumer product. This is in line with Tidd & Bessant (2013). The authors demonstrate that the length of the introduction stage for an industrial good is relatively long. Moreover, there are less direct contacts among consumers. Channels of communication include industry associations, conferences and communication with a purchasing/sale agent in addition to online platforms which are increasing their roles in a word of mouth behavior. The latter factor can be transferable to aggregate international behavior through information access availability dimension which specifically deals with adoption rate of computers (with internet) in a country, mobility and the number of major population centers. These proxies are closely

linked to a word-of-mouth communication. Additionally, an information access might increase awareness about the existence of products which is one of the elements of the diffusion process. Arora et al. (2014) examine awareness of the manufactured nanotechnology products. The authors concluded that there is a gap between awareness and use of the products which can be explained by the introduction stage of the nano-enabled product in the construction industry. Given that an access to information also influences awareness about a new product, the other proxies of media intensity seem relevant to studies on international diffusion in a situation of uncertainty.

Köhler & Som (2014) claim that difficulties in communication along the value chain might also result in a loss of safety information as a supplier might avoid providing information on nano-enabled technology to a customer³⁹. This topic is closely linked to liability issue and regulations. Köhler & Som (2014) claim that a lack of regulations on safety might discourage companies to take safety of products into consideration. This might influence consumer acceptance and as a result companies might delay an adoption of nano-enabled products until more knowledge about potential side effects are acquired or related regulations/standards are imposed. A potential negative societal reaction to an innovation due to its potential side effects is considered by companies to be an important barrier to adoption of nanotechnology (Köhler & Som, 2008).

Several authors recognize the importance of policies to the adoption of nanotechnology in building construction and water treatment (Arora et al., 2014; Dilaver, 2010; OECD, 2011). This is in accordance with an international literature on the diffusion of innovation, which identifies regulatory policies as important determinant of diffusion of innovation. Arora et al. (2014) have studied government regulations in the construction industry in terms of their ability to provide an incentive to adopt an innovation. They have concluded that there is no direct encouraging government regulation on adoption of innovation in the building construction industry.

Another study that focuses on barriers to the diffusion of nanotechnology concludes that a lack of “access to early stage capital” and “access to university equipment” are the main barriers related to the diffusion of nanotechnology (Bozeman et al., 2008, p. 749). Bozeman et al. (2008) state that properties of nanomaterials and their commercial potential are not

³⁹ This might reduce safety of employees given there is a lack of legislation on the safety of smart textiles. The authors study the nano-textile sector (Köhler & Som, 2014). This topic is out of scope of our study.

completely understood which leads to a lack of access to early-stage capital. The R&D companies face a shortage of facilities and equipment needed to retain their positions. However, they invest in equipment as the technology becomes more developed. Besides, Bozeman et al. (2008) claim that qualified labor can be another barrier (Bozeman et al., 2008). The importance of human capital is also recognized as a determinant of growth together with innovation (Evangelista, Meliciani, & Vezzani, 2017). To sum up, recent studies on innovations under conditions of uncertainty reveal some pattern of diffusion of nanotechnology, but they have not fully explained it. These findings can be useful in order to generate first insights into determinants of takeoff and slowdown of innovations in a situation of uncertainty about environmental and health risks at international level. However, some studies focus on barriers to the diffusion of nanotechnology from the laboratory to commercialization, while we are interested in the products which are on the market.

2.6. Uncertainty about environmental and health risks and new scientific knowledge

2.6.1. The nature of uncertainty

Prior research on the diffusion of innovation has explored the issue of uncertainty concerning performance and profitability of innovation (Jensen, 1982; Klingebiel & Rammer, 2011; Oren & Schwartz, 1988; Ziamou, 2002). In Management, research has focused on technical (technological), market (commercial), regulatory, social acceptance, managerial and timing uncertainty (Freel, 2005; Hall, Matos, Silvestre, & Martin, 2011; Jalonen, 2011; Littler & Pearson, 1972; Liu & Hart, 2011). Several studies (Littler & Pearson, 1972; Pearson & Hauschildt, 1992) discuss uncertainty related to project management. Project involves uncertainty about objectives, whether a chosen goal can be achieved, and means, “where a given type of research activity or approach is likely to lead to (Pearson & Hauschildt, 1992, p. 48). A relatively recent literature review on this topic reveals that technological and market uncertainty are among the most widely discussed types of uncertainty (Jalonen, 2011). The terms “technical and market uncertainty” are defined by Littler & Pearson (1972). The authors state technical uncertainty “stems from the difficulty in predicting the nature of the technical problems which might arise during the course of development. These often demand novel technical solutions, the cost of which undoubtedly inflate the initially estimated development costs”. Market uncertainty “ranges from the uncertainty about whether or not competing technologies which might inhibit demand for the innovation are being developed, to that

concerning the reaction of users/consumers and therefore the possible market size for the product” (Littler & Pearson, 1972, p. 112).

As discussed in the Introduction, uncertainty related to nanosilver is associated with environmental and health risks of nanosilver. To risk assessors, risk is a function of exposure and hazard. To evaluate risks, both hazard and exposure should be considered (Berube et al., 2010; Mark R. Wiesner et al., 2006). Insufficient knowledge on exposure and hazards levels leads to uncertainty about environmental and health risks.

Incomplete scientific understanding results in epistemic uncertainty (Köhler & Som, 2014). Nanosilver faces an epistemic uncertainty about environmental and health risks. Quantitative risk assessment requires the determination of probability of occurrence of an event. If uncertainty is due to a lack of knowledge (that is epistemic uncertainty), then it will be complicated to measure it and depict it in the form of a probability distribution over possible outcomes (Beven et al., 2015). In the seminal book of 1921, Knight discusses an unmeasurable uncertainty which can be related to an epistemic uncertainty. The author distinguishes the terms “risk” and “uncertainty”. The term “uncertainty” is used by Knight (1921) to mean “in some cases a quantity susceptible of measurement, while at other times it is something distinctly not of this character; and there are far-reaching and crucial differences in the bearings of the phenomenon depending on which of the two is really present and operating... It will appear that a measurable uncertainty, or “risk” proper, as we shall use the term, is so far different from an unmeasurable one that is not in effect an uncertainty at all” (Knight, 1964, p. 19).

One of the ways to deal with epistemic uncertainty is to acquire additional knowledge and improved representation of process which could reduce the uncertainty (Beven et al., 2015). However, scientific opinions alone are not always sufficient for risk assessment (Falkner & Jaspers, 2012). An issue-driven risk assessment is different from a curiosity-driven exploration. The former might involve political pressure and high-stake decisions. Scientific consensus on risks might not be reached. We might face a situation where scientific knowledge leads to more than one reasonable interpretations. Science might not be able to give a definitive authoritative answer. Meanwhile scientific knowledge about risk might serve as basis for policy discussions, knowing its limits in terms of changing the focus from decreasing uncertainty to “coping with irresolvable uncertainties and complexities” might clear up the role of science (World Commission on the Ethics of Scientific Knowledge and Technology;

United Nations Educational Scientific and Cultural Organization, 2005). For example, risk assessment of GMOs is subject to different types uncertainties, some of the cannot be currently resolved. The risk assessment cannot be defined as issue-driven. It involves political pressure and high stakes and high stakes decisions.

2.6.2. Risk management principles

According to a positivist concept (paradigm), uncertainty is supposed to decrease proportional to knowledge development until the moment when it disappears (Godard, 1999). Godard (1999) states that this view does not correspond to the conception that we have acquired over the 20th century. Scientific progress involves new uncertainties which do not decrease the previous ones. In the case of decisions under scientific uncertainty, the precautionary principle applies which is one of principles of risk management based on the nature of risk (Merad, 2009; World Commission on the Ethics of Scientific Knowledge and Technology; United Nations Educational Scientific and Cultural Organization, 2005). Figure 8 shows the cycle of risk management and the position of the precautionary principle in this cycle.

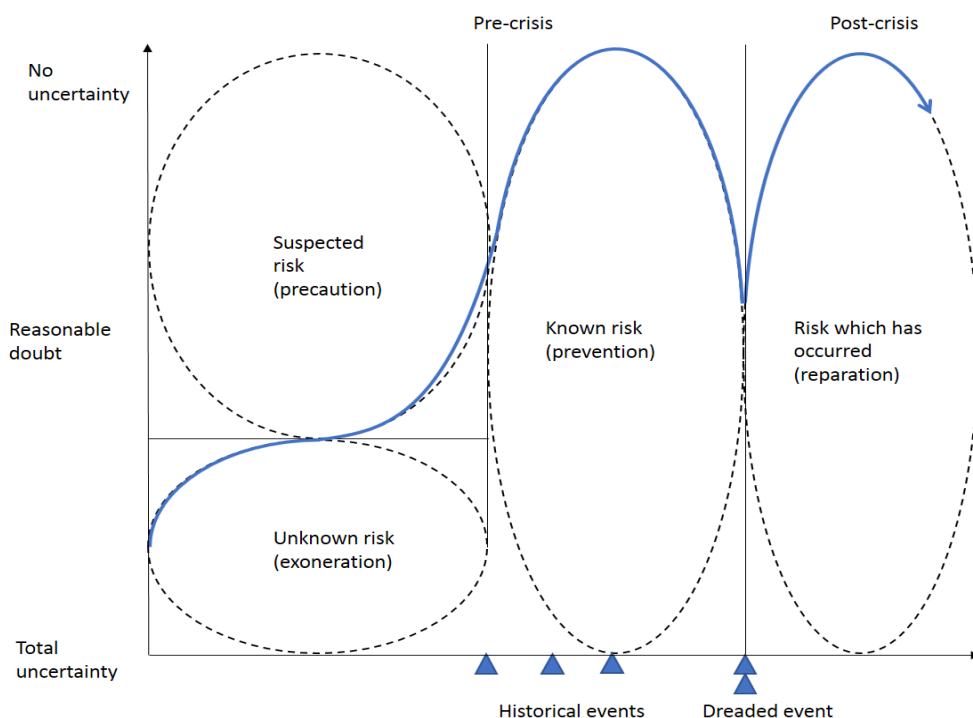


Figure 8. *The cycle of risk management*
Source: Adapted from Merad (2009, p. 35)

Once a potentially harmful phenomenon is scientifically known and its probability of occurrence can be determined, we deal with a known risk. A reaction to risk involves a

preventive approach which allows the government or a citizen to take preventive measures (a priori). In the absence of certainty regarding the phenomenon, two situations might arise. 1. There is a reasonable doubt which is scientifically grounded in the damage potential. In this case, precautionary principle is implemented. 2. The ignorance line of phenomenon is not crossed. The phenomenon is not suspected before its occurrences. The risk is in the “development” phase and the exoneration principle is established. Once risks have occurred, the reparation principle is applied. According to this principle, necessary measures are implemented in order to take responsibility for physical harm, moral injury and economic loss following the occurrence of harmful phenomenon (Merad, 2009).

2.6.3. The precautionary principle (PP)

We will discuss the PP in more detail as it underpins one of our working hypotheses together with a model of impact for an unfortunate event. One of the first formulations of the PP in the World Charter for Nature “Activities which are likely to pose a significant risk to nature shall be preceded by an exhaustive examination; their proponents shall demonstrate that expected benefits outweigh potential damage to nature, and where potential adverse effects are not fully understood, the activities should not proceed” dates from 1982 (General Assembly of the United Nations, 1982, Principle 11b).

PP has appeared in the EU Article 191 of the Treaty on the Functioning of the European Union⁴⁰, Article L. 200-1 of the Law n° 95-101 of February 2 on the strengthening the protection of the environment (Table 3). It is recognized by the World Trade Organization Appellate Body and the International Court of Justice (Sunstein, 2005). Besides, Sunstein (2005) suggests that each country applies precautionary measures against some possible risks, but not others. For instance, the European Union takes precautionary actions on genetically modified organisms and the USA applies precautionary measures to control possible risks related to carcinogenic food additives (Sunstein, 2005).

⁴⁰<http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:12016E191>, accessed in June 2017

Table 3. Citations from the Treaty on the Functioning of the European Union, the French Law n° 95-101 and the French Charter for the environment

Source	Citation
Article 191 of the Treaty on the Functioning of the European Union:	“Union policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Union. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay”
Article L. 200-1 of the French Law n° 95-101 of February 2 on the strengthening the protection of the environment:	“Le principe de précaution, selon lequel l'absence de certitudes, compte tenu des connaissances scientifiques et techniques du moment, ne doit pas retarder l'adoption de mesures effectives et proportionnées visant à prévenir un risque de dommages graves et irréversibles à l'environnement à un coût économiquement acceptable” ⁴¹
Article 5 of the French Charter for the environment:	« When the occurrence of any damage, albeit unpredictable in the current state of scientific knowledge, may seriously and irreversibly harm the environment, public authorities shall, with due respect for the principle of precaution and the areas within their jurisdiction, ensure the implementation of procedures for risk assessment and the adoption of temporary measures commensurate with the risk involved in order to preclude the occurrence of such damage” ⁴²

PP can be considered as a strategy to deal with scientific uncertainty related to risk evaluation and management such as risks of nanotechnology. The term “precaution” refers to taking action to protect human health and the environment against possible danger of severe damage” (World Commission on the Ethics of Scientific Knowledge and Technology; United Nations Educational Scientific and Cultural Organization, 2005, p. 8). Meanwhile, various interpretations of PP can be found in the literature (World Commission on the Ethics of Scientific Knowledge and Technology; United Nations Educational Scientific and Cultural Organization, 2005).

The precautionary principle is applied to situations which can be described by:

- “complexity in the natural and social systems that govern the causal relationships between human activities and their consequences” (World Commission on the Ethics of Scientific Knowledge and Technology; United Nations Educational Scientific and Cultural Organization, 2005, p. 25)

⁴¹ <https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000000551804&categorieLien=id>, accessed in June 2017

Taking into account the existing scientific knowledge and techniques, the precautionary principle aims to prevent a risk of serious and irreversible harm to the environment at an economically acceptable cost. According to the PP, the absence of certainty should not delay the adoption of effective and proportionate measures.

⁴²<http://www.conseil-constitutionnel.fr/conseil-constitutionnel/english/constitution/charter-for-the-environment.103658.html>, accessed in June 2017

- uncertainty about risk that cannot be quantified (World Commission on the Ethics of Scientific Knowledge and Technology; United Nations Educational Scientific and Cultural Organization, 2005)

The idea behind PP: “regulators should take steps to protect against potential harms, even if causal chains are unclear and even if we do not know that those harms will come to fruition” (Sunstein, 2005, p. 4). We might expect that ordinary people follow a similar logic “better safe than sorry” (Sunstein, 2005, p. 13). Ordinary people do what is necessary to avoid possible risks. For instance, we stay away from a dangerous place when it gets dark (Sunstein, 2005). Even if the science is inconclusive, PP can be used in the face of a potential danger. A lack of conclusive scientific evidence showing the danger might postpone the implementation of precautionary actions. Several measures can be taken by authorities responsible for risk management within the framework of the precautionary principle. These measures include research funding, public information, etc⁴³. More details on this will be given below. In the case of asbestos, if different categories of measures had been taken, they could have saved lives (World Commission on the Ethics of Scientific Knowledge and Technology; United Nations Educational Scientific and Cultural Organization, 2005).

2.6.4. Different interpretations of PP

We will discuss two different interpretations of PP in order to clarify the existing regulatory tools and the role of new scientific knowledge in the process of decision making in a situation of uncertainty about environmental and health risks.

The French interpretations are among many other interpretations of the Precautionary Principle. One of the interpretations (developed in the European doctrine, included in the French legal framework, called the 1995 Barnier law) is about “an early but proportionate consideration of potential hazards” (Godard, 2003, p. 1245). Another interpretation is introduced by the French Council of State, supported by NGOs and it is diffused by the media. According to this interpretation, a proof of no risk and an elimination of all sources of risk are demanded. Figure 9 shows these two interpretations.

⁴³ <http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=URISERV:l32042>, accessed in June 2017

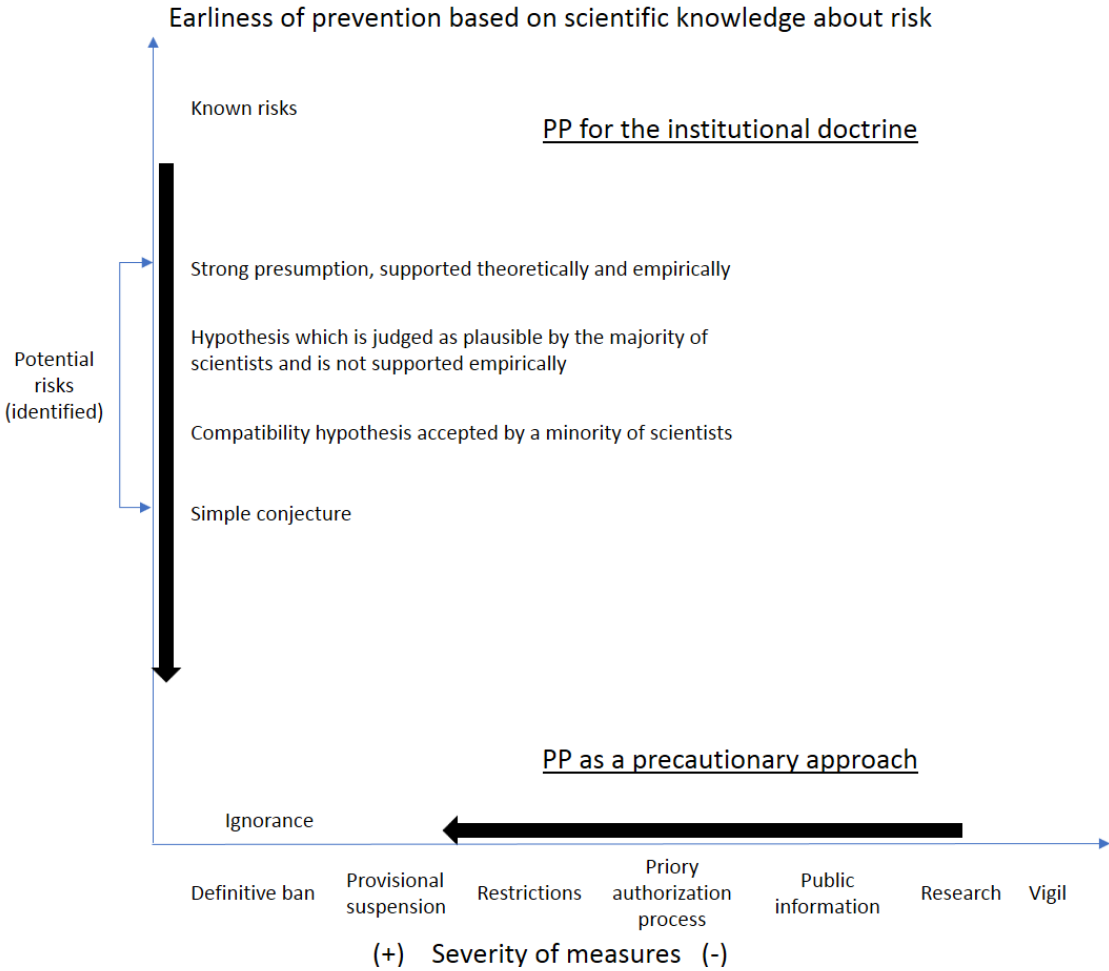


Figure 9. Two conceptions of precautionary principle
 Source: Adapted from Godard (2003, p. 1251)

PP has become a reference norm for actions and public policies in the field of protection of the environment, food safety and public health. The vertical axis on the graph (Figure 9) represents the moment when the authorities decide to take into consideration a potential risk (identified) with respect to adoption of a prevention policy. The scale of this axis depends on the maturity of scientific knowledge. The highest point represents a known risk (existence, probability of occurrence). If the authorities decide to consider only the risks which have reached this stage of maturity of knowledge, it means that they neglect the risk which have not reached this stage of maturity. This situation corresponds to the domain of prevention. The vertical axis from up to down shows moments when risks are taken into account based on lower stages of scientific knowledge (less and less scientifically grounded), from strong presumption which is supported theoretically and empirically to simple conjecture. These moments correspond to potential risks (the term is defined below). The point which is the

closest to the origin corresponds to the ignorance state with respect to the existence of potential risks which are not identified.

The term “potential risks” refers to dangers whose existences are not scientifically established (neither proved, nor disproved) and in spite of established existence, it is impossible to define through logical analysis or through a probability distribution (Godard, 2003). According to Kourilsky-Viney (as cited in Godard, 2003), hypothetical risks correspond to weak plausibility. It is about a working hypothesis which is not supported (Godard, 2003). A certain level of scientific plausibility is required by the notion of possible risks (Sunstein, 2005). Potential risks (plausible) refer to observations which have led to hypothesis which has been judged as acceptable by a non-negligible part of scientific community. Potential risks (supported) have been applied to risks whose existence has been “accepted” by the majority of scientists. Bernard Chevassus-au-Louis (as cited in Godard, 2003) suggests two additional dimensions of plausibility: quantity of additional information related to the hypothesis about risk (the quantity of independent studies) and the degree of consensus of scientific community on this topic.

The horizontal axis shows different types of measures related to PP which can be adopted (from a vigil to a definitive ban). The intermediate measures include:

- Provisional suspension
- Restrictions
- Priory authorization procedure
- Public information
- Research
- Vigil

The main idea of the institutional doctrine is “the absence of certainty should not delay the adoption of measures”. It can be interpreted as a vertical movement in the direction toward the origin over the scientific time when the risk is taken into account by managers. The main idea of the precautionary approach is that the precaution means the adoption of the strictest measure of prevention. It can be interpreted by a horizontal movement toward the origin from a point representing the measures which have been adopted as part of classical prevention policy (Godard, 2003).

Godard (2003) suggests the good interpretation of PP “enforcing the consideration of potential benefits the same way as potential hazards: proportioning preventive measures to

the scientific plausibility of hypotheses of risks, in order to give a lower weight to assumptions deprived of significant evidence” (p. 1245).

Godard (2003) defines 4 elements that should be considered in relation to the proportionality of actions (cost-benefit reasoning):

- anticipated seriousness of risk in question taking into account existing uncertainties
- level of safety that the public authorities set as an objective
- cost of precautionary measures (direct expenses, advantages which can be abandoned as a precaution)

-plausibility or scientific consistency of hypothesis about risk. PP is situated between the ignorance and known risk. The ignorance can be simple (we do not know, we have no doubt) or reflexive (is there an unknown risk?). The ignorance is not associated with a particular potential risk and no proportional action are applied. Known risks (existence and probability of occurrence) are related to prevention principle. PP can be applied to potential risks (identified, but not known). The dimension of plausibility is essential in the context of PP. Between the state of ignorance and known risk, there are different possible risks (identified) which vary depending on the state of scientific knowledge. The choice of appropriate action (measure) should be the result of available scientific knowledge about risk. According to the scale of scientific knowledge, the less a hypothesis is scientifically consistent, the less it is plausible, the less reasons to take strong decisions exist (Godard, 2003).

According to Burch (2008), Peirce suggests that uncertainty that cannot be identified mathematically is closely linked to plausibility. The latter can be described only qualitatively. This raises the question of claim plausibility which is related to hypothesis plausibility (Burch, 2008). Pierce highlight that that two meanings of scientific hypothesis tend to be mixed up. Pierce states (as cited in Wible, 2008): “Scientific hypothesis is usually defined ... as a supposition of circumstance which, by the action of known laws (or a generalization of known laws), would result in facts, such as have been observed. It is also common to use the term scientific hypothesis to denote a very doubtful conclusion of science. These two meanings are apt to be confounded...” (p. 51). The notion of generalization, in turn, is an important element of “conceptive research”. The term “conceptive research” has been used by Le Masson & Weil (2016) to refer to a research management model that is used for a systematic exploration of unknown. The laboratory that was established by Fayol, Guillaume and Chevenard followed the logic of conceptive research. According to the founders of this laboratory, it becomes

responsible for advising executives. When generalization is governed, the discovery is not a pure chance. Contributing to action planning is coherent when a laboratory is able to investigate unknown, reveal a phenomenon, value new types of performance, design disruptive tools and procedures. In the absence of generalization about research, publications, the number of patents, customer satisfaction are used as efficiency criteria for scientific knowledge production by managers. Contrary to these criteria, in 1879 Pierce suggested evaluating research based on uncertainty reduction (Le Masson & Weil, 2016). However, Le Masson & Weil (2016) mention that this suggestion was ignored in the debate about the value of research in the first half of the 20th century (over the studied period).

To sum up, a variety of regulatory tools exist (definitive ban, provisional suspension, restrictions, research funding, information disclosure). Actions should be undertaken based on proportionality of seriousness of potential risks and scientific consistency of a hypothesis about risk. Reason for acting/not acting in a certain way should be based on available knowledge. The PP adds an incentive further exploration and research is one of the available tool. We see that new scientific knowledge is one of the key elements that allow to reach a sound decision. And the quantity of additional scientific information is one of the plausibility dimensions that is used to evaluate research. And we might expect that users follow a certain logic in their choices which is in some way similar to the logic of the PP: “better safe than sorry” together with “the more we know, the better we decide”.

2.6.5. Models for the governance of innovation and risk

A social dimension of technology opens a discussion about consequence of scientific research and scientific research itself. The technology assessment movement of the 1970s is a result of the need to prove the innocence of new technology and science accused of disastrous consequences. Man-made disasters (technological, military and industrial) are different from natural disaster. They are characterized by inability of humans to manage all of the elements of systems that they have constructed. Salomon (1992) identifies 3 forms of man-made disasters: insidious (pollution, extinction of species, direct (the Seveso disaster, a radioactive cloud of Chernobyl) or potential (genetic manipulation). The issue of technology control and public involvement in technological innovation is closely related to the technology assessment movement.

The role of the public and science is also discussed in relation to innovation and risk governance by Joly (2001). The author discusses 4 different models for the governance of risk and innovation which are based on two different factors: the public and science. Some of these models can be relevant to our study given that we are interested in the role of science, namely scientific knowledge about risk, in the diffusion of innovation.

In the first model, the difference in risk evaluation between experts and laymen suggests that the latter behaves irrationally. The public assess risks with a great degree of subjectivity. In the second model, the public is considered to have reasonable grounds for not evaluating the risks in a similar way as experts. Experts consider the risk itself while those who are exposed to risk consider it to themselves. The third model goes beyond a fragmented approach to society. It takes into account the role of special interest groups, the media, political leaders, scientists and public administration in the phenomenon of risk amplification. These differences in the role of the public lead to different recommendations with respect to a procedure for risk evaluation, information and/or public involvement. The fourth model also questions science at work in a procedure for risk evaluation. It focuses on uncertainty rather than risk and collective exploration of socio-technical options. In the fourth model, the risk governance is inseparable from innovation. The originality of European experience is basically related to exploration of the fourth model with respect to GMOs (Joly, 2001). According to Joly (2001), the conflict over GMOs between the EU and the US can be explained by differences in innovation and risk governance. In the EU, with reference to the precautionary principle, the notion of uncertainty and public involvement become the focus. In the USA, risk management is built on the natural authority of science and delegation to qualified administrative bodies. These models deal with the issue of public participation and risk governance related to GMOs. We will present Model 3 and Model 4 in more details given the signs of public involvement in relation to BPA and nanosilver (more details will be given in the next chapter) and our interest in new scientific knowledge. Model 3 is related to robustness of controversies. Model 4 clarifies the issues related to public engagement and public decisions' choices.

Model 3 focuses on the interactions between regulatory process characteristics, pressure groups and the media. Collective behavior is linked to a publicization of risk and uncertainty. Public concerns lead to a reinforcement of regulation. This results in additional studies which allow to better understand risks and identify them. Better knowledge does not always reassure the public as it might increase uncertainty. Emphasizing the uncertainty, the

administration lays itself open to criticism from some groups. These groups might put pressure on the administration using the amplification effect of the media.

Public engagement is linked to expertise organization in a way that it offsets special interests group and those who are amplified by the media. Public management is based on the following elements:

- Delegate the authority over risk management to qualified administrative bodies
- Distinguish a risk evaluation (risk assessment) with the aim of measuring risks from a risk management with the aim of translating this evaluation into a decision
- Conduct a comparative analysis based on different action scenarios in order to respect a general principle of coherence in the analysis of risk and introduce an economic dimension
- Confidence is not a result of openness, but it is a result of reputation, morality and competency. The risk management should not be open to the public in order to avoid confusion (Joly, 2001).

According to Joly (2001), these principles inspire the European Commission concerning the precautionary principle.

If this model also incorporates how the behavior of different actors including experts and laymen impacts a risk management, it remains anchored in a scientific perspective on expertise. Besides, if it takes into account the knowledge of the sociology of perception, its goal is to limit the possibility of public intervention. This model corresponds to a technocratic perspective, the reinforcement of intended scientific perspective is the cornerstone of risk management.

Model 4 questions the concept of science applied to the expertise. New studies on Science and Technology have studied progressively the traditional concept of science as a universal truth revelation independent of a social system that produces it. The capacity of investigation is built on the sequence of past decision with an intervention of economic, social and technical choices. A critique of sound science which is a basis of risk analysis in Model 3 leads to the following characteristics of science:

- At one time, the border between what is considered scientific and what is considered non-scientific is the result of historical contingencies
- A knowledge dissemination which is relevant to an action is not limited to scientific patents. Ordinary people or associations contribute to problem using their knowledge
- The use of scientific results in the “real world” requires a translation which is not often immediate. The mobilization of scientific knowledge to reply to questions

posed by public decision makers systematically places researchers in a sequence of translations.

There is a need for a clarification of how subjective values are taken into account and specific forms of reasoning which determine the risk evaluation whenever scientific criteria cannot be used (factors analyzed and their relevance).

The existing controversies allows to open “black boxes” (implicit hypothesis, which are set by default) which could have been closed quickly under commercial pressure. The controversies appear to be a powerful tool of world exploration which makes choices available again. Individuals or groups can play an important role in a problem characterization. Public controversies can have different trajectories. The productivity can be weak because of the dynamic effect of debate polarization and weaken the arguments. The productivity of controversy can be measured by robustness of scientific statements and produced technical artefact. In this model, a factor that favors debates should contribute to robustness of controversy.

These two models focus on the interaction of different actors and they provide different characteristics of science. The mixture of these two models help us to understand the evolution of BPA and nanosilver industries which are at the intersections of science and the public.

While concepts of risk governance date from the late 1990s, the structure and role of risk governance for nanotechnology have been developing (Tinkle & Auplat, 2016). The importance of risk governance for nanotechnology is underlined by Tinkle & Auplat (2016) as a result of “the diversity of applications and the global race to commercialize nanotechnology-enabled products; the number of stakeholder communities involved in or impacted by their development and use; the uncertainty surrounding hazard and exposure, including the potential for transformation and persistence in the body or the environment; and the potential need for regulation and policy” (p. 8).

2.6.6. A model of impact for unfortunate events

We use a model of impact for unfortunate event in order to formulate our hypothesis about new scientific knowledge about risk in addition to the PP. The hypothesis is presented in detail in Chapter 3. In this subsection, we briefly present the model.

Risk analysis deals with the direct influence of “an unfortunate event (such as an accident, a discovery of pollution, sabotage, product tampering) in terms of direct harm to victims -

deaths, injuries and damages” (Slovic, 1987). Such an event might also influence companies or government agencies indirectly and it may result, for example, in loss of sales, regulatory constraints, litigation, community opposition and/or investor flight (company level). In some cases, a whole industry or other industries can be influenced. Some unfortunate events influence only direct “victims” and others pass from one victim to another (Slovic, 1987, p. 283).

Slovic (1987) presents a model of impact for unfortunate event in terms of indirect costs, monetary and non-monetary (Figure 10). The author posits that “spread of impact” can be partly determined through event characteristics and “signal potential (value)”. The author posits that “signal potential” seems to be associated with the following qualitative characteristics of hazard: dread and unknown risks. The term “dread risk” refers “to perceived lack of control, catastrophic potential, fatal consequences, and the inequitable distribution of risks and benefits”. “Unknown risk” is defined by Slovic (1987) to refer to “hazards judged to be unobservable, unknown, new, and delayed in their manifestation of harm” (Slovic, 1987, p. 283). For example, an event, which is not well-understood might have significant consequences if it is perceived as a sign of impending catastrophe. This model has preceded a model of the social amplification of risk and potential impacts on a corporation. This model provides a framework for understanding the link between technical assessment and sociological, cultural and psychological dimensions of risk perception and public responses to an unfortunate event. The term “amplification” has come to be used in communication theory to refer to “the process of intensifying or attenuations signals during the transmission of information from an information source, to intermediate transmitters, and finally to a receiver” (Kasperson et al., 1988, p. 180). Amplification happens during the processes of sending and receiving signals. Someone who passes the message (transmitter) to another person organizes the message. Someone who receives the message (receiver) interprets and assesses this message. The term “social amplification of risk [or risk event]” refers to “the phenomenon by which information process, institutional structures, social-group behavior, and individual responses shape the social experience of risk, thereby contributing to risk consequences” (Kasperson et al., 1988, p. 181). The significance of an event depends, among other things, on how people interpret and evaluate it.

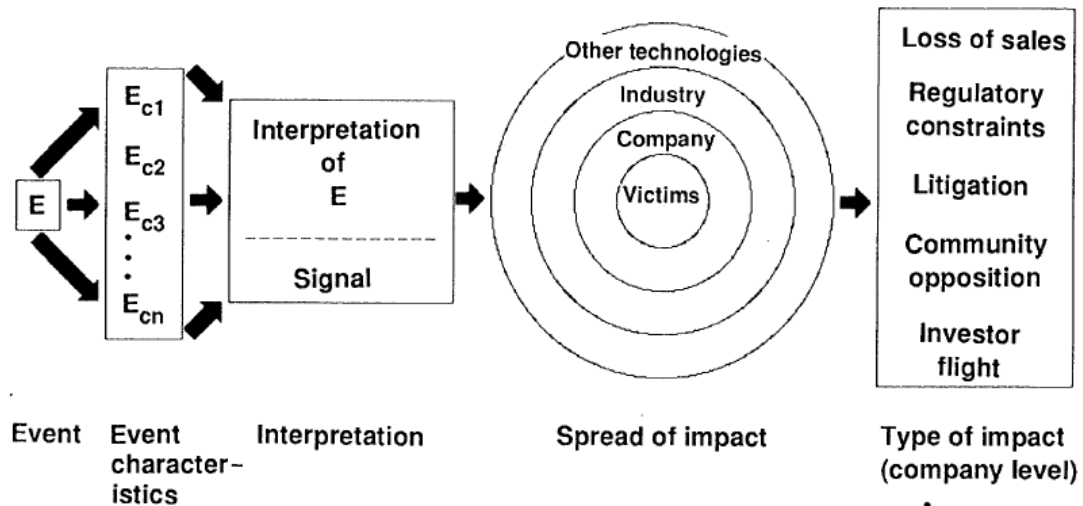


Figure 10. *A model of impact for unfortunate events*
 Source: Reproduced from Slovic (1987, p. 283)

Signals originate from personal experience with an event or through the process of receiving information about this event. Signals can be processed by the media, scientists, different institutions and opinion leaders. These transmitters diffuse information about an event via different communication channels and they might amplify it. Besides, receivers might also amplify events. A flow of information is one of the main determinants of public response and it can act as an important agent of amplification. A considerable amount of information flow might amplify risks (Kasperson et al., 1988). Kasperson et al. (1988) have extended a model of impact for unfortunate events by integrating another stage of amplification, namely interpretation and response. The authors describe 4 scenarios of response mechanism which include interpretation and evaluation of the message:

- Heuristics

The term “heuristics” refers to “a set of mental strategies that people employ in order to make sense out of an uncertain world” (Kasperson et al., 1988, p. 281). Relying on heuristics helps to deal with the complexity of risk through the use of simplifying mechanisms of risk evaluation and actions to be taken. However, it may lead to different kinds of biases⁴⁴.

- Social group relationships

⁴⁴ Further information on different types of heuristics (representativeness, availability, adjustment and anchoring) can be found in Tversky & Kahneman (1974), one of the seminal papers related to this subject.

In a situation where there are conflicts over certain events among different political and social groups depending upon their ideology, more attention is turned to the controversial topic. These groups may influence, for example, risk management practice.

- Signal value (discussed above)
- Stigmatization

The term “stigma” is defined as “the negative imagery associated with undesirable social groups or individuals” (Kasperson et al., 1988, p. 186). Environments with waste or hazardous technology are related to negative images. As stigmatized individuals or environments are avoided, unfortunate events can be also associated with negative imagery which might shape the responses.

These scenarios help us to understand the response mechanisms to an unfortunate event, which is a part of amplification process. In fact, these mechanisms are beyond the scope of this study.

2.6.7. Information dissemination

As reported above, signals can be processed by the media, scientists, different institutions and opinion leaders. In the case of communication of scientific knowledge through different media channels, the media acts as a mediator between scientists and the general public as non-science journalists usually present simple messages avoiding scientific language. Regarding risks, the media breaks the news on a potential risk rather than wait until the uncertainty starts decreasing. Then, it can report on evolution of uncertainty over time. Expression of different (opposite) scientific opinions by scientists about health risks may cause differences in public’s comprehension of a potential risk. While the majority of the public interprets it as a risk, some people consider it as an empty threat. Existing uncertainty can be communicated by the media through contradictory messages to describe the events in a neutral manner and to hold a debate, which is an entertaining dimension of the media (Klöckner, 2015).

While the media is considered to be the most influential communication channel, primary sources of information include expert publications from scientific, industry, governmental and non-governmental sources (Allan, Anderson, & Petersen, 2010; Berube et al., 2010; Kenkel & Chen, 2000). Various fields may use different types of sources. In the field of nanotechnology, scientists are considered a main source of information: their publications are the most cited sources in the news discussing nanotechnology in the United Kingdom, UK (Allan et al., 2010).

There are a number of approaches of presenting the information. The salience of news is often linked to its framing. How the media frames the news on emerging issues and their potential risks might have impact on the perception of information (Allan et al., 2010; Berube et al., 2010). Closely related question is which scientific discoveries should be reported. According to Berube et al. (2010), putting an issue on the public agenda depends on several internal and external factors together with the specific features of an issue. Internal factors include norms of news production, ideology of journalists and media owners. External factor might refer to efforts of interested parties. Specific features of the news might be connected to geographical proximity of the issue to audience and/or its extraordinariness (Berube et al., 2010). It seems that the latter might also include a psychological distance if the news is related to a product in a situation of uncertainty about environmental and health risks. While Berube et al. (2010) state that NGOs might influence decisions on which stories about risk or uncertainty to set in the public agenda, Allan et al. (2010) have revealed that NGOs are rarely cited sources. Another source of information is the industry that is involved in a controversy. Moreover, it might influence the process of knowledge acquisition. For example, the tobacco industry sponsored studies are less likely to reveal harmful effects of passive smoking (Kenkel & Chen, 2000). Vogel (2009) states that out of 115 studies on BPA low-dose effects conducted between 1997 and 2005, none of the industry funded research reveal adverse effects of BPA.

Interpersonal communication is another means of transferring scientific information which the public might have received via the mass media. A personal experience with a product under conditions of uncertainty and consequences associated with its use can be communicated (Kenkel & Chen, 2000). Moreover, a negative event can be extrapolated to other events which can be compared to contagion. A failure of one or several companies can be overgeneralized, and the public might conclude that the whole industry has been hit by a crisis. However, it is unlikely that contagion goes beyond one product line or industry (Berube et al., 2010).

2.6.8. Disagreement between experts and the public (hazard and outrage)

A terminology used in relation to an event may have different meanings for different groups (Kasperson et al., 1988). For example, despite the widespread acceptance of the definition of risk by experts. Sandman (1993) indicates that risk can be defined differently by the public. The risk which is considered negligible by experts can be perceived as important by the public

(Sandman, 1993). It leads Sandman (1993) to redefine the definition of risk. The author states that risk includes two parts: risk defined by experts and risk defined by the public. The latter deals with what worries the public and what is often disregarded by risk assessors and he calls it outrage. The author redefines risk as a function of hazard and outrage. Outrage stands for events which cause a reaction from the public and the reaction itself. A risk controversy might arise as a result of a hazard overestimation and it can lead to outrage. In this case, a careful hazard explanation might reduce a controversy. One of the components of outrage which leads to a risk controversy is “knowability”. The latter includes 3 components: uncertainty, expert disagreement and detectability. The public is likely to be more concerned about uncertainty than experts, especially if uncertainty has not been recognized early. A disagreement among experts can be one of the results of uncertainty. However, their disagreement might suggest that they will work less together on reducing uncertainty. Regarding detectability, Sandman (1993) states that if a risk is more detectable, then it is better knowable which does not cause an outrage, and as a result the risk has not increased. The author states that there are at least 35 different components of outrage. He discusses 12 of them. The difference between hazard and outrage is about which aspect of risk is considered. Ignoring outrage, experts often perceive incorrectly the risk. In contrast to experts, the public might misperceive the hazard. Changes in uncertainty about risk defined by experts that are results of new knowledge acquisition might change also outrage. It implies that both expert and the public can be affected by changes in new scientific knowledge.

2.6.9. Cultural contexts

2.6.9.1. Different cultural contexts and new scientific knowledge

The literature on the diffusion of innovation defines cultural factor as important in our study. We expect that it might impact how new scientific knowledge effects consumption.

The role and nature of scientific knowledge may vary across different cultures. What is considered as new scientific knowledge may also differ across cultures. It can be limited to natural science or it can involve social science. Besides, knowledge may go far beyond scientific knowledge. Traditional knowledge includes folk knowledge and it can be as important as scientific knowledge. It adds on to technical and scientific knowledge (World Commission on the Ethics of Scientific Knowledge and Technology; United Nations Educational

Scientific and Cultural Organization, 2005). Understanding and attitude to particular scientific knowledge can be culture-specific.

A recognition of cultural differences related to new scientific knowledge may help to understand why particular scientific knowledge has an impact in one region and it has less impact in another region.

Besides, one of the amplification steps includes a cultural dimension, which suggests that an interaction with a cultural group may impact an interpretation and validation of the signal. The other steps include “formulating behavioral intentions to tolerate the risk or to take actions against the risk or risk manager” and “engaging in group or individual actions to accept, ignore, tolerate, or change the risk” (Kasperson et al., 1988, p. 181).

2.6.9.2. Different cultural contexts and the precautionary principle

Sunstein (2005) suggests that an application of the precautionary principle can be selective based on several mechanisms. Politicians can use these mechanisms to turn public attention to a particular direction. These mechanisms can help to clarify differences between cultures. These mechanisms are explained by behavioral economics and cognitive psychology. They include:

- Heuristics (discussed above)
- Probability neglect: people concentrate on the outcome which holds the attention, for example, the worst-case scenario. The value of high-risk information is overestimated by ordinary people. Besides, when people search for information, they do not to make an attempt to find out what is associated probability, for example, when they decide to buy warranty for durable goods. People can also consider something as safe or unsafe neglecting the likelihood of harm. Or when a risk is below a particular level, it is neglected
- Loss aversion: “People will be closely attuned to the losses produced by any newly introduced risk, or by any aggravation of existing risks, but far less concerned with the benefits that are forgone as a result of regulation” (p. 41)
- System neglect: “it is understood as an inability to see that risks are part of systems, and that interventions into those systems can create risks of their own” (p. 35).

Besides, when people belong to a group that is predisposed to environmental protection or opposed to environmental controls, they are more likely to think in one way or another. Well-

publicized events such as a mad cow disease or a bomb attack can result in risk overestimation (Sunstein, 2005).

2.6.10. Conceptive research

In order to study the role of new scientific knowledge in the diffusion of innovation, it is necessary to better understand characteristics of new scientific knowledge about risk. To answer our third research question, we have searched for studies which could help us to characterize new scientific knowledge. A 'conceptive' research model has been used by Le Masson & Weil (2016) to refer to a research model aiming to explore unknown from the perspective of strong generativity⁴⁵. This research model clarifies the link between research and innovation. Contrary to the conceptive research model, a resolute research model minimizes the generativity. Le Masson & Weil (2016) demonstrate an interesting logic related to research classified as conceptive using the model of the organization of laboratory established by Fayol, Guillaume and Chevenard. The model of laboratory organizations and its contributions will help us to understand the characteristics of new scientific knowledge about risk.

The issue of generativity is in line with the following governance principles related to research:

1. The laboratory is in charge of a search for a progress
2. The laboratory should contribute to development of action plan
3. Contribution to formulation of action plan is coherent when the laboratory is in position of exploring unknown, reveal phenomena, promote new types of performance, design processes and disruptive tools. The generativity of activity justifies this. Besides, investment pushes the laboratory towards generative explorations.

Within this type of governance, a generative science also corresponds to a logic of production of scientific knowledge. This knowledge is oriented towards the generativity without sacrificing scientific methods (Le Masson & Weil, 2016).

The main contributions of the laboratory founded by Fayol:

1. The research enriches future action plans of enterprise by collecting documents which will be a basis of new manufacturing. The activity of exploration is not driven by new product and process research (development).

⁴⁵ « Une perspective de générativité forte » (Le Masson & Weil, 2016, p. 80)

The exploration of the nature of properties is an unknown space. Different devices are used in order to measure all these properties. This helps to explore reaching a maximum generativity. The scientific activity is related to the capacity to identify and measure new properties, the capacity to provoke the shift in the space of properties.

2. The studies on development of workshop on new processes, production and quality control and appraisal work (final work assessment).

Conceptive research is related to a situation where a creation contributes to strong conceptual expansion (disruptive products or services, new use, new technology). It is about new laws (rules), anomalies, surprises, theoretical propositions allowing fundamental reorganizations, unexpected connections.

A production of knowledge can be linked with different internal stakeholders, contribute to innovation, its results can be used by groups who integrate it. The production of knowledge can be more or less generative concerning concept as well as new knowledge (Le Masson & Weil, 2016).

These two characteristics seem to be common to new scientific knowledge about environmental and health risks. It is worth presenting the difference between conceptive and resolute research in order to understand that there are less similarities between new scientific knowledge about risk and resolute research than between new scientific knowledge and conceptive research.

A resolute research is defined as “a system that produces knowledge focused on the analysis of what already exists, and which thus minimizes generativity”. Contrary to the conceptive research which “produces knowledge for the exploration of the unknown” (Le Masson & Weil, 2016, p. 79). Table 4 presents the difference between the conceptive research and resolute research.

Table 4. Difference between the conceptive research and Mees' research model

	Fayol-Guillaume-Chevenard (conceptive research)	Mees (resolute research)
Governance	“Etat-major” Action plan to explore unknown	Staff and line Insurance against the loss control risk
Logic of action	New properties, new means of action (laws, rules), orientation towards unknown	Theory of the subject, a critical role of methods Direct link with the development of products

Source: Adapted from Le Masson & Weil (2016)

According to Mees, the generativity is neither avoided nor organized. The discovery is not searched, it is a consequence of methods applied. The generativity is not managed, it is a result of the probabilistic perspective. It is the absence of governance of generativity which produces the feeling of uncontrollable hazard. When the generativity is managed, the discovery is not a pure chance (Le Masson & Weil, 2016). While this distinction helped us to understand new scientific knowledge better, one might ask if some characteristics of this knowledge are different from conceptive research defined by Le Masson & Weil (2016). Besides, one might ask what is the role of the truth in the relationship between new scientific knowledge and consumption.

To sum up, in order to analyze the determinants of market uptake of innovation in a situation of uncertainty about environmental and health risks, we have reviewed different streams of literature. In Subsection 2.5, we have focused on the literature related to uncertainty about environmental and health risks. First, we have discussed different types of uncertainty including epistemic uncertainty. This type of uncertainty is due to a lack of scientific knowledge and it is related to nanosilver and BPA. Second, we have briefly presented different principles of risk management including the PP and its interpretation. The latter applies to BPA and nanosilver. Third, we have overviewed the model of impact of unfortunate event. This model does not focus directly on determinants of diffusion of innovation, but it seems useful for understanding the relationship between new scientific knowledge about risk and its consequences. Applying these studies to our study, we are able to formulate our main working hypothesis about the impact of new scientific knowledge about risk, clarify a potential link between science, innovation and the public, better understand the characteristics of new scientific knowledge.

Chapter 3. Research design and methodology

The goal of this research is to explore determinants of market uptake of a nanotechnology innovation in a situation of uncertainty about environmental and health risks. In order to design a starting point for the study of nanosilver, we examine the case of bisphenol A at international level. As we have mentioned, we have chosen BPA as a possible model for nanosilver for several reasons: (1) lack of consistent data on nanosilver (2) time sequences of bisphenol A diffusion: potential risk emerged once the chemical had been adopted worldwide, (3) similar positions of BPA and nanosilver in their value chains, (4) similarities in their perceived psychological distance. We will discuss all these items, as well as the similarities between bisphenol A and nanosilver in later chapters. Chapter 4 presents the positions of BPA and nanosilver in the product's life cycle and the history(ies) of evolution of BPA and nanosilver industries.

The following research questions are addressed in Chapter 6 and Chapter 7

1. What are the key determinants of international uptake of innovation in a situation of uncertainty about environmental and health risks?
2. Does the number of risk-related scientific publications impact consumption?

This chapter discusses among other things:

- Data collection: aggregate data on bisphenol A and secondary intermediate good containing BPA (polycarbonate), and we provide
- Framework for data analysis: to address the first and second questions we use different quantitative research methods.

A prior review of the relevant literature refines the kind of data that we need to collect. However, the unavailability of data does not allow to tackle every single factor influencing the diffusion of innovation. These factors are defined by reviewing the literature. They are discussed in Chapter 3. We try to explain how we have chosen the relevant factors in this

chapter. To explore one of the drivers, a construction of original variable is performed. The variable captures the quantity of articles related to potential risks of BPA in uncertainty of environmental and health risk. The discussion related to the hypothesis about new scientific knowledge about risks is presented in Chapter 3. The analysis of the data set on BPA is presented in Chapter 6 and the analysis of data on polycarbonate is presented in Chapter 7. Main factors and the direction of their impact are explored under conditions of uncertainty. This chapter is organized as follows. First, the hypothesis about new scientific knowledge about risks is presented. Second, a research approach and epistemological positioning are discussed. Then, data sources and measures for our dependent variables are presented. Then, a conceptual model for the international slowdown of industrial product is developed. Finally, methods of data analysis are presented.

3.1. Hypothesis (our main hypothesis)

Different patterns of diffusion across products and countries are observed as we have discussed in the literature review. It has been suggested that differences in the diffusion of products at international level can be explained by, among other things, disparities in socio-economic, cultural, demographical and media intensity factors. It is not clear if factors that influence the diffusion process under different conditions are the same and if the patterns of their impact do not change, given that the literature on the diffusion of innovation in a situation of uncertainty about environmental risk has not dealt with these questions in depth. Are there additional factors which are not widely discussed in the literature and which are of considerable importance if a product is in a situation of uncertainty about environmental and health risks? Is the quantity of scientific knowledge among these factors? We hypothesize that the quantity of scientific knowledge about risk in the context of uncertainty about environmental and health risks can be among these factors. Drawing upon the precautionary principle and a model of impact for unfortunate event, we hypothesize that the increasing quantity of new scientific knowledge about risks impacts negatively the diffusion of innovation in a situation of uncertainty about environmental and health risks.

In the literature, there are many interpretations of the precautionary principle. As we have mentioned in Introduction, the basic idea behind the precautionary principle: the absence of proof should not be a justification for no action. And there is another interpretation of PP presented in French approach which includes (takes as a starting point) the principle of

proportionality: “proportioning preventive measures to the scientific plausibility of hypotheses of risks” (Godard, 2003, p. 1245). Combining these strategies which do not exclude each other allows us to formulate our working hypothesis. Scientific knowledge can be seen as a means of dealing with epistemic uncertainty and as an element of unfortunate event that has economic and social impact. We consider it an important element of the precautionary principle. We might expect that final consumers follow a certain logic in their choices which is in some way similar to the logic of the precautionary principle: “better safe than sorry” together with “the more we know, the better we decide”. This underpins our hypothesis together with a model of impact of an unfortunate event.

The sociology of perception helps to understand negative attitude of consumers to GMOs as they are confronted with new and imposed risks (Garud & Karnoe, 2003). The study of risk perception (Slovic, 1987) describes the link with an unfortunate event. Slovic (1987) compares an unfortunate event with a stone which has fallen in a pond. The author does not explain how ripples diffuse outward from the directly affected victims to others. The essence of a model of unfortunate events is that the public response partly depends on the spread of impacts which can be defined by characteristics associated with an event involving risks. This study has introduced the notion of signal value, its link to event characteristics and spread of impact. Slovic (1987) suggests that a spread of impact is related to two factors: dread and unknown risks (defined above). Each factor contains several characteristics. Many of these characteristics correlate with each other. We assume that the high level of one of the characteristics suggests the high degree of the factor (related to the event that has been judged). According to Carreira et al. (2016) out of 1000 respondents (German-speaking population), 67 % completely agree or tend to agree with the statement “it is almost impossible to control the health risks of nanotechnology”, about 64 % completely agree or tend to agree with the statement “nanomaterials may be harmful to nature and the environment”, about 63 % completely agree or tend to agree with the statement “nanotechnology may result in completely new health problems” (Carreira et al., 2016, p. 63). The survey was conducted in 2012. While the perception of risk may change over time, the results of this survey suggest a current perceived lack of control and the hazard perceived to be new (which correspond to the high degree of dread and unknown risks). These findings are in line with previous results discussed by Sunstein (2005). People are able to accept risks which are familiar and they are concerned about risks which are relatively new. Many people worry

about risks which seem to be newer. For examples, risks related to GMOs, chemicals and terrorism. Those who support the precautionary principle worry about new technologies. “Most people believe that natural chemicals are more safe than man-made chemicals. Most toxicologists disagree” (Sunstein, 2005, p. 44).

The high degree of dread and unknown risks is likely to result in a wide spread of impact⁴⁶ (Slovic, 1987). We expect that an introduction of new scientific knowledge about risks is likely to have an important economic consequence. This hypothesis remains relevant to both cases, namely BPA and nanosilver. We hypothesize that a discovery of potential risks can be considered as an unfortunate event which might lead to loss of sales, community opposition, etc.

New scientific discoveries are made all the time. Some of them are less/more important than other. The term “unfortunate event” is used by Slovic (1987) to refer to events such as “an accident, a discovery of pollution, sabotage, product tampering” (p. 236). The term “risk event” is used by Kasperson et al. (1988) to refer to “unfortunate event” in the extended model. For the sake of simplicity, we will use the term “unfortunate event”. Some examples of unfortunate/risk events include the accident at the Three Mile Island nuclear reactor, “report that chlorofluorocarbon releases are depleting the ozone layer” and “scientists dispute over the validity of an epidemiological studies” (p. 186).

As it can be argued that not all scientific knowledge are unfortunate events, we will present the elements which are common to scientific knowledge about risk and unfortunate events defined by Slovic (1987). These elements will help to understand what kind of scientific knowledge about risk we consider as an unfortunate event.

If the context of uncertainty about environmental and health risks, we define the following elements related to new scientific knowledge about risk which allow to characterize it as unfortunate:

- Unexpected discovery of risk event
- Process of knowledge acquisition which results in scientific articles with convergent conclusions

⁴⁶ This might suggest that these factors moderate the effect of an unfortunate event on its spread (for example, immense social consequences reaching other technologies). The moderating effect of dread and unknown risks is not the focus of this study. Besides, we do not have the historical data on these factors and other technologies. Future studies on the current topic are suggested.

- Scientific dispute

In this case, a discovery of risk event can send a message “a new and possibly catastrophic risk has emerged”, a scientific dispute and a process of knowledge acquisition can be interpreted as: “the experts do not understand the risks” (Kasperson et al., 1988, p. 186). Besides, environmental and health risks related to BPA/nanosilver can be perceived as new and unknown at its high end. New scientific knowledge which possesses these characteristics is considered as an unfortunate event in our study, contrary to new scientific knowledge which is not locked in a dispute⁴⁷.

These distinctions allow us to build out hypothesis about new scientific knowledge (Figure 11).

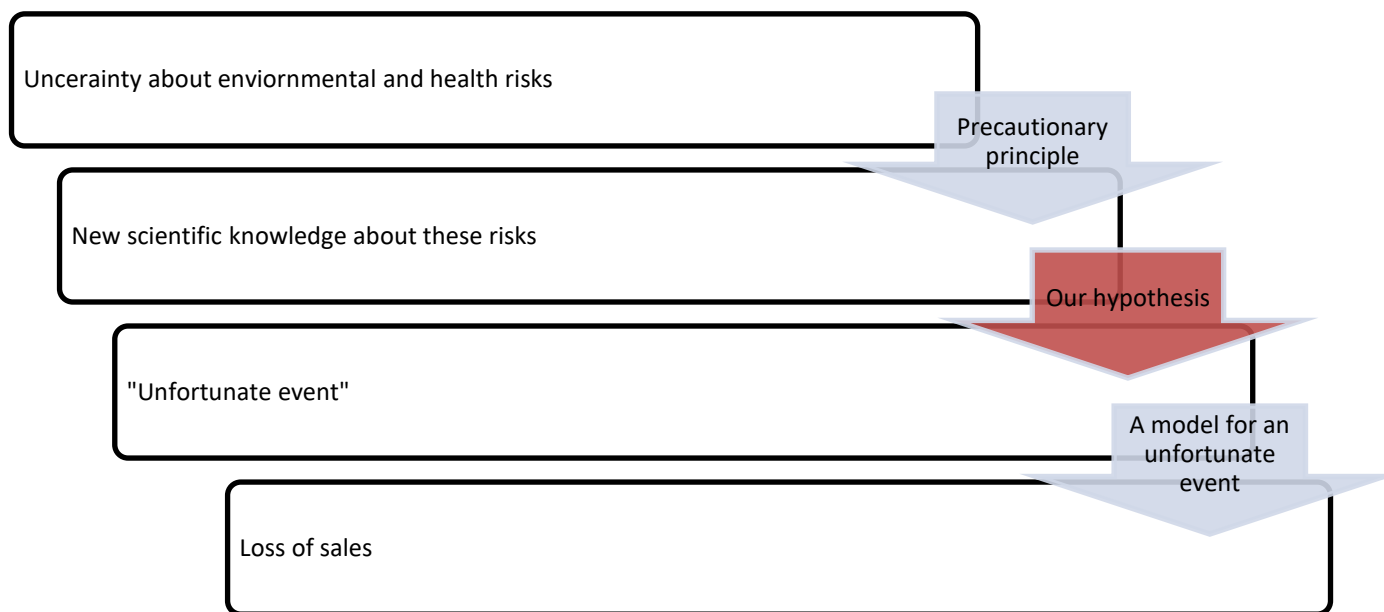


Figure 11. *Hypothesis about new scientific knowledge*

Source: *Own work*

The controversy can be provoked by inconclusiveness of scientific knowledge with respect to risk together with increasing quantity of articles. Besides, a significant amount of information flow might amplify the unfortunate event involving risk. A large volume of scientific information may serve as an amplifier. We hypothesize that the increasing quantity of new scientific knowledge about risk (which adds to scientific controversy) impacts negatively the diffusion of innovation in a situation of uncertainty about environmental and health risks. The higher the quantity of scientific knowledge about risk related to a product, the lower the sales of this product.

⁴⁷ For example, the Earth is round.

As soon as information about harmful side-effects of a product has reached the public, consumers can be dissatisfied with this product as one of the seminal studies on diffusion of innovation suggests (Rogers, 2003). As a result, an eventual demand for a new product can be affected by changes in the state of scientific knowledge. The number of adopters is defined by consumers' decisions to adopt, reject, continue consuming or discontinue. Information shocks can reduce (aggregate) product consumption in several ways: they can lead to rejection/discontinuance of a product or they lead to reduction in its consumption (Kenkel & Chen, 2000). On the other hand, Paddock (2010) argues that individuals do not necessarily revise their attitude to emerging technologies and their decisions to use a product in a situation of scientific uncertainty as a result of new information. Besides, several authors (Berube et al., 2010; Godard, 2003; Kasperson et al., 1988; Kenkel & Chen, 2000; Paddock, 2010; World Commission on the Ethics of Scientific Knowledge and Technology; United Nations Educational Scientific and Cultural Organization, 2005) explain that individuals' response to new scientific information depends on their culture, education, etc.

The effect of new scientific information on the consumption of industrial intermediate goods is still not well understood. Some early empirical studies have shown the link between food consumption and associated health and safety concerns (even if they are not always scientifically grounded) for several food categories (Moon & Ward, 1999; Van Ravensway & Hoehn, 1991). In contrast to these findings, Kenkel & Likwang Chen (2000) review a set of literature over the 1954-1991 period focusing on demand for tobacco and the authors present several studies indicating no effect or only a slight reduction in demand as a result of health information shocks. The latter refers to publication of new information on the health effects of tobacco⁴⁸ (Kenkel & Chen, 2000). The term "information shock" is defined by Kenkel & Likwang Chen (2000) to refer to "the publication of new reports on the health effects of smoking ... [for instance,] the 1964 report of the US Surgeon General on tobacco markets" in the study on consumer information and tobacco use (p. 177, 196). We use this term to refer to the publications of new reports/articles related to health and environmental effects of potentially harmful product/input. We are not aware of a single paper testing this relationship for the items containing nanosilver. For example, French National Institute for Agricultural

⁴⁸ Besides, Smith et al. (2001) have found that smokers are more sensitive to information that smoking can result in an inability to do some kind of physical activity in the future than to information on potential decline in life expectancy. However, whether similar findings on health information shocks hold for other goods with potentially adverse health or environmental effects is to be investigated.

Research (INRA) has evaluated political, economic and sanitary effects of its scientific studies on bisphenol A which is also concerned by the precautionary principle (both, nanosilver and BPA are concerned by the precautionary principle). INRA has concluded that it is recognized as an expert on low-dose effects of BPA and its reports have impact on the formulation of regulations in France (Hocdé & Colinet, 2014). Hocdé & Colinet (2014) claim that INRA's reports potential economic impact is considered to be important. However, they do not provide the information on the reasons that have led to this conclusion.

Based on the discussion above we will test the relationship between new scientific knowledge and BPA consumption taking into account cultural characteristics. In order to study the relationship between new scientific knowledge about risk and the consumption of an intermediate good in a situation of uncertainty about environmental and health risks, we have chosen BPA due to the lack of data on nanomaterials. Our hypothesis is based on the PP and the model of impact for unfortunate event. As we have mentioned, the PP applies to nanosilver and BPA as both of them are in the situation of uncertainty about environmental and health risks. Besides, regarding BPA, Goodman (as cited in Shaw, 2011), "there is no proposed BPA ban anywhere in the world that is based on the premise that BPA causes harm. Rather, such bans are said to be based on the precautionary principle, which demands proof that something is not harmful—essentially demanding the inherent impossibility of proving a negative".

To explore the impact of new scientific knowledge, given that the main primary source of information is scientific journals, we will use scientific publications as a proxy for information shocks. To construct our measure of scientific shocks, we use one of the search engines which includes life science and biomedical studies. We collect all publications which are related to potential risks of BPA⁴⁹.

We will make an attempt to classify these scientific publications under several groups based on their conclusions regarding risks in order to see if their conclusions diverge with time. Debates among experts tend to intensify public uncertainty about "what the facts really are" and raise doubts about "whether the hazards are really understood" which is likely to increase

⁴⁹ The quantity of scientific articles regarding nanosilver and its toxicity has increased substantially and it continues increasing. Controversy might have arisen over the use of nanosilver and its potential side effects and it could be further provoked by the increasing volume of papers.

concern (Kasperson et al., 1988, p. 184). The divergence of conclusions (risk, no risk, uncertain) might add to debate and amplify the controversy.

We use scientific articles on BPA as a proxy for new scientific knowledge. While we have assigned the scientific articles related to risk to three categories: “Risk”, “No risk” and “Uncertain” based on their conclusions⁵⁰, in our analysis we will not distinguish between these categories.

One of the reasons behind this decision is “what the facts really are”. The industry that is involved in a controversy participates in the production of new scientific knowledge related to risk, therefore, its conclusions should be treated with caution (we will discuss this topic in Chapter 4). Besides, in the context of potential risks, scientific knowledge is a controversial topic due to its hypothetical nature. According to Godard et al. (as cited in Merad, 2009) and Merad (2009), if there is a potential risk, scientific knowledge becomes a topic of controversy as the knowledge is hypothetical. The diffusion of scientific information leads to an overlap between scientific and public controversies associated with challenges of knowledge and challenges of actions.

To explore if culture has an impact on the relationship between new scientific knowledge and consumption, we will use Hofstede’s uncertainty avoidance index. This index is one of the cultural dimensions that seems relevant. As we have mentioned in Chapter 1, it is defined as “the extent to which the members of a culture feel threatened by unknown situations” (Hofstede, 2001, p. 161). The uncertainty avoidance index construct is the most frequently used dimension in the literature on international diffusion and most studies examine how it impacts the probability of takeoff (Chandrasekaran et al., 2013; Dwyer et al., 2005; Tellis et al., 2003; van Everdingen & Waarts, 2003; Yenyurt & Townsend, 2003). Contrary to these studies, we are interested in its impact on response to new scientific knowledge rather than on its impact on diffusion rates as it might explain why certain countries are less sensitive to scientific shocks. It does not reflect a nations’ anxiety towards a particular subject (for example, uncertainty about environmental and health risks associated with a product), but it is “related to the level of stress in a society in the face of an unknown future” in general (Hofstede, 2001, p. 29). It refers to the capacity of a society to tolerate uncertain conditions. It shows how society feels about unorganized or non-regulated situations. Societies with a high rate of

⁵⁰ More details are given in Chapter 5.

uncertainty avoidance prefer a stable legal environment (Hofstede, 2001; Hofstede et al., 2010). Moreover, a relationship between a high uncertainty avoidance index and “a search for safety” is found (Hofstede, 2001, p. 170). Hence, high-uncertainty avoidance countries are more likely to respond negatively to information shocks, such as new scientific information about potential negative health and environmental effects (potential environmental and health risks) related to a new or existing product in a situation of uncertainty about these risks. We expect that sales of an intermediate good are lower as a result of information shocks in high uncertainty avoidance countries than in low uncertainty avoidance countries over all stages of the product life cycle. It is likely that information shocks decelerate the time to takeoff and accelerate the time to slowdown in high uncertainty avoidance societies in a situation of uncertainty about environmental and health risks.

It is important to note that an intermediate good⁵¹ is demanded by a producer only if a final (or intermediate) good provided by this producer meets the demand of households (or other manufacturers). If consumption of a product containing a potentially dangerous component changes as a result of scientific information, consumption of this component changes as well. Depending on the position of this good in the value chain, response to scientific information might occur with a time lag. There are several possible reasons for the existence of a time lag⁵²:

- Bourbonnais & Usunier (2013) state that the existence of numerous transformation phases between intermediate industrial and final goods can explain a time lag between changes in demand for a final good and changes in demand for intermediate good,
- carry-over effect: an impact of scientific knowledge can be carried over into next periods⁵³, repetition of the same message or contradictory messages might result in accumulative effect,
- potential delay between a scientific publication and a communication of its mediated version.

We have presented our main working hypothesis, proxies which we will use to test it and possible reasons for time lag. Next, we will present our research approach and data sources.

The other working hypothesis related to BPA will be presented in Subsection 6.3.

⁵¹ Used as an input (component) by other manufacturers

⁵² A time lag can be observed if we analyze quarterly data and it does not necessarily hold for annual data

⁵³ Carry-over effect and purchase reinforcement existence in the advertising literature is discussed, for example, by Dekimpe & Hanssens (1995)

3.2. Research approach and epistemological positioning

Mixed methods are used to answer our research questions. Quantitative methods are employed in an attempt to answer the first two research questions mentioned above. Secondary data⁵⁴ on BPA consumption, polycarbonate sales value and other variables is obtained from different sources. Additionally, a qualitative approach is employed in order to answer the third research question. Primary and secondary data have been collected through interviews with experts and different secondary sources (discussed further). Besides, a qualitative approach is used to analyze new scientific knowledge based on scientific articles related to potential risks of bisphenol A, to classify these articles under different categories and to construct a related primary dataset. We have disregarded the articles which are not directly related to our issue and we have assigned the other publications under 3 groups, namely “Risk”, “No risk” and “Uncertain”.

The epistemological⁵⁵ position of this research is situated within the positivist paradigm adopting primarily the hypothetico–deductive model. Research methods are not necessarily linked to an epistemological paradigm. The leading approach in the research design defines an epistemological position of this research. Thietart et al. (2014) stay that the quantitative approach with an additional qualitative phase remains within the positivist paradigm which is dominant. According to this paradigm, “theories are accepted if they correspond to reality – understood through empirical observation – and are rejected if they do not”. Positivists view reality independently of individuals’ ideological positions. Moreover, the reality is controlled by universal laws: “real causes exist and causality is the rule of nature” (Thietart, 2001, p. 37). From a positivist standpoint, a research problem primarily involves studying facts. The research problem is constructed by determining contradictoriness or disagreements between theories and observations or in theories. The outcome of the research often deals with settlement of disagreements or contradictoriness to acquire new knowledge (Thietart, 2001).

⁵⁴ Secondary data is “data that already exists”. Secondary data has not been collected for specific purposes of the researcher. Internal and external secondary data include existing studies, databases, archives, reports, governmental publications, etc (Thietart, 2014, p. 291).

⁵⁵ “Epistemology is the study of knowledge, and so of science: the study of its nature, its validity and value, its methods and its scope” (Thietart, 2001, p. 13).

3.3. Data sources and measures for our dependent variables (quantitative studies)

The literature on the diffusion of innovation employs different measures for the diffusion process which are often based on sales and market penetration data. The literature that follows the Bass model estimates the coefficients of internal and external influence dealing with data on first purchases of consumer durables. The availability of data on first purchases can be critical as datasets rarely distinguish between first purchase and repurchases. Besides, sales data can be presented by “shipments” which corresponds to supply of new products (Chandrasekaran & Tellis, 2007). Alternative diffusion rates include the time to peak, time to takeoff, and time to slowdown. While several measures of takeoff exist in the literature, Chandrasekaran & Tellis (2007) states that the measures of slowdown are still provisional (under development).

We analyze two different datasets. The first dataset contains annual data on BPA consumption. This data set contains information on the following regions: North America, South America, Western Europe, the Commonwealth of Independent States (CIS) and Baltic States, Middle East and Africa, Indian Subcontinent, Northeast Asia (including China, Japan and the Republic of Korea and Taiwan separately) and Southeast Asia for the 1990, 1995 and over the period of 2000-2013. Data on BPA consumption has been bought from the IHS Chemical Economics Handbook on Bisphenol A (Sriram, Smith, & Feng, 2014)⁵⁶.

The international dataset covers 12 entities over 15 years (the number of regions is limited) and 7 out of 12 regions reach the maturity stage over the studies period. Because of right censoring and a relatively small sample size with a limited number of regions, we have chosen to use a logarithmic transformation of consumption as a dependent variable (we have not used the time to slowdown as a dependent variable). This explains why we use the term “uptake” while discussing the diffusion of innovation in this work. The noun “uptake” is defined as “the act of accepting or taking up something on offer or available” by Collins English Dictionary (2014). This interpretation is close to the definitions of implementation and confirmation stages in the innovation-decision defined by Rogers (2003) and it is synonymous with the term consumption. Thus, this term is appropriate for our research.

⁵⁶ Additional details on data collection process are presented in Chapter 5.

The second data set deals with quarterly data on sales value of polycarbonate (PC) in Japan for the following period: 1990–2013. Data on polycarbonate sales value has been collected from Datastream⁵⁷. In order to conduct our analysis, we transform quarterly sales value to sales in volume at constant prices (2010).

⁵⁷<http://financial.thomsonreuters.com/en/products/tools-applications/trading-investment-tools/datastream-macroeconomic-analysis.html>, data was collected in 2014

3.4. Conceptual model

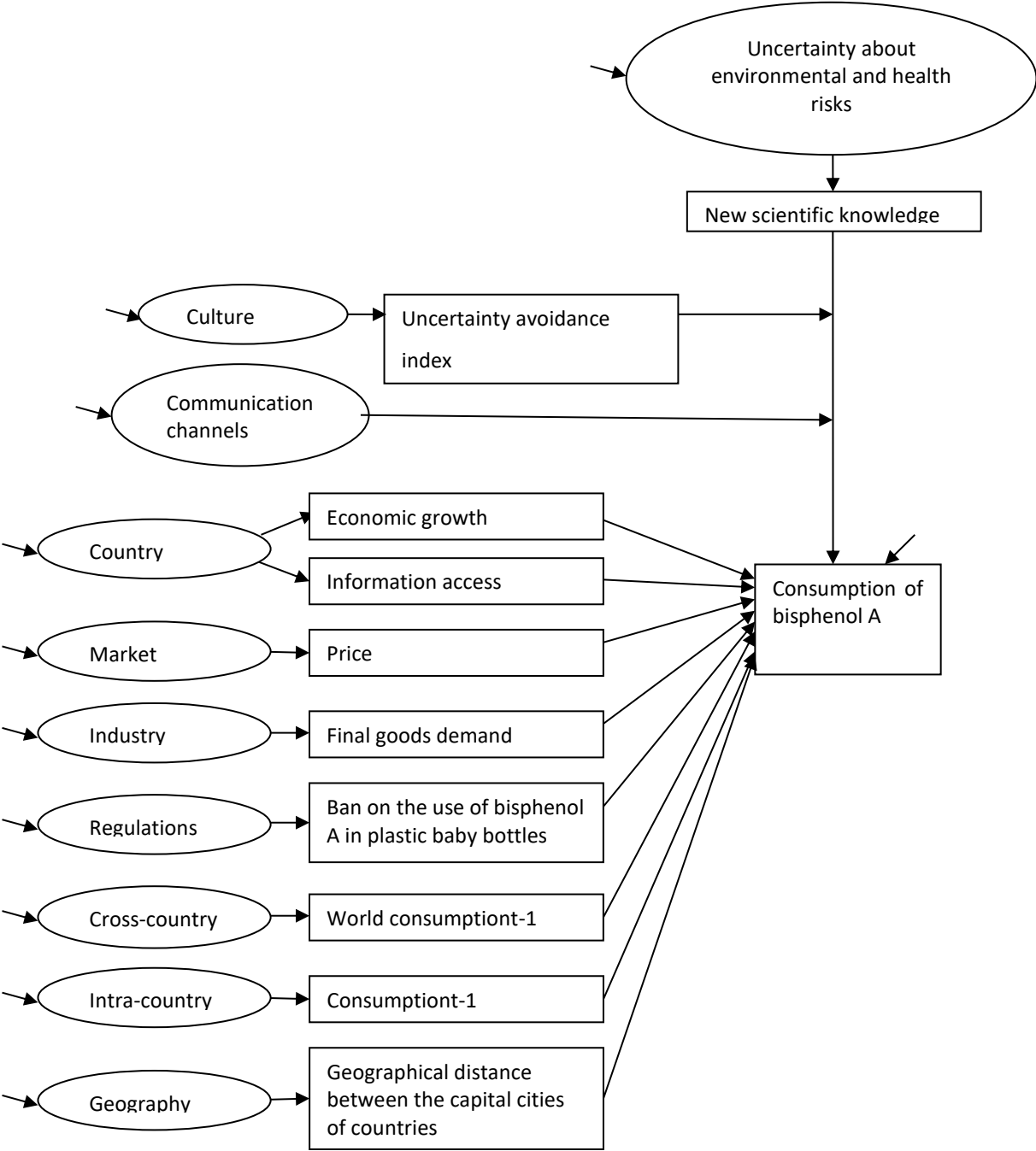


Figure 12. A conceptual model for the influence of new scientific knowledge on industrial product slowdown⁵⁸
 Source: Ostapchuk

This research is based on the diffusion of innovation theory of Rogers (2003), theoretical perspectives of Abrahamson (1991), the Bass model (1969) and on the empirical studies that

⁵⁸ According to the diagrammatic convention: variables which are not directly observed are represented by ellipses, variables which can be directly observed are represented by rectangular, "arrows without origin indicates errors or residues, causal relationships are indicated by tipped arrows" (Thietart, 2014, p. 370)

explore different stages of product's sales growth in the product's life cycle theory at international level, in particular, the study of Golder & Tellis (2004) and others (Chandrasekaran & Tellis, 2008; Chandrasekaran, Arts, Tellis, & Frambach, 2013; Dekimpe, Parker, & Sarvary, 2000a, 2000b; Kauffman & Techatassanasoontorn, 2005; Tellis, Stremersch, & Yin, 2003). Besides, the literature on demand for intermediate industrial goods and the papers on the Environmental Kuznets curve, in particular, the study of Ghimire and Woodward (2013), provide background for our research.

Based on prior studies, this chapter gives an overview of different drivers which might contribute to consumption of bisphenol A which is in the transition from the growth to maturity stage over the period of 1990 to 2013. A new conceptual model is developed to explain slowdown. It contributes to the limited literature on determinants of slowdown. This conceptual model serves a basis to begin to understand the slowdown of an industrial product in a situation of uncertainty about environmental and health risks at international level. Figure 12 presents our conceptual framework to help understand the slowdown. It shows two main factors which may influence the relationship between scientific shocks and BPA consumption. We examine the direct impact of new scientific knowledge related to potential risks of BPA on its over- and under-consumption. Additionally, we explore the impact of cultural factor on the relationship between new scientific knowledge and over- and under-consumption. Although communication channels might have an important influence on the relationship between new scientific knowledge and consumption of bisphenol A, unavailability of data does not permit to study a moderating effect of communication channels in the international context. The lack of the data can be explained by the number of languages of the mass media and the number of the media itself which calls attention to environmental and health issues.

The other key factors that might influence consumption of an industrial good include: country, market and industry characteristics, and regulations. We can assign country's wealth and access to information to country-level factors. The literature on the diffusion provides controversial evidence of the impact of wealth on diffusion rates (Chandrasekaran & Tellis, 2008; Dekimpe et al., 1998, 2000a, 2000b; Kauffman & Techatassanasoontorn, 2005; Putsis Jr. & Srinivasan, 2000; Tellis et al., 2003; van Everdingen et al., 2009). Moreover, the link between GDP per capita and BPA consumption has not been explored yet. Thus, this issue needs further investigation. This explains why another stream of literature, namely the literature on the Environmental Kuznets Curve (EKC) is used to study this link. Regarding access to information,

media intensity appears to be an important driver of the diffusion of different products. Besides, Golder and Tellis (2004) have concluded that the probability of slowdown depends on price reduction which can be classified as market characteristics. Governments can intervene in markets through different regulations which can influence the diffusion process (Kauffman & Techatassanasoontorn, 2005). Concerning bisphenol A, we have identified a ban on the use of bisphenol A in the production of baby bottles as a potential factor that might influence its consumption. A discussion of specific hypotheses for each of these variables and available measures are presented in Chapter 6.

Besides, the literature suggests that inter-country interactions and intra-country communication have an impact on the probability of takeoff (Chandrasekaran et al., 2013; Ganesh & Kumar, 1996; Mirowski, 1983; Takada & Jain, 1991; Tellis et al., 2003; van Everdingen et al., 2009). At present we have no evidence of impact of inter-country impact on slowdown, but Golder and Tellis (2004) have found that a contagion effect (which can be compared to intra-country communication) has an influence on slowdown. These two effects can be measured by world-country consumption and single-country consumption in previous period, respectively. Although we expect that both variables have an effect on consumption, we do not include them in the model in the international context given the existence of gaps in our dataset (several missing years). Another factor that might have an impact on consumption of bisphenol A is a geographical dimension (Dekimpe et al., 1998, 2000b; Kuester et al., 2000; van Everdingen et al., 2009). It is hypothesized that countries with a high rate of urbanization might have a positive impact on the probability of takeoff (van Everdingen et al., 2009). However, whether this dimension has an effect on slowdown has to be investigated. Given that data on bisphenol A consumption at international level is available for regions which often include several countries, we have chosen to exclude this variable from our analysis.

Regarding our study on polycarbonate sales in Japan, the nature of our data and the sample size permit us to examine only several factors presented in this conceptual model. Chapter 7 presents the specification of the model that has been tested.

3.5. Methods of data analysis (quantitative studies)

The first empirical chapter (Chapter 5) focuses on the construction of the new scientific knowledge variable construction. After collecting the scientific articles on BPA from the

PubMed website, we have identified the articles related to the issue of potential risk to health/environment by reading their abstracts. Around 1500 abstracts over the 1960-2013 period are analyzed and classified under 3 categories. The difference in the quantity of articles assigned to each category over the analyzed period is presented. Besides, this chapter discusses difficulties with data collection and it explains main data sources.

Chapter 6 aims to define determinants of international uptake of an industrial good under conditions of uncertainty about environmental and health risks. This good is in the phase of transition from the growth stage to the decline stage of its life cycle over the studied period. Specifically, this chapter has two goals. The first one is to study the impact of economic growth on aggregate consumption of bisphenol A per capita in a situation of uncertainty about environmental and health risks through an estimation of the Environmental Kuznets curve. While the link between economic growth and BPA consumption has been suggested (Sriram et al., 2014), the shape of the relationship has not yet been studied. Besides, relatively little published literature examines the Environmental Kuznets Curve (EKC) in a situation of uncertainty and the studies on the international diffusion provide controversial evidence of the impact of wealth on diffusion rates. The second goal of Chapter 6 is to study the effects associated with the introduction of new scientific knowledge about potential risk on over- and under-consumption of BPA as an industrial intermediate good in a situation of uncertainty regarding these risks. Understanding of under-consumption may contribute to the emerging literature on the management of uncertainty. Given that the impact of risk and uncertainty on innovation is crucial to strategic planning (Olson et al., 2014), this study might also help to bridge the gap in the existing literature on this subject. Moreover, this research adds to available studies on the rejection of innovation in a situation of uncertainty about environmental and health risks. Under-consumption can be an alternative indicator of rejection, discontinuance of innovation or slowdown of product's sales growth at international level.

In Chapter 6, we use data on bisphenol A at international level. A principal component approach will be applied to choose a subset of predictors in addition to economic growth among multiple proxies to construct a parsimonious model. Then, to estimate this model, the type of collected data allows us to apply different panel data methods in accordance with the existing empirical studies on the Environmental Kuznets Curve. We will start with the pooled ordinary least squares, the fixed effect estimation and the random effect estimation. Then,

we will perform the Breusch-Pagan Lagrange multiplier test for the existence of random effects. Formal tests for random effect or fixed effect after their estimation will be conducted (the Sargan-Hansen version of the test for random effect vs fixed effect). Then, if heteroskedasticity is present, the random effect generalized square procedure (RE GLS) with robust standard errors and the Feasible Generalized Least Squares with heteroskedastic error structure (FGLS) will be compared. To find out whether the RE GLS with robust standard errors is preferred to FGLS with heteroskedastic error structure, we will apply a leave one out cross validation or a k-fold cross validation.

Drawing on the study of Ghimire and Woodward (2013), we will construct a measure of over- and under-consumption of bisphenol A and empirically examined the impact of scientific information on under-consumption. A robust locally weighted scatter plot smoothing technique (Lowess) is applied to analyze the relationship between under-consumption of bisphenol A and new scientific knowledge.

In Chapter 7, we carry out analysis for polycarbonate sales in Japan. It is one of the countries that has started replacing bisphenol A. Besides, it has the highest uncertainty avoidance index among regions analyzed in Chapter 6. BPA consumption has crossed the turning point which is characterized by a decrease in sales together with a higher income as we conclude in Chapter 6. Availability of quarterly data on sales value of polycarbonate in Japan allows us to extend our analysis and to explore if the results found in Chapter 6 hold for an individual country with a slightly different dataset. Besides, we are able to study if sales of a secondary intermediate good are affected by scientific shocks related to bisphenol A. We use the Vector Error Correction Model (VECM) of the polycarbonate sales in volume at constant prices (2010), GDP per capita in Japan, its quadratic term together with the global volume of scientific articles related to BPA risks. Chapter 6 and Chapter 7 provide a basis for answers to the first and second research questions.

3.6. Qualitative study

A comparative study of the evolution of two industries, BPA and nanosilver, provides insight into the role of information about potential risks of bisphenol A and nanosilver. To understand the evolution of BPA and nanosilver industries and answer the third research question, we have to trace the history of BPA and nanosilver industries containing a chronological order of events as objective as possible.

As we have mentioned, our third research question:

- What is the link between new scientific knowledge and stakeholders in a situation of uncertainty about environmental and health risks?

There are several questions which might arise: what is the role of each actor in the process of new scientific discoveries? What is the motive behind their activities? How does the relationship between new scientific knowledge and stakeholders change over time? What type of scientific knowledge is used by regulators to take decisions? Which stakeholder is most important based on their contribution to research and regulatory decisions? Are there new types of collective responses to new scientific knowledge? There are a lot of questions and at this point many questions remain unanswered. We will focus on interactions between new scientific knowledge and stakeholders, whether these interactions take place in a passive or active manner in terms of contribution to new scientific knowledge (whether stakeholders contribute in some way to new scientific knowledge or passively seek and receive the information that they need). The actions of stakeholders help us to interpret our main result and make a comparison between BPA and nanosilver.

We will define the main stakeholders (nanosilver and BPA) and activities of these stakeholders in Chapter 4. We will assign stakeholders to different categories building on Fligstein & McAdam (2012): internal (dominant actors, governance units and challengers) and external stakeholders. We will discuss these categories in detail below. However, this classification seems incomplete in our context. In order to discuss the link between new scientific knowledge and stakeholders, we will extend this classification by demonstrating difference among stakeholders with respect to new scientific knowledge about risk. While actions of stakeholders might impact the uptake of BPA and nanosilver we conduct an analysis of the role of new scientific knowledge. Taking this approach, the actions of actors help us to interpret our main result and make a comparison between BPA and nanosilver. The history of BPA and the beginning of history of nanosilver are written containing a chronological order of main events in Chapter 4.

While we have already mentioned many parallels between nanosilver and BPA, we will discuss critically each parallel in Chapter 8. Additionally, two specific goals are: 1. to refine the interpretation of the main results of quantitative study related to bisphenol A and 2. to understand what these results mean to nanotechnology, in particular nanosilver, in the light of a qualitative study. We try to see if there are important lessons to be learned from the

studies on BPA and polycarbonate in light of the development of nanotechnology. We will make an attempt to see similarities in the pathways of consumption of bisphenol A and nanosilver. In that chapter, we will discuss if these studies give us an insight into factors influencing the probability of takeoff of nanosilver.

Besides, we give a brief comparison of the interactions with new scientific knowledge between the BPA and nanosilver industries. We try to compare briefly a range of activities that different stakeholders take part in as a response to new scientific knowledge. And we discuss who are involved in exchange of knowledge and expertise and who might influence the process of learning about potential risks (the role of prescriber in the relationship between a product and consumers) based on data presented in Chapter 4. We will see if a lack of change levers might affect the link between consumption and new scientific knowledge in a situation of uncertainty about environmental and health risks. We adopt an explanatory approach to interpret and explain our findings of quantitative studies. This approach is necessary in order to investigate findings in more detail.

To study the evolution of two industries, we use a qualitative approach. Thus, we use mixed methods in this thesis⁵⁹. A qualitative method deals with another issue than a quantitative method. “Qualitative data explores the process experienced”, it helps to provide a wider picture of the issue and complete a discussion by exploring different dimensions which are difficult to quantify (Creswell, 2009, p. 214). In terms of mixing, this thesis embeds qualitative data within a study having quantitative data as an initial form of data. The data is collected sequentially. Mixing of data occurs at the interpretation stage. Our strategy for designing a research is sequential explanatory design (Figure 13). QUAN/QUANT stands for the qualitative/quantitative approach, respectively. An arrow indicates a sequence of data collection.



Figure 13. Sequential explanatory design
Source: Adapted from Creswell (2009)

⁵⁹ According to Creswell (2009), dimensions of mixed methods are timing (sequentially, concurrently), weighting (equal, qualitative and quantitative) and mixing (integrating, connecting, embedding).

Primary and secondary sources of data have been collected. We have addressed experts in the field and asked them to participate in this research by giving an interview or completing the questionnaire. The aim of this interview/questionnaire is to identify BPA and nanotechnology stakeholders (in particular related to nanosilver industry) and to write the history of BPA and the early history of nanotechnology (a chronological order of main events, which could influence nanosilver consumption and reactions of different stakeholders to information about potential risks related to nanosilver).

We have conducted 5 interviews with experts in the field. These interviews lasted between 30 minutes and 2 hours. The interviews were semi-structured. We have sent our questionnaire to 16 experts in the field (earlier defined during interviews with two experts), 9 responses are received. Some experts have provided us with additional sources of information. The structure of interview guide is similar to questionnaire (see Appendix B). Pascal & Romelaert (2005) and Thietart (2014) have been used to design the questionnaire, interview guide and cover letter. Secondary data was obtained from the web searches, workshop proceedings, legislation, NGOs websites, newsletters, scientific opinion on the safety assessment, newspaper articles, scientific articles, governmental reports, books, inventory of products, reports of intergovernmental and non-profit organizations and other documents which include the history of BPA and nanotechnology. We have used data focused mainly on French (and American) stakeholders and their activities. These data enabled us to define main stakeholders and how reactions of different stakeholders evolved over time. Besides, secondary sources allow to compare events defined in the literature and mentioned by the interviewees. However, we cannot exclude that some important events are missed given that this study is embedded within a study having quantitative data as an initial form of data.

The documents were selected based on their relationship with activities (reactions related to new scientific knowledge about risk) of different stakeholders which are related to scientific knowledge about potential risks and which might be connected to nanosilver and BPA consumption. We have studied the BPA industry before the end of 2013 given that our quantitative study was conducted over the period of 1990-2013.

We have identified different actors and assigned them to different categories building on Fligstein & McAdam (2012): dominant actors⁶⁰, governance units and challengers.

⁶⁰ The authors use the term "incumbents"

Dominant actors have an unbalanced influence within a field and their interests and opinions are likely to be recognized in the dominant organization of the strategic field⁶¹. This might suggest that the goal and field's structure are suitable for their interests. Their influences are identified by "their claim on the lion's share of material and status rewards (Fligstein & McAdam, 2012, p. 13).

Contrary to dominant actors, challengers have smaller niches and they have less influence on field's operations. "While they recognize the nature of the field and the dominant logic of incumbent actors, they can usually articulate an alternative vision of the field and the position in it" (Fligstein & McAdam, 2012, p. 13). This does not suggest that they are against unfairness or opposition. They often follow the existing order while waiting for opportunities to question the field's structure and logic.

Internal governance units often make it easier for a system to function. Trade associations can be categorized under this category. In general, they support the main views and the incumbents' interests. During the emergence stage, the governance units "free incumbents from the kind of overall field management and leadership" (Fligstein & McAdam, 2012, p. 14). They gather and share information about the field with other actors. This information can be standardized. The regular exchange of information between the field and key external actors is one of the functions of governance units. Trade associations are another example of governance units (Fligstein & McAdam, 2012, p. 13).

Thus, we have used the following categories:

Internal stakeholders (internal to the field, at French and European level)

- dominant actors which include producers, users and representative bodies (trade associations, trade unions),
- governance units, para-public institutions and agencies responsible for food, environmental and occupational health & safety
- challengers

External stakeholders (external to the field, at French and European level)

- other NGOs and the media

⁶¹ Strategic action fields are "the fundamental units of collective action in society. A strategic action field is a constructed meso-level social order in which actors (who can be individual or collective) are attuned to and interact with on the basis of shared understandings about the purpose of the field, relationships to others in the field (including who has power and why), and the rules governing legitimate action in the field (Fligstein & McAdam, 2012, p. 9).

- external governance units (other European institutions, international organizations, researchers, world's largest producers, users and other agencies responsible for food, environmental and occupational health & safety)

A historical perspective can be seen as process-based approach that explores the subject in terms of “flow”. It studies its behavior over time. The analysis of process has an objective to explain an observed phenomenon, which is an explanatory research⁶². One of the phases of this approach is a decomposition of process variable which can correspond to reflection on content based research⁶³. In our case, we decompose the process (the evolution of an industry based on different activities related to new scientific knowledge about risk) with respect to different stakeholders involved in it (Thietart, 2014).

⁶² “The positivist vision of reality leans towards explanatory research, to answer the question “for what reasons” (Thietart, 2001, p. 19)

⁶³ Other phases: a description of the subject through different dimensions over time that constitutes a process and an identification and classification of important event to show temporal intervals influencing the process.

Chapter 4. Evolution of nanosilver and BPA industries

4.1. Turning points of the product's life cycle

Prior studies on the diffusion of innovation at international level have extensively studied the growth stage of the diffusion of innovation neglecting the other stages of product's life cycle despite their potential importance to the development of marketing strategies (Golder & Tellis, 2004). More recent literature on the diffusion of innovation addresses drivers of two turning points of the diffusion curve, namely takeoff and slowdown (Chandrasekaran et al., 2013; Chandrasekaran & Tellis, 2007, 2008; Golder & Tellis, 2004; van Everdingen et al., 2009). Takeoff and slowdown are principal turning points in a product life cycle. However, most existing literature focuses on takeoff point and further investigation of determinants of slowdown are needed (Chandrasekaran & Tellis, 2007). Moreover, to the extent of our knowledge, there is limited literature regarding drivers of takeoff and slowdown in a situation of uncertainty about environmental and health risk.

Levitt (1965) defines 4 stages of a product life: market development, market growth, market maturity and market decline (Figure 14). Market development (introduction stage) represents the period between a new product introduction on the market and its takeoff (Golder & Tellis, 2004). Growth stage is characterized by a rapid increase in the market size (Levitt, 1965). It is also defined as the period between takeoff and its slowdown (Golder & Tellis, 2004). Maturity is characterized by market saturation. Demand stops rising and becomes steady (Levitt, 1965). Maturity is also defined as the period between a new product slowdown and a constant decline of sales. Decline is the period that can be characterized by a steady decline of sales until a demise of a product (Golder & Tellis, 2004).

As we have mentioned in Chapter 1, the term takeoff is defined by Chandrasekaran & Tellis (2007a) to refer to "the first dramatic and sustained increase in a new product's sales" (Chandrasekaran & Tellis, 2007, p. 40). Slowdown is identified as "the beginning of a period of

level, slowly increasing, or temporarily decreasing product sales after takeoff” (Chandrasekaran & Tellis, 2007b, p. 40).

A new product can be considered as a new finished good or a new intermediate good.

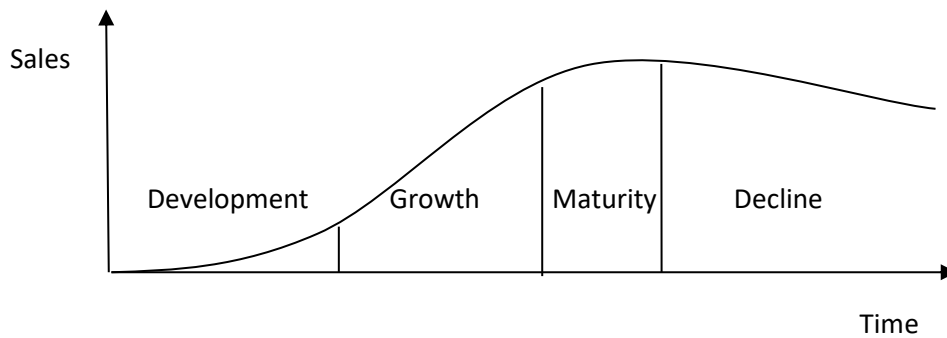


Figure 14. *The Generalized Product Life Cycle*
Source: Reproduced from Levitt (1965)

Several measures of takeoff and slowdown are available in the literature. While bisphenol A was launched as a new intermediate product for the production of polycarbonate and epoxy resin in the early 1950s, data on bisphenol A is available from 1990 to 2013. It is most likely that takeoff has occurred before 1990 in most regions. Therefore, we will define how many regions are at the end of the growth stage and in the maturity stage (or even in the decline stage) rather than in the introduction and at the beginning of growth stages. As very few measures of slowdown are available in the literature. Golder & Tellis (2004) state that slowdown occurs after takeoff when sales are lower than the highest previous sales for two consecutive years. However, we posit that this point corresponds to the beginning of the declining stage where sales start a steady decline. As the measure suggested by Golder & Tellis (2004) requires a takeoff determination, we modify it to suit our panel data (our data excludes these years: 1992-1994 and 1996-1999 years). We define the beginning of the decline stage as the first year when the sales growth is negative for two consecutive years over the period from 1990 to 2013. We posit that slowdown is the first year when the sales growth is lower than the highest previous sales for two consecutive years and the sales growth is non-negative for at least one of two consecutive years. We compute the growth separately for each country. This point corresponds to the definition of slowdown suggested by Chandrasekaran & Tellis (2007a). Table 5 shows the years of the beginning of the maturity (slowdown) and the years of the beginning of the declining stage for 12 entities which are main consumers of bisphenol

A. The details are presented in Appendix C. Given that our data excludes the following years: 1991-1994, 1996-1999, we assume that the growth rate is constant over these years. To get the growth rate in 1991, which equals the growth in 1992,1993, 1994 and 1995, we subtract the sales in 1990 from the sales in 1995, and then divide by 5. To get the sales growth in 1996, which equals the growth in 1997, 1998, 1999 and 2000, we subtract the sales in 1995 from the sales in 2000, and then divide by 5.

Table 5. Years of beginning of the decline stage by entities

Entity	Slowdown (beginning of the maturity stage)	Beginning of the decline stage
Brazil	2003	No
Central Europe	2006	2002
China	2010	No
CIS and Baltic States	2011	No
India	2005	2011
Japan	1996	2004
Middle East	2001	2008
Republic of Korea	2003	No
Southeast Asia	2003	No
Taiwan	2005	2011
United States	2001	2008
Western Europe	2001	2007

Source: Ostapchuk, based on Sriram et al. (2014)

We assume that the takeoff of BPA has occurred in many regions given that this input has been in use for more than 60 years ago and the level of BPA consumption is high. Besides, the average time to takeoff is between 2 and 8 years for durables (Chandrasekaran & Tellis, 2007; Tellis et al., 2003). BPA is used in the production of many durables (we discuss it in later chapters). We can observe that all entities have reached the beginning of the maturity stage. Therefore, over these years bisphenol A is at the end of growth and at the beginning of the decline stage. However, several entities have reached the slowdown twice (for example, Central Europe and Japan). This might suggest that we observe the phase of recovery. Besides, one entity (Central Europe) has reached the beginning of the decline stage followed by a slowdown. According to this table, 7 entities out of 12 reach the declining stage over the period 1990 and 2013.

Sales of nanosilver can be currently considered in the transition between the introduction and growth stage which corresponds to takeoff point. As stated in the Introduction, the global market for nanosilver is growing steadily (Figure 1 in Chapter 1). And the first commercial

application of nanosilver, which is Acticoat was launched in 1998. Acticoat was invented by Robert Burnell in 1991 (Burell, 2009) and it was launched in 1998⁶⁴. It accelerates a process of wound healing and it minimizes potential scars. Contrary to silver nitrate and silver sulfadiazine, which have been used to treat burns, silver nanoparticles has “antimicrobial as well as anti-inflammatory properties”.

4.2. Descriptive comparison between the history of BPA and the beginning of history of nanosilver

4.2.1. General facts

While an antimicrobial wound dressing with silver nanoparticles can considered to be “the first commercial application of nanotechnology” (Burell, 2009, p. 24), Nowack et al. (2011) states that the evidence of the synthesis of a citrate-stabilized colloidal silver with the size of nanoparticles lower than 10 nm dates to 1889. Besides, the commercial medical application of nanosilver called “Collargol” has been produced since 1897 (as cited in Nowack et al., 2011). The use of colloidal silver nanoparticles under the names Argyrol, and Protargol as over-the-counter and prescribed medications became common over the last 50 years (Nowack et al., 2011). Nowack et al. (2011) have explored a public patent database and related literature and for registered biocides over the last 60 years. The authors have found that 53% of the biocidal silver products are likely to have nanosilver. Thus, the authors conclude that unlike the majority of nanomaterials, the history of production and use of colloidal silver nanoparticles might improve our knowledge of nanosilver without making explicit the term “nano”. Historical data on the consumption of nanosilver is unavailable.

Moreover, one of the experts (Daniel Bernard, Senior Scientific Advisor, chairman of Comité Nanotechnologies des Ingénieurs et Scientifiques de France, questionnaire) wrote “L’argent sous forme colloïdal est connu depuis l’antiquité. Il est largement utilisé dans la pharmacopée française depuis le XIX^{ème} siècle, et est en vente libre dans les pharmacies sous forme de dispersion pour application antiseptique locale externe, voire en bain de bouche ou par ingestion.

Ses propriétés antiseptiques sont connues ou pour le moins pressenties depuis très longtemps, par exemple dans les armées en campagne l’utilisation de couverts en argents par les officiers, par opposition à l’utilisation de couverts en bois par les hommes de troupe

⁶⁴ http://www.nucryst.com/acticoat_dressings.htm, accessed in August 2016

expliquerait en partie le différentiel de mortalité constaté entre officiers et hommes de troupe dans les armées en campagne aux XVIII^{ème} et XIX^{ème} siècles (Etude anglaise sur les guerres napoléoniennes notamment)⁶⁵.”

BPA was invented in 1891 and it could have been used as a medication. But it was put on the market in the early 1940s to make plastics. While its estrogenic properties were discovered in 1930, it was not used as a medication. Diethylstilbestrol (DES), another estrogenic substance, was introduced onto the market for the prevention of miscarriages, among other things. DES was banned in 1971 due to its carcinogenicity to women who were exposed to this substance “while in their mothers’ wombs” (Fox, Versluis, & Asselt, 2013, p. S554). As we will discuss in Chapter 5, its potential adverse effects were discovered in 1993. Table 6 presents general facts about BPA.

Table 6. Reference points (BPA)

1891	The invention of BPA
1930s	The discovery of its estrogenic properties. Its potential pharmaceutical application was not launched given the effectiveness of diethylstilbestrol (DES)
1970s	DES was withdrawn from the market due to undesirable health effects. Van Asselt et al. (2013) suggest that the comparison between DES and BPA might impact the risk perception of BPA
Since the 1940s	BPA has been used in the production of plastics
1991	The expression "endocrine disruptors" was invented at the Wingspread Conference Centre
1993	BPA migration from the polycarbonate was detected. Some of the first publicly available evidence of “unsuspected estrogenic activity” of bisphenol A was revealed by Krishnan et al. (1993)
Since the 1960s	BPA has been used in production of packaging

Source: Ostapchuk, based on Van Asselt et al. (2013) and Krishnan et al. (1993)

The structure of this subsection is the following. First, we will introduce different stakeholders related to BPA and nanosilver industries and assigned them to different categories. We will proceed with tracing the recent history of BPA and nanosilver.

⁶⁵ Colloidal silver has been known since ancient times. It has been widely used in the French pharmacopoeia since the 19th century, and pharmacies sell it as an over-the-counter medication. Its antiseptic properties have been known for a long time. For example, the armed forces officers used silver cutlery sets in contrast to soldiers who used wooden cutlery sets. This partially explains the difference in mortality rates between officers and soldiers from the 18th to 19th centuries.

BPA and different categories of stakeholders

Internal stakeholders

Producers (France, the EU)

Western Europe: Bayer (Belgium, Germany), SABIC innovative Plastics (Netherlands), Dow (Germany)

BPA producers are downstream integrated (polycarbonate and/or epoxy resin)

No producers are defined in France

Users (at one point within 1990-2013, France, the EU)

Thermal paper producer (France): Ricoh Industrie France

Baby bottles (France): Chicco, Dodie, Philips Avent

Polycarbonates-use 3 main sectors: Optical media, electrical and electronics applications, assembly

Epoxy-resin use 3 main sectors: electrical and electronics applications, insulation covering, bobbins and cans coating

Representative bodies (trade associations, unions, France, the EU)

PlasticsEurope,

BPA coalition,

SNFBM,

European Trade Union Confederation

Challengers (France, the EU)

Le Réseau Environnement Santé

La Ligue contre le cancer

André Cicoella, Réseau Environnement Santé (RES) in France

UFC-Que Choisir

Génération Futures

Governance units, para-public institutions and agencies responsible for food, environmental and occupational health & safety (France, the EU)

Direction Générale de la Concurrence, de la Consommation et de la Répression des Fraudes" (DGCCRF)

French Ministry of Ecology

EFSA

ANSES

European Commission

European Parliament

Joint Research Centre

Institute for Health and Consumer Protection

Directorate General for Health and Food Safety - European Commission

Assemblée nationale et le Sénat

European Chemical Agency (ECHA)

INERIS

INRS (non-profit organisation)

External stakeholders (including international organizations, international researchers, international producers, users and other para-public institutions and agencies responsible for food, environmental and occupational health & safety

INRA

Women's Voices for the Earth

US producers of BPA: SABIC Innovative Plastics, Bayer MaterialScience, Dow, Momentive Speciality

US epoxy resins producers: Dow, Huntsman and Momentive Speciality

The production of tetrabromobisphenol A (TBBPA) and BPA bis-diphenylphosphate: Albemarle Corporation supplies Chemtura with TBBPA, ICL Industrial Products (formerly Supresta) is the sole U.S. producer of BPA

Polyacrylates and polyetherimides producer: SABIC Innovative Plastics (General Electric) is the only producer of polyetherimide (PEI) resins in the world.

Northeast Asia is the largest region-producer in 2013 (the Republic of Korea and China).

Producers of BPA (China): Bayer MaterialScience, Shanghai SINOPEC Mitsui Chemicals (SSMC), SINOPEC Mitsubishi Polycarbonate (SMP)

Producers of epoxy resin (China): Nan Ya, Kingboard, Chang Chun PC (Jiangsu)

Polycarbonate resins producers (China): Bayer MaterialScience, Teijin Polycarbonate owned by Teijin Chemicals (Japan), Ling You Engineering Plastics owned by Mitsubishi Gas Chemical (Japan)

Producers of BPA (Japan): Mitsubishi Chemical, Mitsui Chemicals, Nippon Steel

Polycarbonate resins producers: Mitsubishi Gas, Mitsubishi Chemical at Kurosaki

Tosoh Corporation and MANAC Inc. are the only producers of TBBPA in Japan.

Currently, bisphenol F is produced by Honshu Chemical Industry Co., Ltd. and Mitsui Chemicals.

Republic of Korea producers: Kumho P&B, LG Chem, Samyang Innochem

US baby bottles producers: Avent America, Evenflo, Gerber, HandiHandi-Craft (Dr. Brown's) and Playtex. Leading producers of polycarbonate water bottles in the USA: Nalgene Outdoor, CamelBak, UTS and Pacific Market International.

Danish Environmental Protection Agency

Canadian government department Environment Canada

German Federal Environment Agency

American Chemistry Council

American Chemical Society

American Plastics Council (APC)

Food and Agriculture Organization of the United Nations, World Health organization

US FDA

National Toxicology Program Center for the Evaluation of Risks to Human Reproduction, part of the National Institutes of Health (the USA)

FDA's Center for Food Safety and Applied Nutrition

U.S. Congress

California's Office of Environmental Health Hazard Assessment, the Massachusetts Department of Public Health (MassDPH), the Maine Department of Environmental Protection

US EPA

Nanosilver and different categories of stakeholders

Internal stakeholders

Sectors

Food packaging, food supplements, textiles, electronics, household appliances, cosmetics, medical applications (devices, catheters, antimicrobial wound dressing), dental materials, water treatment.

Producers and users (worldwide)

Electronics: Cambrios, Agfa, Carestream Advanced Materials, cima Nanotech, PolyIC, Ferro, Blue Nano, Sigma-Aldrich, Suzhou NanoGrid Technology (NGT), NanoOpto Corporation - Sumitomo Metals and Mining, Ames Goldsmith Corporation, Creative Technology Solutions Co. Ltd., Bayer MaterialScience AG., PEN Inc., Samsung Electronics, Hitachi Chemical, Sun Innovations

Medicine: Smith & Nephew, Johnson & Johnson, Argentum Medical, Beiersdorf, Applied nanosciences, Scoutburg, Hyosung, Urgo Medical, Acticoat

Other: Saint-Gobain, NovaCentrix, NaBond Technologies Co., Limited, Inframat, skySpring Nanomaterials Inc, Plasmachem Gesellschaft mit beschränkter Haftung (GmbH), HiQ-Nano, BASF, DuPont

Food, cleaning, hygiene, cosmetics: Nano Silver Manufacturing Sdn Bhd (NSM), Philips, Valera, Skybright, Tacony Corporation, Toto, Engineered nanoProducts,

Textile: Dow Chemical, SILVIX Co. Ltd, Polartec, Patagonia, R.STAT

Companies which might have used nano- ingredients in their products:

Kraft (KRFT), General Mills (GIS), Hershey (HSY), Nestle (NSRGY), Mars, Unilever (UL), Smucker's (SJM) and Albertsons

No producers are identified in France

Representative bodies

Nanotechnology Industries Association (NIA)

Eurométaux

The European Federation of Pharmaceutical Industries and Associations (EFPIA)

Collectif citoyen Nanotechnologies du Plateau de Saclay

European Trade Union Institute (ETUI)

CFDT (Confédération française démocratique du travail)

CEFIC (European Chemical Industry Council)

Challengers

Avicenn

Agir pour l'Environnement (APE)

Friends of the Earth

European Environmental Bureau

ECOS

ClientEarth

Ciel Center for International Environmental Law

Pesticide Action Network (Germany, Europe, UK), Health & Environment Alliance (HEA), et Women in Europe for a Common Future (WECF)

Association Santé Environnement France (ASEF)

ETC Group

Environmental Defense

Greenpeace

Sierra Club

OXFAM

World Wildlife Fund (WWF)

Confédération française démocratique du travail

VivAgora

Governance units, para-public institutions and agencies responsible for food, environmental and occupational health & safety (France, the EU)

ECHA

ANSES

Joint Research Centre

European Commission and Parliament

Scientific Committee for Consumer Safety (SCCS)

Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR)

EFSA

EMA

European Centre for Disease Prevention and Control (ECDC)

Scientific Committee on Occupational Exposure Limits (SCOEL)

Direction générale de la santé (DGS)*

Direction générale du travail (DGT)*

Direction générale de l'alimentation (DGAL)*

Direction générale de la prévention des risques (DGPR)*

Haut Conseil de la santé publique*

Direction générale de la concurrence, de la consommation et de la répression des fraudes (DGCCRF)

Assemblée nationale et le Sénat*

OECD (it can be considered as an external stakeholder)*

French Ministry of Ecology

INERIS

**while these stakeholders are not indicated in the list related to BPA, it seems that these stakeholders are also related to BPA industry*

Consumer associations, the media, other NGOs

L'Institut National de Recherche et de Sécurité (INRS), a non-profit organisation which can be assigned to the previous category

Amis de la Terre

France Nature Environnement (FNE)

Center for Food Safety (US)

International Center for Technology Assessment

Beyond Pesticides

Center for Environmental Health

Clean Production Action

International Center for Technology Assessment (ICTA)

Beyond Pesticides (formerly National Coalition Against the Misuse of Pesticides)

60 Millions de Consommateurs

Fédération des Industries des Peintures, Encres, Couleurs, Colles et Adhésifs (FIPEC)

External stakeholders (including international organizations, international researchers, international producers, users and other para-public institutions and agencies responsible for food, environmental and occupational health & safety)

C'nano IdF

CNRS

ANR

INRA

The Food and Environment Research Agency (Fera)

US:

US EPA⁶⁶, the Office of Environmental Health Hazard Assessment (OEHHA) is a division of the California Environmental Protection Agency (Cal/EPA)

Department of Toxic Substances Control (DTSC) is another division of California EPA

Different agencies (US), which have nanotechnology R&D budgets:

Consumer Product Safety Commission (CPSC)

Department of Commerce (DOC)

National Institute of Standards and Technology (NIST)

Department of Defense (DOD)

Department of Energy (DOE)

Department of Health and Human Services (DHHS)

Food and Drug Administration (FDA)

National Institute for Occupational Safety and Health (NIOSH)

National Institutes of Health (NIH)

⁶⁶ Environmental Protection Agency

Other:

Department of Education (DOEd)

Department of the Interior (DOI)

U.S. Geological Survey (USGS)

Department of Justice (DOJ)

National Institute of Justice (NIJ)

Department of Labor (DOL)

Occupational Safety and Health Administration (OSHA)

Department of State (DOS)

Department of the Treasury (DOTreas)

Intelligence Community (IC)

Office of the Director of National Intelligence (ODNI)

Nuclear Regulatory Commission (NRC)

U.S. International Trade Commission (USITC)

Department of Homeland Security (DHS)

Department of Transportation (DOT)

Federal Highway Administration (FHWA)

American Chemical Society

Environmental Protection Agency (EPA)

National Aeronautics and Space Administration (NASA)

National Science Foundation (NSF)

U.S. Department of Agriculture (USDA)

Agricultural Research Service (ARS)

Forest Service (FS)

National Institute of Food and Agriculture (NIFA)

White House Emerging Technologies Interagency Policy Coordination Committee (ETIPC)

National Nanotechnology Coordination Office (NNCO)

Woodrow Wilson International Center for Scholars

International Center for Technology Assessment

Natural Resources Defense Council (NRDC)

American Chemical Society

Danish EPA

Danish Consumer Council and Ecological Council and the Technical University of Denmark's Department of Environmental Engineering

Producers of silicon dioxide, titanium dioxide : Grace (Allemagne), Merck Performance Materials SAS, Evonik Aerosil France Sarl, Clariant Production SAS, Rhodia Operations SAS (France)

Other producers: Nanomakeres, Grupo Antolin, Avanza, nanoComposix, NanoGap, DSM

4.2.2. The regulatory framework

Both BPA and nanosilver as chemical substances fall under REACH⁶⁷, which is the Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals. The regulation entered in force in 2007.

⁶⁷ Registration, Evaluation, Authorisation and Restriction of Chemicals

Table 7. Reference points (nanosilver) *

September 2006	The Voluntary Reporting Scheme for Manufactured Nanomaterials, the UK ⁶⁸
2006	OECD established the Working Party on Manufactured Nanomaterials (WPMN)
March 2007	European Commission: M/409 mandate addressed to Cen, Cenelec and Etsi for the elaboration of a programme of standards to take into account the specific properties of nanotechnology and nanomaterials
November 2007	OECD's Working Party on Manufactured Nanomaterials (WPMN) launched the Sponsorship Programme for the Testing of Manufactured Nanomaterials (hereafter the Testing Programme)
2008	REACH and the Regulation (EC) No 1272/2008
2008-2009	Series of OECD publications: Compilation and Comparison of Guidelines related to Exposure to Nanomaterials in Laboratories (2010) List of Manufactured Nanomaterials and List of Endpoints for Phase One of the Sponsorship Programme for the Testing of Manufactured Nanomaterials: Revision (2010) Current Developments/Activities on the Safety of Manufactured Nanomaterials, Tour de Table at the 7th Meeting of the Working Party on Manufactured Nanomaterials (2010) Guidance Manual for the Testing of Manufactured Nanomaterials: OECD Sponsorship Programme: First Revision (2010) Preliminary Guidance Notes on Sample Preparation and Dosimetry or the Safety Testing of Manufactured Nanomaterials (2010) Regulatory Regimes for Manufactured Nanomaterials (2010) Analysis of Information Gathering Initiatives on Manufactured Nanomaterials (2009) Manufactured Nanomaterials: Work Programme 2009-2012 (2009) Preliminary Review of OECD Test Guidelines for their Applicability to Manufactured Nanomaterials (2009) Report of an OECD Workshop on Exposure Assessment and Exposure Mitigation: Manufactured Nanomaterials (2009) Comparison of Guidance on Selection of Skin Protective Equipment and Respirators for Use in the Workplace: Manufactured Nanomaterials (2009) EHS Research Strategies on Manufactured Nanomaterials: Compilation of Outputs (2009) Manufactured Nanomaterials: Programme of Work 2006-2008 (2008) Report of the OECD Workshop on the Safety of Manufactured Nanomaterials (2009)
July 2008	Agence Francaise De Securite Sanitaire De L'environnement Et Du Travail (AFFSSET) : Les nanomatériaux : sécurité au travail. Recommendations for strengthening the safety of employees
2009	Grenelle de l'environnement, Article 42
March 2009	La Fédération Française pour les sciences de la Chimie et l'Union des Industries Chimiques : Guide de bonnes pratiques Nanomatériaux et HSE ⁶⁹
2009	The RIVM ⁷⁰ conducted a hypothetical registration of nano-silver to examine if REACH is appropriate to evaluate the safety of nanomaterials
2009	The cosmetics regulation (notification and labeling requirements): manufacturers should inform the Commission about the presence of in the form of nanomaterials in the product 6 months before launching the product, the presence of all ingredients in the form of nanomaterials should be indicated in the list of ingredients. The ingredient name should be

⁶⁸ <http://www.oecd.org/unitedkingdom/45989396.pdf>, accessed in April 2017

⁶⁹ Health, Safety and Environment

⁷⁰ Netherlands National Institute for Public Health and the Environment

	followed by the word "nano" in brackets. The regulation came into force in June 2013. Few enterprises label their products in accordance with this requirement. Besides, it was planned that in 2014 the Commission would provide "a catalogue of all nanomaterials used in cosmetic products placed on the market" (Article 16). It was not published in 2015 and 2016
2009	Opinion of the Scientific Committee of 2009 "The Potential Risks Arising from Nanoscience and Nanotechnologies on Food and Feed Safety"
2009	Commission recommendation on responsible nanosciences and nanotechnologies research ⁷¹
2010	Grenelle de l'environnement 2, Article 185
March 2010	Haut Conseil de la santé publique : Recommandation de vigilance relative à la sécurité des nanoparticules d'argent
March 2010	Avis de l'Agence française de sécurité sanitaire de l'environnement et du travail. Relatif à « Évaluation des risques liés aux nanomatériaux pour la population générale et dans l'environnement ». Main recommendations of the report are related to labelling, monitoring devices and improved knowledge on health and environmental effects
March 2010	Anses recommended limiting the exposure to nanomaterials using a step by step approach
October 2011	European Commission: Recommendation on the definition of nanomaterial
2011	Food Regulation 1169/2011. Regulation (EU)No 1169/2011 on the provision of food information to consumers
May 2011	Scientific opinion Guidance on the risk assessment of the application of nanoscience and nanotechnologies in the food and feed chain, European Food Safety Authority (EFSA) Scientific Committee. It deals with 3 main categories of products/applications: "those that are intended for consumption (by humans or animals), agrochemicals used in plant production (e.g. pesticides) and nanomaterials that are incorporated into products which come into contact with food/feed (e.g. packaging materials)" (p. 7)
January 2011	Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food. "Nanoparticles ... should be assessed on a case-by-case basis by the Authority as regards their risk until more information is known about such new technology"
2012	Workshop on the Second Regulatory Review on Nanomaterials related to REACH organized by the Commission. The Commission concluded that "Nanomaterials are similar to normal chemicals / substances ... a case-by-case approach for the risk assessment of nanomaterials is still warranted" (p. 4). Communication from The Commission to the European Parliament, the Council and the European Economic and Social Committee Second Regulatory Review on Nanomaterials
2012	Medical devices - Regulation proposed in September 2012
2012	Food additives Regulation 231/2012
May 2012	Regulation (EU) No 528/2012 of the European Parliament and of the Council of 22 May 2012 concerning the making available on the market and use of biocidal products. "Labeling requirement: "the name of all nanomaterials contained in the biocidal products, followed by the word 'nano' in brackets; any relevant instructions for use, including any precautions to be taken because of the biocidal products with which a treated article was treated or which it incorporates" (Article 58). According to SCENIHR (2014), the main nanomaterial used in the biocidal products is nanosilver
February 2012	Decree no. 2012-232 of 17 February 2012 on the annual declaration on substances at nanoscale in application of article R. 523-4 of the Environment code (entry into force: January 2013). "Obligation to declare the quantities and uses of substances at nanoscale produced, distributed or imported in France. A declaration is mandatory if the minimum quantity of 100

⁷¹ http://ec.europa.eu/research/science-society/document_library/pdf_06/nanocode-apr09_en.pdf, accessed in April 2017

	grams of substance has been produced, imported or distributed during the previous year". ANSES ⁷² - French agency for food safety, the environment and labor is in charge of declarations and collected data
March 2012	ANSES : Analyse bibliographique comparée de rapports d'expertise sur les risques liés à l'exposition aux nanoparticules d'argent
April 2012	SCENIHR requests information about nanosilver
June 2013	European Commission: Guidance on the protection of the health and safety of workers from the potential risks related to nanomaterials at work. Guidance for employers and health and safety practitioners
November 2013	ANSES : Avis de l'Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail relatif à « l'évaluation des risques liés au GRAPHISTRENGTH C100 réalisée dans le cadre du programme Genesis »
2013	Joint Research Centre of the European Commission (JRC): Towards a review of the EC Recommendation for a definition of the term "nanomaterial". Compilation of information concerning the experience with the definition
2014	Joint Research Centre of the European Commission (JRC): Towards a review of the EC Recommendation for a definition of the term "nanomaterial". Compilation of information concerning the experience with the definition. Assessment of collected information concerning the experience with the definition
April 2014	Anses : Évaluation des risques liés aux nanomatériaux. Enjeux et mise à jour des connaissances. Assessment of the risks associated with nanomaterials. Issues and update of current knowledge. Opinion of Anses. Collective Expert Appraisal Report.
April 2014	Avis de l'Anses relatif à la modification des annexes de REACH en vue de la prise en compte des nanomatériaux. ANSES insists that a differentiation the level of information required for registration depending on the quantity of substance is not relevant for nanomaterials
March 2014	European Commission Report: nanotechnologies: a preliminary risk analysis on the basis of a workshop organized in Brussels on 1–2 March 2004 by the health and consumer protection directorate general of the European commission
June 2014	Final opinion on nanosilver: safety, health and environmental effects and role in antimicrobial resistance, the Scientific Committee on Emerging and Newly Identified Health Risks
November 2014	European Commission: Employment, Social Affairs & Inclusion Working Safely with Manufactured Nanomaterials Guidance for Workers
November 2014	Science for Environment Policy (European Commission): Silver nanoparticles could pose risk to aquatic ecosystems ⁷³
2014	Joint Research Centre of the European Commission (JRC): Towards a review of the EC Recommendation for a definition of "nanomaterials". Assessment of collected information concerning the experience with the definition.
2014-2020	"The Horizon 2020 programme aims to bridge the gap between nanotechnology research and markets, and to realise the potential contribution to sustainable growth, competitiveness, environment, highly skilled jobs and increased quality of life" ⁷⁴
April 2015	ANSES: AVIS de l'Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail
February 2015	AVIS de l'Agence nationale de sécurité sanitaire de l'alimentation, de l'environnement et du travail relatif à l'expertise concernant la mise à jour des connaissances sur « l'évaluation des

⁷² Agence Nationale Sécurité Sanitaire Alimentaire Nationale

⁷³ http://ec.europa.eu/environment/integration/research/newsalert/pdf/risk_to_aquatic_ecosystems_from_silver_nanoparticles_394na1_en.pdf, accessed in April 2017

⁷⁴ <https://ec.europa.eu/programmes/horizon2020/en/h2020-section/nanotechnologies>, accessed in April 2017

	risques sanitaires et environnementaux liés à l'exposition aux nanoparticules d'argent ». Anses recommended limiting the exposure to nanosilver particles for which hazard alert had been identified using a step by step approach
February 2016	OECD report: Nanomaterials in Waste Streams. Current Knowledge on Risks and Impacts. "Literature review on four specific waste treatment processes"
August 2016	The Commission requested the SCCS a safety assessment of the nano form of Colloidal Silver covered in the notifications listed in the annex to this mandate ⁷⁵
September 2016	OECD Environment, Health and Safety Publications Series on the Safety of Manufactured Nanomaterials No. 74 Exposure Assessment of Nano-silver (AgNP): case study ⁷⁶
June 2016	Proposition de règlement du Parlement européen et du Conseil relatif aux dispositifs médicaux, et modifiant la directive 2001/83/CE, le règlement (CE) n° 178/2002 et le règlement (CE) n° 1223/2009
February 2017	Science for Environment Policy (European Commission): Risk of silver nanoparticles to terrestrial plants is low, but increased by chlorine ⁷⁷
February 2017	Direction générale de la concurrence, de la consommation et de la répression des fraudes (DGCCRF) reminded companies about obligations about nanomaterials labelling on food products ⁷⁸
February 2017	Benoit Hamon planned to ban endocrine disruptors, nanoparticles and dangerous pesticides in food products based on the precautionary principle. Benoît Hamon prévoit d'interdire les perturbateurs endocriniens, les nanoparticules et les "pesticides dangereux" dans l'alimentation ⁷⁹

Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 states that "This Regulation should ensure a high level of protection of human health and the environment as well as the free movement of substances, on their own, in preparations and in articles, while enhancing competitiveness and innovation. This Regulation should also promote the development of alternative methods for the assessment of hazards of substances" (p. 2).

REACH requires that producers and importers of substance register it with the European Chemicals Agency (ECHA). ECHA is one of the internal governance units. However, the European Commission, the European and the Council of the European Union are principal institutions involved in legislation at European level (Directorate-General for Communication European Commission, 2014). Other internal governance units, para-public institutions and agencies responsible for food, environmental and occupational health & safety related to BPA and nanosilver are listed above. In 2012, a workshop on the Second Regulatory Review on

⁷⁵http://ec.europa.eu/health/scientific_committees/consumer_safety/requests_en, accessed in April 2017

⁷⁶[http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono\(2016\)55&doclanguage=en](http://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=env/jm/mono(2016)55&doclanguage=en), accessed in April 2017

⁷⁷http://ec.europa.eu/environment/integration/research/newsalert/pdf/risk_silver_nanoparticles_terrestrial_plants_low_increased_by_chlorine_482na1_en.pdf, accessed in April 2017

⁷⁸<http://www.economie.gouv.fr/dgccrf/produits-alimentaires-etiquetage-obligatoire-pour-nanomateriaux-manufactures>, accessed in April 2017

⁷⁹<http://www.sudouest.fr/2017/02/13/sante-hamon-veut-interdire-les-perturbateurs-endocriniens-dans-l-alimentation-3193749-10152.php>, accessed in April 2017

Nanomaterials related to REACH was organized by the Commission (Table 7). The Commission concluded that "Nanomaterials are similar to normal chemicals / substances ... a case-by-case approach for the risk assessment of nanomaterials is still warranted" (European Commission, 2012, p. 4). However, in April 2014, ANSES insisted that a differentiation of the level of information required for registration (the quantity of substance) was not relevant for nanomaterials. Since 2014, the Netherlands as a Member State (Ministry of Infrastructure and the Environment) has been undertaking the nanosilver evaluation according to the ECHA website⁸⁰. ECHA has set the registration deadline for nanosilver at May 2018. Figure 15-Figure 19 show the number of event⁸¹ occurrences for each table that details reference points.

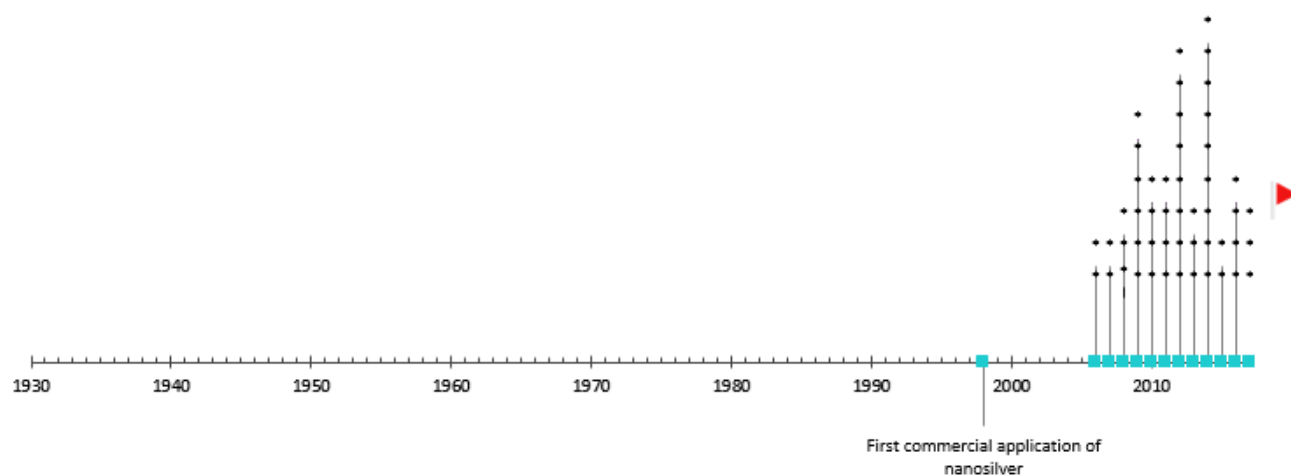


Figure 15. *Event occurrences, governance units, para-public institutions and agencies responsible for food, environmental and occupational safety (internal) related to the nanosilver industry, activities, * indicates one event*
 Source: Ostapchuk, based on Table 7

Regarding BPA, the European Chemicals Agency (ECHA) received the BPA registration dossier prepared by the BPA REACH Consortium in April 2010. The BPA REACH Consortium provided additional information regarding skin and environmental exposure at the request of ECHA in November 2013 (Table 8). In 2016, the European Commission banned bisphenol A from

⁸⁰<https://echa.europa.eu/information-on-chemicals/evaluation/community-rolling-action-plan/corap-table/-/dislist/details/0b0236e180697558>, accessed in April, 2017

⁸¹ "Longitudinal analyses are often chosen because a researcher is particularly concerned with certain events that may affect the life of an organization... Any relatively sudden qualitative change that happens to an individual or to an organization can be classes as an event. Examples of events that may occur include an individual, or an organization experiencing a strike or a takeover bid" (Thietart, 2001, p. 339). For me, an event means any activity undertaken by a stakeholder, publications of scientific opinions, regulations, etc. We focus on events are related to scientific knowledge about potential risks and which might be connected to nanosilver or BPA consumption.

thermal paper across the EU. In 2017, the Member State Committee identified bisphenol A in the EU as a substance of very high concern⁸².

*Table 8. Reference points (BPA) **

2003	European Union Risk Assessment Report, Bisphenol A, European Commission Joint Research Centre, Institute for Health and Consumer Protection, European Chemicals Bureau. This report highlights the need for additional information and risk assessment to resolve the uncertainties concerning low dose effect. It states that consumer exposure is low, thus there is no need for measures related to risk reduction
October 2004	The harmonized legal EU framework, Regulation (EC) No 1935/2004 of the European Parliament
2006	EFSA: the Tolerable Daily intake is estimated (0.05 milligrams per kilogram of body weight per day)
2007	REACH entered in force
October 2008	ANSES: OPINION of the French Food Safety Agency regarding bisphenol A in polycarbonate baby bottles. The quantity BPA migrating from baby bottles made of polycarbonate and heated in a microwave oven is lower than the TDI defined by EFSA
July 2009	France: The draft law that envisages to ban BPA is submitted.
2010	EFSA: Scientific Opinion on Bisphenol A was published (evaluation of a study investigating its neurodevelopmental toxicity, review of recent scientific literature on its toxicity and advice on the Danish risk assessment of Bisphenol A). The Panel on food contact materials, enzymes, flavorings and processing aids (CEF) reached a conclusion that the revision of the TDI is not necessary based on the existing studies. The current level of TDI "is based on the No-Observed-Adverse-Effect-Level (NOAEL) of 5 mg/kg b.w./day from a multi-generation reproductive toxicity study in rats, and the application of an uncertainty factor of 100".
January 2010	ANSES: OPINION of the French Food Safety Agency on the critical analysis of the results of a developmental neurotoxicity study of bisphenol A together with other recently-published data on its toxic effects. The safety factor of TDI is recommended to be reevaluated, the need for a new methodology to assess risks of very low doses of BPA is highlighted, the importance of understanding the osteogenic activity of bisphenol A, its effect on humans is mentioned. New data on sources of exposure is required.
July 2010	The French Government informed the Commission and the Member States about its temporary ban on "the manufacture, import, export and placing on the market of feeding bottles containing BPA " (p. L 26/11)
August 2010	The European Chemicals Agency (ECHA) received the BPA registration dossier prepared by the BPA REACH Consortium
October 2010	The EU commission stated its intention to ban the BPA use in baby bottles
September 2011	ANSES: Effets sanitaires du bisphénol A Rapport d'expertise collective, Connaissances relatives aux usages du bisphénol A, Rapport d'étude
2011	The EU imposed a ban on infant feeding bottles containing polycarbonate
2011	Commission Directive 2011/8/EU of 28 January 2011 amending Directive 2002/72/EC as regards the restriction of use of Bisphenol A in plastic infant feeding bottles
March 2013	ANSES: OPINION of the French Agency for Food, Environmental and Occupational Health & Safety on the assessment of the risks associated with bisphenol A for human health, and on toxicological data and data on the use of bisphenols S, F, M, B, AP, AF and BADGE "The risks identified for the unborn child relate to the mammary gland and may be characterized by an increase in the number of undifferentiated epithelial structures associated with an increased susceptibility of the mammary gland to tumor transformation" (p. 9). ANSES recommends to decrease exposure to BPA of pregnant women through metal food

⁸²<https://echa.europa.eu/fr/chemicals-in-our-life/hot-topics/bisphenol-a>, accessed in September 2017 (this period is beyond the scope of this research)

<https://echa.europa.eu/fr/-/msc-unanimously-agrees-that-bisphenol-a-is-an-endocrine-disruptor>, accessed in September 2017 (this period is beyond the scope of this research)

	and beverage cans which lined with BPA epoxy resins and thermal paper handling. New knowledge on toxicity is required together with a harmonization of analysis methods. Additionally, ANSES recommends evaluating risks of substitutes.
June 2013	ANSES: OPINION of the French Food Safety Agency regarding exposure to bisphenol A in the French population and maximum levels of bisphenol A in foods. The dietary exposure level is lower than the TDI. However, ANSES encourages to develop substitutes and label utensils to minimize the exposure of sensitive individuals.
November 2013	The BPA REACH Consortium provided additional information regarding skin and environmental exposure at the request of ECHA.
April 2014	ANSES: OPINION of the French Agency for Food, Environmental and Occupational Health & Safety in response to the consultation of the European Food Safety Authority on its draft Opinion regarding the assessment of risks to human health related to dietary exposure to Bisphenol A
August 2015	ANSES: OPINION of the French Agency for Food, Environmental and Occupational Health & Safety regarding the solicited request 2015-SA-0001 "Analysis of the results of the recent study published in Toxicological Sciences (Delclos et al., 2014) on the toxicity of Bisphenol A (BPA) administered by gavage to Sprague Dawley rats exposed from gestation day 6 to postnatal day 90"
January 2015 EFSA: the TDI for BPA was reduced from 50 to 4 µg/kg bw/day	EFSA admitted that several studies conclude that BPA could be related to "changes in brain, immune-modulatory effects and enhanced susceptibility to breast tumors". However, the Panel revealed several limitations of these studies. EFSA showed its readiness to reconsider the opinion if appropriate data exists



Figure 16. Event occurrences, governance units, para-public institutions (INRS, JRC) and agencies responsible for food, environmental and occupational safety (internal) related to the BPA industry (internal: France, the EU), * indicates one event
Source: Ostapchuk, based on Table 8

*

Moreover, nanosilver is subject to existing legislative framework: directive 89/391/EEC on the safety and health of workers at work, directive 98/24/CE on the protection of the health and safety of workers from the risks related to chemical agents at work, directive 2004/37/EC - carcinogens or mutagens at work (Bernard, 2016b). It seems that BPA is also subject to this legislative framework⁸³ except for directive 2004/37/EC⁸⁴.

The nanospecific legislative framework includes: Cosmetics Regulation 1223/2009, Medical devices - Regulation proposed in September 2012, Food Regulation 1169/2011, Food additives Regulation 231/2012, Food contact materials Regulation 10/2011, Biocides Regulation 528/2012.

The cosmetics regulation (notification and labeling requirements) states that manufacturers should inform the Commission about the presence of nanomaterials in the product 6 months before launching the product, the presence of all ingredients in the form of nanomaterials should be indicated in the list of ingredients. The ingredient name should be followed by the word "nano" in brackets. The regulation came into force in June 2013. However, few enterprises label their products in accordance with this requirement. Besides, it was planned that in 2014 the Commission would provide "a catalogue of all nanomaterials used in cosmetic products placed on the market" (Article 16). It was published neither in 2015 nor in 2016.

The Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food states that "Nanoparticles ... should be assessed on a case-by-case basis by the Authority as regards their risk until more information is known about such new technology".

According to labeling requirement (Regulation (EU) No 528/2012): " the label of the biocidal product must show the name of each nanomaterial, followed by the word 'nano' in brackets; any relevant instructions for use, including any precautions to be taken because of the biocidal products with which a treated article was treated or which it incorporates" (Article 58). This regulation is applicable to nanosilver given that the main nanomaterial used in the biocidal

⁸³ According to the European Commission Directive (EU) 2017/164 of 31 January 2017 establishing a fourth list of indicative occupational exposure limit values pursuant to Council Directive 98/24/EC, and amending Commission Directives 91/322/EEC, 2000/39/EC and 2009/161/EU. BPA is listed in the Annex to Commission Directive 2009/161/EU until 21 August 2018.

⁸⁴ Over the period 1991-2013, the Directive does not include reprotoxic substances, only if they are mutagenic or carcinogenic. However, it is a matter of debate and reprotoxic substance can be eventually included in the Directive (Bakker et al., 2014).

products is nanosilver (Scientific Committee on Emerging and Newly Identified Health Risks, 2014).

Besides, decree no. 2012-232 of 17 February 2012 on the annual declaration on substances at nanoscale in application of article R. 523-4 of the Environment code states "Obligation to declare the quantities and uses of substances at nanoscale produced, distributed or imported in France. A declaration is mandatory if the minimum quantity of 100 grams of substance has been produced, imported or distributed during the previous year". ANSES - French agency for food safety, the environment and labor is in charge of declarations and collected data.

*

BPA is subject to existing legislative framework: the CLP⁸⁵ Regulation (EC No 1272/2008), the European Regulation on Classification, Labelling and Packaging of chemical substances and mixtures, the Framework Regulation for all food contact materials (EC No 1935/2004), the European Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys⁸⁶, the Regulation on plastics used as food contact materials (EU No 10/2011), Loi n° 2012-1442 of 24 December 2012. The Commission Directive 2011/8/EU of 28 January 2011 states that the EU imposed a ban on the use of BPA in baby bottles.

A large number of risk assessment reports have been published at French and EU levels by Joint Research Centre of the European Commission, ANSES, European Commission, OECD and SCENIHR. The reports related to BPA have been published after the evidence of potential adverse effects of BPA was obtained. The list of reports is presented in Table 7 and Table 8 together with other events. Other events in the history of external governance units, para-public institutions (INRS, JRC) and agencies responsible for food, environmental and occupational safety related to the BPA industry are listed in Table 9.

⁸⁵ Classification, Labelling and Packaging of substances and mixtures

⁸⁶ The European Commission Directive 2014/81/EU of 23 June 2014 amending Appendix C of Annex II to Directive 2009/48/EC of the European Parliament and of the Council on the safety of toys, as regards bisphenol A Text with EEA relevance adds a specific migration limit of 0,1 mg/l for bisphenol A into Directive 2009/48/EC. The revised limit is 0,04 mg/l as the Draft Commission Directive amending, for the purpose of adopting specific limit values for chemicals used in toys, Appendix C to Annex II to Directive 2009/48/EC of the European Parliament and of the Council on the safety of toys, as regards bisphenol A states. This draft is published by the World Trade organization in July 2016.

Table 9. Reference points (nanosilver) #

Since 2001	The National Nanotechnology Initiative (NNI): 3 programs for coordinating research and development (R&D) 4 communication and collaborative activities in nanoscale science, engineering, and technology ⁸⁷
May 2008	"U.S. EPA fines Southern California technology company \$208,000 for "nano coating" pesticide claims on computer peripherals" ⁸⁸
January 2008	The US EPA established the Nanoscale Materials Stewardship Program (NMSP)
December 2009	The Federal Institute for Risk Assessment (BfR) indicated that it was still impossible to evaluate risks of nanosilver, li recommended to abandon the use of nanosilver in food and everyday consumer products until the data allows to evaluate risks of these products Anses 2012: avis n° 024/2010 du 28 décembre 2009
August 2010	"Until we are in a position to reliably rule out potential health risks, we recommend that manufacturers refrain from using nanosilver in consumer products", says BfR President Professor Dr. Dr. Andreas Hensel ⁸⁹
May 2012	The Lake Ecosystem Nanosilver (LENS) project in collaboration with Fisheries and Oceans Canada and Environment Canada is launched to study the effect of nanosilver in a lake's ecosystem ⁹⁰
February 2014	National Nanotechnology Initiative Strategic Plan Goals: "Advance a world-class nanotechnology research and development program. Foster the transfer of new technologies into products for commercial and public benefit. Develop and sustain educational resources, a skilled workforce, and a dynamic infrastructure and toolset to advance nanotechnology. Support responsible development of nanotechnology" (p. 5-6)
March 2014	Pathway corporation received an order from EPA to withdraw unapproved plastic food packaging which contains nanosilver from the market ⁹¹

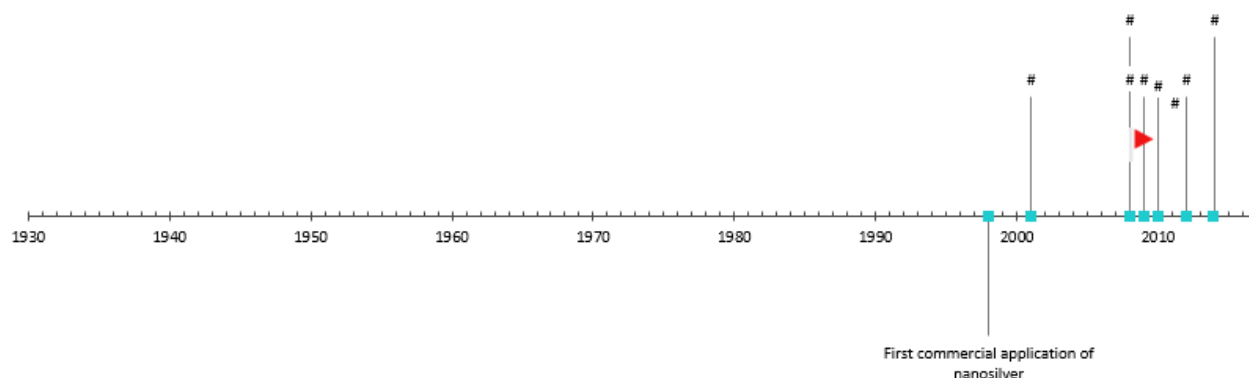


Figure 17. Event occurrences, governance units, para-public institutions and agencies responsible for food, environmental and occupational safety (external) related to the nanosilver industry, # indicates one event
Source: Ostapchuk, based on Table 9

⁸⁷ http://www.nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf, accessed in April 2017

⁸⁸ <https://yosemite.epa.gov/opa/admpress.nsf/6427a6b7538955c585257359003f0230/16a190492f25d585257403005c2851!OpenDocument>, accessed in April 2017

⁸⁹ http://www.bfr.bund.de/en/press_information/2010/08/nanosilver_has_no_place_in_food_textiles_or_cosmetics-50960.html, accessed in April 2017

⁹⁰ <http://www.nanowerk.com/news/newsid=25099.php>, accessed in April 2017

⁹¹ <http://www.centerforfoodsafety.org/press-releases/3026/epa-orders-withdrawal-of-nanotechnology-food-packaging-from-market>, accessed in April 2017

Table 10. Reference points (BPA) #

1958	Companies were required to get FDA authorization in order to use chemicals in the food industry
1977	The carcinogenesis study of BPA, an adult rodent model experiment with animals exposed to high doses. This study is conducted by Litton Biotechnics which is suspected of poor quality studies
1988	Based on the study of carcinogenesis, the EPA set a reference dose
1997	Studies on the low-dose effects of BPA
1997-2005	According to Vogel (2009), out of 115 studies, 11 studies on the impact of BPA funded by industry found no effects compare to other studies funded by government found a number of effects
2000	EPA requested the NTP to review studies on the impact of BPA at low doses. The conclusion of the NTP triggered the alarm
1999	Better understanding of the need for new testing strategy related to endocrine disruptors (Vogel, 2009)
2001	According to Vogel (2009), Steven Hentges (the American Plastics Council) raised doubts about the validity of the NTP assessment
2008	Draft Assessment of Bisphenol A for Use in Food Contact Applications
2008	The National Toxicology Program Center for the Evaluation of Risks to Human Reproduction (the National Institutes of Health) "Monograph on the Potential Human Reproductive and Developmental Effects of Bisphenol A"
2009	FDA: Re-evaluation of studies "Monograph on the Potential Human Reproductive and Developmental Effects of Bisphenol A"
April 2010	FDA: Independent assessment of the studies. The assessment did not indicate the need to adjust BPA level
2007	The American Chemistry Council agrees with the opinion of experts regarding the low level of exposure to BPA
2008	The US National Toxicology Program expressed concern about impact of BPA on infants and children among other things
2012	The U. S. Food and Drug Administration (FDA) prohibited its use in infant bottles (with over 20 States had restricted the use of polycarbonate containing BPA in baby bottles production prior to 2011)

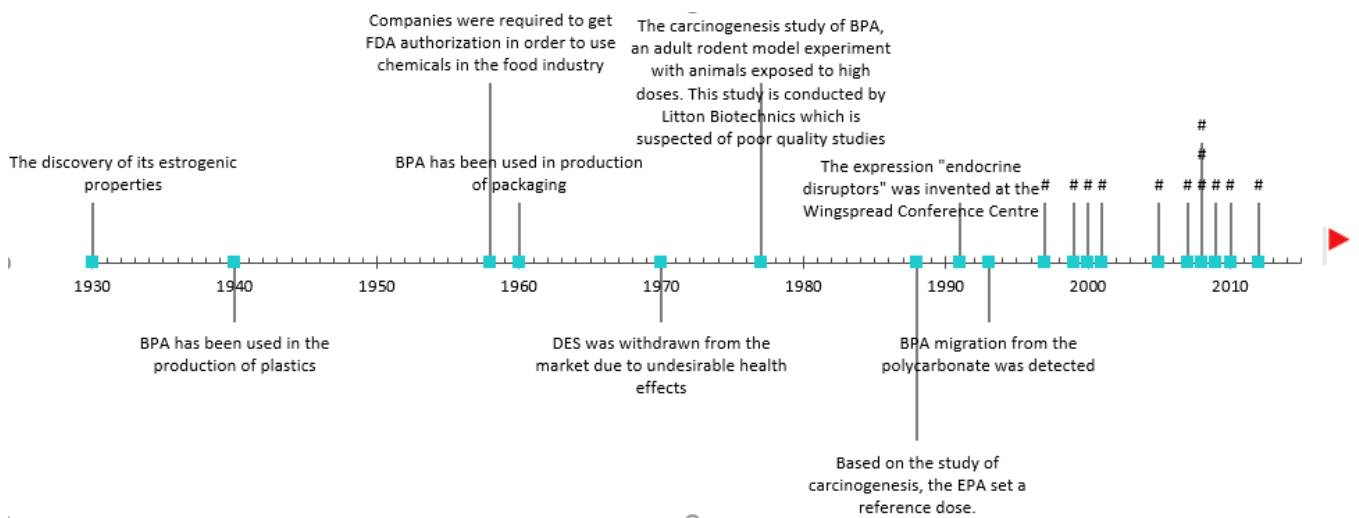


Figure 18. Event occurrences, governance units, para-public institutions and agencies responsible for food, environmental and occupational safety related (external) to the BPA industry, # indicates one event

Source: Ostapchuk, based on Table 10

Table 11. Reference points (BPA) ^

1990s	Dioxin panic in Japan
2001	The Japanese translation of "Our Stolen Future"
2004	The Danish EPA: a study on substitutes of BPA
1998	The Japanese Ministry of Health and Welfare panel explored the issue of BPA
1998	Japan started a voluntary replacement of BPA (in 1998 around 300 local municipalities changed tableware made from polycarbonate used in schools and in 1999 around 500 municipalities were about to replace the tableware)
	The Hokkaido Consumer Affairs Center requested industries to take measures in order to reduce exposure to BPA
April 2008	Environment Canada (2008) Draft Screening Assessment for The Challenge Phenol, 4,4' -(1-methylethylidene) bis-(Bisphenol A). Chemical Abstracts Service Registry, Number 80-05-7. The Existing Substances Assessment Program, the Health Canada and Environment Canada departments reached a conclusion on a basis of experimental data which suggested "increased sensitivity to BPA during early developmental stages"
November 2009	INFOSAN Information Note No. 5/2009 - Bisphenol A (BPA) - Current state of knowledge and future actions by WHO and FAO, Food and Agriculture Organization of the United Nations, World Health organization
November 2010	The joint meeting WHO-UN FAO
2011	The Danish EPA: Migration of bisphenol A from cash register receipts and baby dummies Carsten Lassen, Sonja Hagen Mikkelsen and Ulla Kristine Brandt. COWI. Survey of Chemical Substances in Consumer Products, No. 110 201

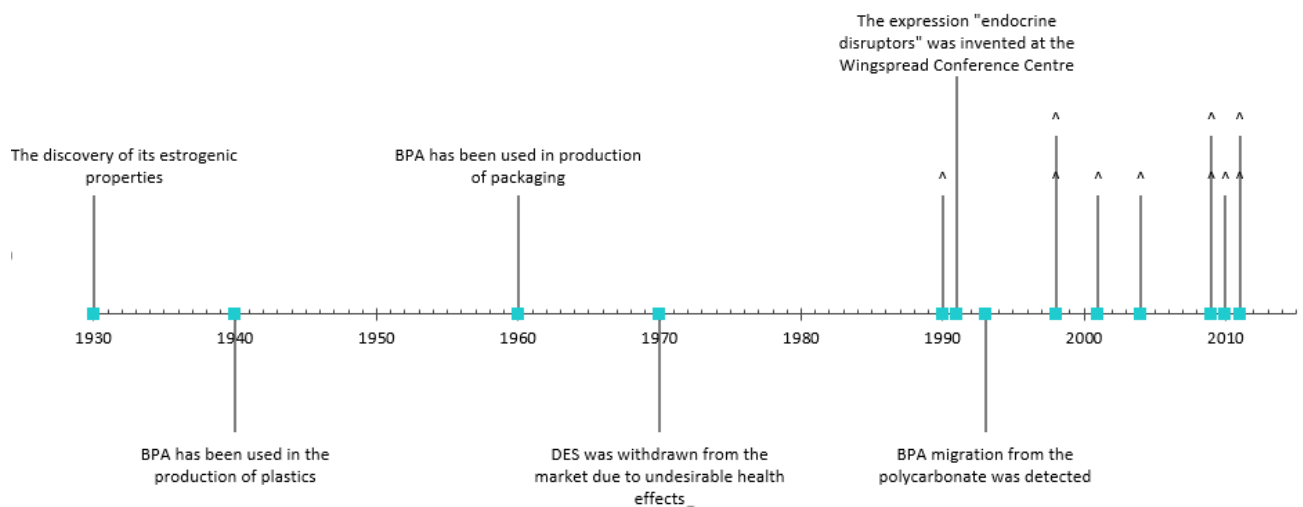


Figure 19. Event occurrences, external stakeholders related to the BPA industry, ^ indicates one event

Source: Ostapchuk, based on Table 11

4.2.3. Responsible development

In addition to risk assessment reports related to nanosilver and other materials, a large quantity of guidance on the risk assessment, code of conduct for responsible nanosciences and guide for public engagement have been published.

For example, OECD established the Working Party on Manufactured Nanomaterials (WPMN) in 2006. OECD prepared guidelines related to exposure to nanomaterials in laboratories and for the testing of nanomaterials over the period of 2008-2009 and published a large quantity of reports related to exposure assessment of nanosilver in 2016 (Table 12).

Following a first report on the implementation of the Nanotechnologies Action Plan for Europe, the Commission published the recommendation on responsible nanosciences and nanotechnologies research in 2008. The goal of this Recommendation is “to promote integrated, safe and responsible nanosciences and nanotechnologies research in Europe”⁹². The UK Responsible NanoCode was developed by Insight Investment, NIA and the Royal Society. But its success remains questionable given that few small companies adopted it. Large companies were concerned about litigation, public claims, etc (Friedrichs, 2016).

Moreover, DuPont and Environmental Defense Fund began creating the Nano Risk Framework in 2005 and BASF created a Code of conduct for nanotechnology.

Besides, BASF and NIA participate in the EU-funded research programs. One of the programs is NANOREG. This program was launched in order to adopt a common approach to regulatory assessment of nanomaterials. Its objectives are:

- “1. Providing legislators with a set of tools for risk assessment and decision making instruments for the short to medium term, by gathering data and performing pilot risk assessment, including exposure monitoring and control, for a selected number of nanomaterials used in products;*
- 2. Developing for the long term, new testing strategies adapted to a high number of nanomaterials where many factors can affect their environmental and health impact;*
- 3. Establishing a close collaboration among authorities and industry with regard to the knowledge required for appropriate risk management, and create the basis for common approaches, mutually acceptable datasets and risk management practices.”*⁹³

NaNoREG output includes a Framework for the Safety Assessment of Nanomaterials and proposed long-term strategies aiming for making the nanomaterial safety evaluation in the REACH framework more efficient.

⁹² http://ec.europa.eu/research/science-society/document_library/pdf_06/nanocode-apr09_en.pdf, p. 11, accessed in April 2017

⁹³ <http://www.nanoreg.eu/project/nanoreg-objectives>, accessed in April 2017

NANoREG2 (coordinated by INERIS⁹⁴) was launched in 2015 in order to implement a permanent process of accessing safer products, production and use. This process should be based on tools within a regulatory framework.

Similarly, several companies and representative bodies were engaged in research related to BPA. “The American Chemistry Council, the Society of the Plastics Industry, Dow Chemical Company, the Business Roundtable, Phillip Morris and General Electric” funded the Harvard Center for Risk Analysis to undertake a review of the existing literature on the risk assessment of BPA. However, several studies regarded conclusions drawn in other low-dose studies as unlikely to be true (Vogel, 2009). Besides, Vogel (2009) states that out of 115 studies on BPA low-dose effects conducted between 1997 and 2005, none of the industry funded research reveal adverse effects of BPA.

Numerous international and national workshops, conferences, summer schools and nanosilver related to nanotechnology are organized all over the world. Some examples of these events are presented in Table 12. For example, in March 2015 the Workshop “Bridging NanoEHS Research Efforts Joint Workshop was held”. The goal of this workshop was a promotion of EU–U.S. collaboration on nanomaterials-related environment, health, and safety (nanoEHS) research. Besides, five editions of NanoSafe were held in Grenoble. This is an international conference which “brings together scientists, researchers and private industries from all around the world to discuss health and safety issues related to nanomaterial use”.

In 2011 the Labex SERENADE⁹⁵ obtained a grant to explore “Safer Ecodesign Research and Education applied to Nanomaterial Development” (as cited in Auplat & Zucker (2014)). Thus, several actors are involved in research.

Moreover, public engagement can also enrich research by getting public opinions on research findings. Besides, it helps to inform the public. Public engagement is being supported by governance units in order to engage the public, NGOs and other stakeholders in dialog (Auplat & Zucker, 2014). A series of debates related to nanosilver were held in France in 2012: “Débat public national sur les nanotechnologies, Le débat se poursuit autour des applications textiles des nanotechnologies et les puces RFID”, “Nanotechnologie et sécurité alimentaire” and “Pharma-cosmétique / énergie”. OECD published a “Planning guide for public engagement

⁹⁴ Institut national de l'environnement industriel et des risques

⁹⁵ Laboratory of Excellence for Safe(r) Ecodesign Research and Education applied to NANomaterial DEvelopment

and outreach in nanotechnology key points for consideration when planning public engagement activities in nanotechnology” in 2012.

Table 12. Reference points ✕

2005	"In 2005 the UK government published its Outline Programme for Public Engagement on Nanotechnologies (OPPEN) as a response to the report from the Royal Society and Royal Academy of Engineering (2005)" (Auplat, 2008, p. 22)
2006	"In November 2006, the Royal Society, Insight Investment and the Nanotechnology Industries Association (NIA) came together to explore the potential societal and economic impact and uncertainties related to nanotechnologies" ⁹⁶
2007	BASF created a Code of conduct for nanotechnology ⁹⁷
September 2008	Woodrow Wilson International Center for Scholars: Silver Nanotechnologies and the Environment - Old problems or new challenges?, Luoma S.N
2008	The EU Code of Conduct for Responsible Nanoscience and Nanotechnology Research
2008	The UK Responsible NanoCode (Insight Investment, NIA and the Royal Society)
2009	Reconfiguring Responsibility Deepening Debate on Nanotechnology. A research report from the DEEPEN Project ⁹⁸
October 2009	Débat "Pharma-cosmétologie / énergie", Orleans
November 2009	Débat public national sur les nanotechnologies, Le débat se poursuit autour des applications textiles des nanotechnologies et les puces RFID ⁹⁹
December 2009	« Débat public » sur le thème : Nanotechnologie et sécurité alimentaire, Rennes ¹⁰⁰
October 2011	The Nanoethics 2011 conference, Warsaw. The goal was to provide "an overview of main issues concerning governance and ethics of nanosciences and nanotechnologies (N&N)" ¹⁰¹
2011	The Labex SERENADE obtained a grant to explore "Safer Ecodesign Research and Education applied to Nanomaterial Development" (as cited in Auplat & Zucker (2014))
February 2012	The Federal Institute for Risk Assessment (BfR) is holding a scientific conference on the health risk assessment of nanosilver. The aim of the conference was to provide an overview of the current scientific state regarding the production and application of nanosilver in consumer products and food" ¹⁰²
March 2012	The 4th annual ObservatoryNano report on Ethical and Societal Aspects of Nanotechnology report. It focuses on Responsible research and innovation. And the goal was "a two-way communication between citizens and EU institutions" ¹⁰³
September 2012	NIA Comments on SCENIHR Call for 'Information on Safety of Medical Devices containing Nanomaterials'

⁹⁶<http://www.matterforall.org/the-responsible-nano-code/>, accessed in April 2017

⁹⁷<https://www.basf.com/en/microsites/nanotechnology/safety/code-of-conduct.html>, accessed in April 2017

⁹⁸http://nanopinion.archiv.zsi.at/sites/default/files/reconfiguring_responsibility_september_2009.pdf, accessed in April 2017

⁹⁹http://cpdp.debatpublic.fr/cdpd-nano/script/ntsp-document-file_downloadb5ba.pdf?document_id=169&document_file_id=264,
http://cpdp.debatpublic.fr/cdpd-nano/script/ntsp-document-file_downloaddea15.pdf?document_id=180&document_file_id=277, accessed in April 2017

¹⁰⁰<http://www.planetenano.fr/article-15-octobre-2009-lancement-du-debat-national-sur-les-nano-technologies-37233037.html>, accessed in April 2017

¹⁰¹http://cordis.europa.eu/result/rcn/162481_en.html, accessed in April 2017

¹⁰²http://www.bfr.bund.de/en/event/bfr_conference_on_nanosilver-128143.html, accessed in April 2017

¹⁰³<http://www.nanowerk.com/news/newsid=24730.php>, accessed in April 2017

December 2013	Workshop U.S.–EU: Bridging NanoEHS Research Efforts Joint Workshop
2013	NANoREG was launched in order to adopt a common approach to regulatory assessment of nanomaterials
February 2014	NIA Comments: SCENIHR preliminary Opinion on Nanosilver ¹⁰⁴
April 2014	Collectif citoyen Nanotechnologies du Plateau de Saclay organized a public debate "La vie des nanomatériaux... et la nôtre ?" ¹⁰⁵
August 2014	ICNFA 4th international conference on nanotechnology, Toronto, Canada
October and December 2014	CNRS organized 2 workshops on risk prevention related to nanotechnology
December 2014	European conference on nanotechnology and nanomaterials: opportunities and challenges, Brussels
March 2015	Workshop Proceedings EU–U.S.: Bridging NanoEHS Research Efforts Joint Workshop. The goal of this workshop is a promotion of EU–U.S. collaboration on nanomaterials-related environment, health, and safety (nanoEHS) research
March 2015	INRS report: Nanoargents : de la production à l'utilisation, quels sont les risques ?, B. Savary
May 2015	Forum NanoResp : Les usages du nanoargent ¹⁰⁶
2015	NANoREG2 (coordinated by INERIS) is launched was order to implement a permanent process of accessing safer products, production and use. This process should be based on tools within a regulatory framework
October 2016	Avicenn coorganized a meeting between different union and associations related to nanomaterials and nanotechnology in the context of NanoSCOPE ¹⁰⁷
2016	Summer School "Safer Design for Nanomaterials", Archamps, France ¹⁰⁸
April 2017	Workshop "Safety aspects of nanomaterials in the development of drugs, medical products and cosmetics" KN 6691 27.04. - 28.04.2017, Berlin, Deutschland ¹⁰⁹
June 2017	16th World Nano Conference, Milan, Italy
2008, 2010, 2012, 2014, 2016	NANOSAFE 2014 18-20 November 2014, MINATEC, Grenoble "NanoSafe is a major international conference, held in Grenoble every two years. The conference brings together scientists, researchers and private industries from all around the world to discuss health and safety issues related to nanomaterial use. Nanosafe give them the opportunity to exchange information on their latest research progresses and to share the future trends in research, safe fabrication and use of nanomaterials. The conference includes plenary lectures, keynote lectures in addition to contributed papers both oral and poster presentations. After the great success of the last four conferences, the next edition will be held from November 7 to 10th, 2016 in MINATEC Grenoble, France. About 400 attendees are expected."

¹⁰⁴ <http://www.nanotechia.org/node/18578>, accessed in April 2017

¹⁰⁵ <http://www.collectif-nanosaclay.fr/wp-content/uploads/2014/02/CNanoS-Invitation-debat-10-04-2014.pdf>, accessed in April 2017

¹⁰⁶ http://www.nanoresp.fr/wpcontent/uploads/2015/07/CR_NanoRESP_Nanoargent_060515_FIN.pdf

¹⁰⁷ <http://veillenanos.fr/wakka.php?wiki=NanoscoopeRencontreInterAssoSyndic2016>, accessed in April 2017

¹⁰⁸ <http://www.biohealth-computing.eu/safer-design-for-nanomaterials/>, accessed in April 2017

¹⁰⁹ <http://www.apv-mainz.de/seminare/pharma-veranstaltungen/veranstaltung/seminar/6659/>, accessed in April 2017

	An important feature of Nanosafe 2016 will be the exhibition of related equipment, products and services, which will be held at the same time of the conference. We have also decided to propose an attractive sponsoring program"
	Understanding Public Debate on Nanotechnologies Options for Framing Public Policy. A Report from the European Commission Services. Among other things it discusses a public engagement DEEPEN (Deepening Ethical Engagement and Participation with Emerging Nanotechnologies) project ¹¹⁰
	A web-based tool to engage stakeholders in informing research planning for future decisions on emerging materials. It was created to prioritize research gaps (Powers et al., 2014)
	LICARA: 'Life Cycle Assessment and Risk Assessment of Nanoproducts' (Som et al., 2014): "It has developed the LICARA concept which helps SMEs ¹¹¹ to 1. Make decisions about developing and producing safe, sustainable products by gathering relevant information to answer the pertinent questions; 2. Learn from best practices; 3. Build a coherent argument about nanoproducts for suppliers, clients, consumer groups, authorities and other stakeholders (a comprehensive guide to the nanoproduct)")"

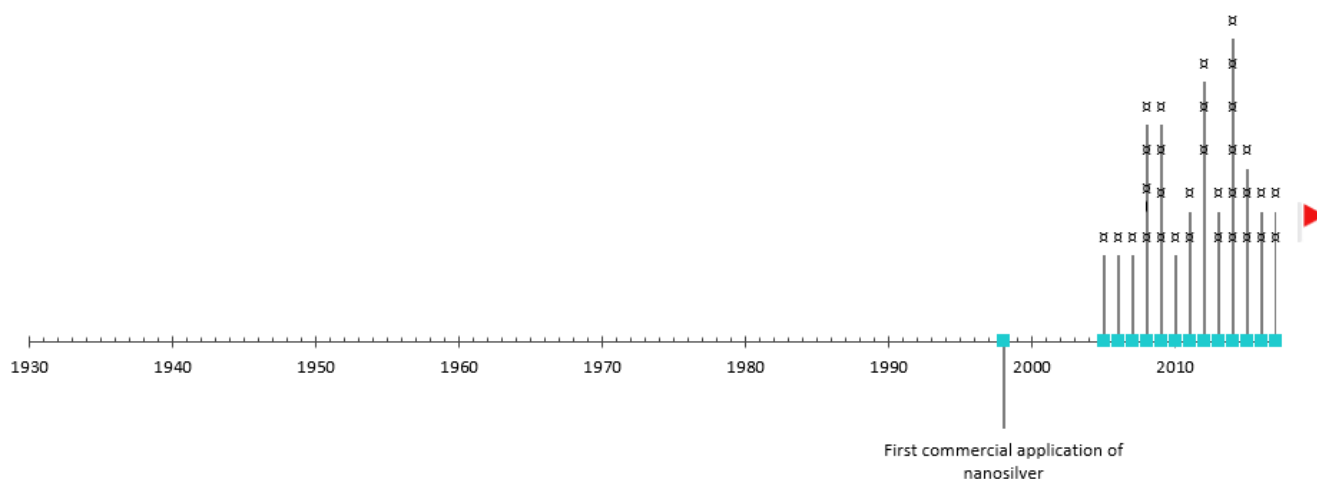


Figure 20. "Responsible research and innovation" event occurrences, x indicates one event
 Source: Ostapchuk, based on Table 12

4.3. Companies' reactions to new scientific knowledge about risk

4.3.1. Industry self-regulation and voluntary reporting schemes

As we have previously discussed, Japan started the voluntary replacement of bisphenol A in the late 1990s before an interim scientific conclusion on potential risks was reached (Nakanishi, Miyamoto, & Kawasaki, 2007). The authors state that in 1998 a large number of local municipalities changed tableware made from polycarbonate used in schools (Table 11). Baby bottles producers on the US and EU markets anticipated the introduction of the ban on polycarbonate baby bottles. Most of them had started manufacturing and selling BPA free

¹¹⁰ <http://www.nanowerk.com/nanotechnology/reports/reportpdf/report134.pdf>, accessed in April 2017

¹¹¹ Small and medium-sized enterprises

baby bottles before the introduction of this ban which had given them trade advantage (personal communication with one of the experts, April 2017; Fox et al., 2013). Table 13 presents reference points related to companies' reactions to new scientific knowledge about risk.

Table 13. Reference points (BPA) x

2008	Difrax (baby products): according to van Asselt et al (2013), this company provided information about existing controversies related to BPA on the website www.difrax.nl. The discussion about substitute(s) could be found of the website.
2008	US baby bottles producers (according to Bailin et al.): Gerber encouraged baby bottles made of substitutes for polycarbonate baby bottles. Handi-Craft introduced baby bottles made of glass and polypropylene baby bottles. Playtex and Nalgene (producer of sports water bottle) made a commitment to phase out BPA by the end of 2008. Avent committed to introduce baby bottles made of BPA-free plastics. BORN free presented BPA-free products.
2008	Class action lawsuits against Avent America, Nalgene Nunc International and Playtex (Stone, Ruoff, Galland, & Passof, 2010)
2009-2010	Food and beverage industry and retail companies. Companies which provided information related to their actions on potential risks of BPA on their websites: Hain, Celestial, ConAgra, H.J. Heinz, General Mills, Nestlé, Sara Lee. Hain Celestial (2009) and ConAgra (2010) provided information regarding the development of alternatives and their introduction on the market and Whole Foods provided information about its actions and different scientific studies. Publicly available position regarding BPA: Hain, Celestial, ConAgra, H.J. Heinz, General Mills, Nestlé, Sara Lee, H. J. Heinz, Del Monte, Campbell (Stone, Ruoff, Galland, & Passof, 2010)
2010	Food and beverage industry and retail companies. Companies that did not commit to stop using BPA (however, they might have explore the existence of substitutes): Dean Foods, Pepsico, JM Smucker, Coca Cola, Del Monted, Kraft, Supervalu, Unilever, Kroger, Safeway, Wal-Mart (Stone, Ruoff, Galland, & Passof, 2010)
2010	Sara Lee admitted their dependence on suppliers with respect to development of BPA-free epoxy resin (Stone, Ruoff, Galland, & Passof, 2010)
2010	Food and beverage industry and retail companies: Companies which committed to stop using BPA: Campbell Soup, ConAgra, Costco, General Mills, Hain Celestial, H.J. Heinz, Kellogg, McCormick, Nestlé, Sara Lee, and Whole Foods. While Hain Celestial, H.J. Heinz, ConAgra and General Mills had already used alternatives (Stone, Ruoff, Galland, & Passoff, 2010)

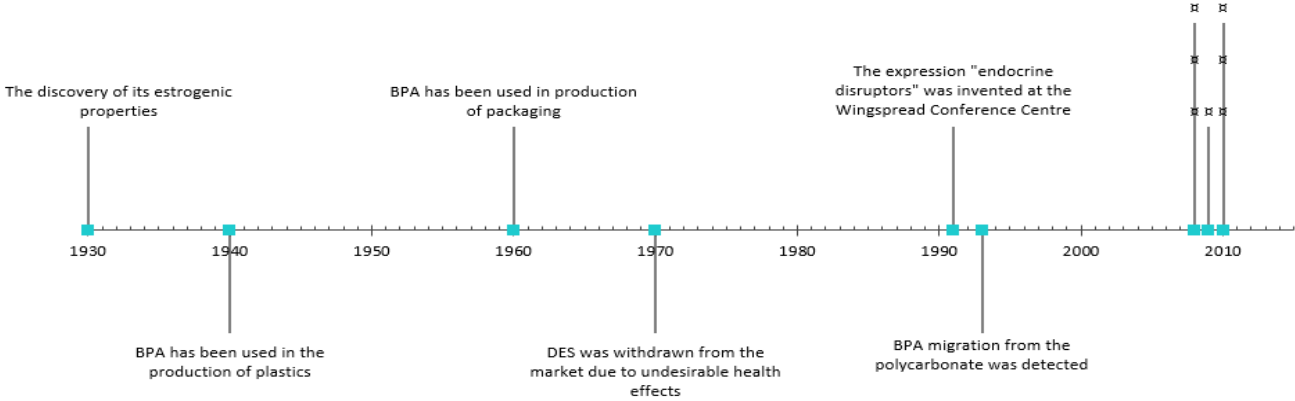


Figure 21. Event occurrences, users of BPA, x indicates one event
Source: Ostapchuk, based on Table 13

Regarding nanotechnology, in 2006 the UK made an attempt to initiate the Voluntary Reporting Scheme for Manufactured Nanomaterials which resulted in a small quantity of submissions of data on the use, production, processing or import of nanomaterials (Tinkle & Auplat, 2016). In 2008, the US EPA established the Nanoscale Materials Stewardship Program (NMSP). This program had similar objectives and it resulted in an unfavorable outcome. The rate of submission was extremely low (Tinkle & Auplat, 2016).

4.3.2. Other reactions to new scientific knowledge

No producers of BPA and nanosilver¹¹² are defined in France. Both BPA and nanosilver are used in numerous industries all over the world (including France). We are not aware of well-documented reactions to information about potential risks of different companies in France over the studied period, but the evidence of different activities in other countries (including the USA) is found. Given that the majority of baby bottles producers went global and there was evidence that some of them had introduced BPA free products prior to the ban introduction on the EU and US markets, we assumed that their activity related to baby products were relatively similar on the EU and US markets.

According to van Asselt et al (2013), Difrax (baby products) provided information about existing controversies related to BPA on the website www.difrax.nl in 2008. The discussion about substitute(s) can be found on the website.

Gerber has encouraged to use baby bottles made of substitutes for polycarbonate. Handi-Craft has introduced baby bottles made of glass and polypropylene baby bottles. Playtex and Nalgene (producer of sports water bottle) made a commitment to phase out BPA by the end of 2008. Avent committed to introduce baby bottles made of BPA-free plastics in 2008. BORN free presented BPA-free products in 2008 (Bailin, Byrne, Lewis, & Liroff, 2008).

In 2009-2010, a number of several food and beverage industry companies, namely Hain, Celestial, ConAgra, H.J. Heinz, General Mills, Nestlé, Sara Lee, H. J. Heinz, Del Monte, Campbell Soup, made their position regarding BPA publicly available. Some of these companies provided information related to their actions on potential risks of BPA on their websites: Hain, Celestial, ConAgra, H.J. Heinz, General Mills, Nestlé, Sara Lee. For example, Hain Celestial (2009) and ConAgra (2010) provided information regarding the development of alternatives and their

¹¹² In 2013, Avicenn explains the absence of declared nanosilver in the ANSES report "Éléments issus des déclarations des substances à l'état nanoparticulaire - Rapport d'étude, ANSES, novembre 2013". The explanation of this phenomena is that nanosilver is integrated in products before arriving in France.

introduction on the market and Whole Foods provided information about its actions and different scientific studies. Companies that did not commit to stop using BPA (however, they might have explored the existence of substitutes) were Dean Foods, Pepsico, JM Smucker, Coca Cola, Del Monte, Kraft, Supervalu, Unilever, Kroger, Safeway, Wal-Mart. Sara Lee admitted that they depend on their suppliers with respect to development of BPA-free epoxy resin: “Since we do not manufacture the epoxy resins, we rely on our suppliers to develop cost-effective useable options that are BPA-free. We do not control the process and work within the suppliers’ options and schedule” (as cited in Stone, Ruoff, Galland, & Passof (2010)). In 2015, the ban on the use of BPA in food packaging and containers (including BPA) in France became effective which was beyond the period of our analysis. While we conducted our study over the period 1990-2013, a private conversation with one of the experts (March 2017) reveals that several producers have agreed to work together on the development of suitable packaging given the diversity of products and their special requirement (with acidic or high in fat contents). Meanwhile, producers have accepted to use food cans coated with different type of resins (that was used before BPA) and to reduce products’ shelf life to maintain the quality of products preventing the migration of chemicals. While this law is not harmonized at the EU level, it gives French producers an advantage if similar law is introduced in other countries.

*

Concerning nanosilver, we have already mentioned that several producers have been participating in the EU-funded research programs and have been conducting risk assessment studies. Furthermore, a private conversation with one of experts (March 2017) reveals that having been requested by a client, one producer ordered tests to evaluate the safety of its substance (carbon nanotube) and its use in production of a particular product. While this example is not directly related to nanosilver, it illustrates the reaction of users to potential risks. Besides, this conversation shows that some of users are not aware of the presence of nanomaterials in substances which they use to produce their products. Some of other events are presented in Table 14.

Table 14. Reference points (nanosilver)

2005	DuPont and Environmental Defense Fund began creating the Nano Risk Framework
2007	BASF created a Code of conduct for nanotechnology ¹¹³
2014-2015	According to Avicenn, a number of companies contest the ECHA's decision to ask for additional information about nanoforms of some substances (Silicon dioxide, titanium dioxide)

4.4. NGOs and their activities related to new scientific knowledge

According to Auplat & Zucker (2014), one of the most important NGOs that participated in the dialog in the early 2000s based on the quantity of reports and the number of internet occurrences¹¹⁴ was the ETC Group. The other important NGOs defined by Auplat & Zucker (2014) were Friends of the Earth, Environmental Defense, Greenpeace, Sierra Club, OXFAM and WWF. To evaluate the relative importance of NGOs nowadays, we have met an expert who has been responsible for the preparation and publication of newsletters on nanotechnology since 2011. The expert has identified the most frequently cited NGOs related to nanotechnology: Avicenn, Agir pour l'Environnement (APE), Friends of the Earth, European Environmental Bureau, ECOS, ClientEarth, Ciel Center for International, Environmental Law. Some examples of their activities:

In 2011, Friends of the Earth published a report "Nano-silver: policy failure puts public health at risk" in 2011. The report states that "Friends of the Earth United States" is calling on the government to act now to seriously restrict the use of nanosilver in consumer, industrial and environmental products¹¹⁵. Besides, it reports that the number of allergies might increase as a result of nanosilver intake (Table 15 and Table 16).

In 2014 Friends of the Earth Australia published a factsheet concerning nanosilver. This factsheet explains environmental and health concerns related to nanosilver.

Avicenn maintains its own website with a section devoted to nanosilver¹¹⁶ where it publishes its own articles and news about nanosilver.

¹¹³ <https://www.basf.com/en/microsites/nanotechnology/safety/code-of-conduct.html>, accessed in April, 2017

¹¹⁴ Number of internet occurrences of ETC Group and the term nanotechnology: 1000000 (Auplat & Zucker, 2014)

¹¹⁵ <http://emergingtech.foe.org.au/wp-content/uploads/2014/09/Nano-silver-Fact-Sheet.pdf>, (p. 3), accessed in April, 2017

¹¹⁶ <http://veillenanos.fr/wakka.php?wiki=RisquesNanoArgent>, accessed in April, 2017

In 2016, Agir pour l'Environnement published a list of 200 food products which might contain nanoparticles on their website which complemented the existing inventories on nanotechnology (in particular, nanosilver):

- ANEC/BEUC inventory of products claiming to contain nanosilver particles available on the EU market in 2013,
- the Nanotechnology Consumer Product Inventory (the Woodrow Wilson International Center for Scholars and the Project on Emerging Nanotechnology),
- the consumer products inventory launched by National Institute of Advanced Industrial Science and Technology,
- "The Nanodatabase" created by the Danish Consumer Council and Ecological Council and the Technical University of Denmark's Department of Environmental Engineering and
- the inventory of nanosilver applications in food (Center For Food Safety).

In addition to the dissemination of information about particular subject, NGOs might contribute to regulation preparation. According to Avicenn (2012), the Greens-European Free Alliance (Greens-EFA) and several NGOs: Pesticide Action Network (Germany, Europe, UK), Health & Environment Alliance (HEA) and Women in Europe for a Common Future (WECF) played an important role in accelerating the preparation of biocide regulation and remained satisfied with the adoption of the regulation concerning nanotechnology. Besides, in 2014, 6 NGOs in the USA brought a lawsuit against the EPA claiming its inaction on regulation on consumer products containing nanosilver.

NGOs might also issue a health hazard alert warning the public and suggest banning the substance while their suggestions are based on a total lack of information about other applications (for example, medical applications of nanosilver). These applications might be useful and their substitutes do not exist (personal communication, April 2017). Meanwhile, some applications do not necessarily require nanoscale forms of substances, but producers of intermediate goods might not be aware that they use nanomaterials.

Table 15. Référence points (nanosilver) +

January 2001	Publication of the ETC Century by Pat Mooney, Dag Hammarskjold Foundation
June 2001	International seminar: What next? Technological transformation: Addressing nanotechnology and other emerging technologies in the ETC Century, Dag Hammarskjold Foundation
September 2001	Regional seminar, follow up of What next international seminar, ETC

December 2001	Regional seminar, follow up of What next international seminar, ETC
June 2002	Report on health and safety impacts of nanotechnology: No small matter! Asks for a moratorium on engineered nanoparticles, ETC
December 2002	Regional seminar, follow up of What next international seminar, ETC
January 2003	Report The big down: from Genomes to Atoms: Technologies Converging at the nano-scale (80-page report) , ETC
April 2003	Study explaining the case for a global moratorium on nanotech and including a scientific literature review: Size matters, coauthored with ETC
June 2003	ETC Group speaker at European seminar on nanotechnology and converging technologies at the European Parliament, Brussels, ETC
September 2003	ETC identifies first major environmental release of nanotechnology product in an Indian territory in New Mexico (SoilSET™ soil binders, a revolutionary new nanotechnology product used for dust control, soil stabilization, re-vegetation, and erosion control caused by wind, rain and water runoff, ETC
March 2004	Dinner with Prince Charles and members of the Royal Society to offer advice on nanotechnology, ETC
November 2004	Report Down on the Farm, on the impact of nano-scale technologies on food and agriculture, ETC
January 2005	ETC workshop on new technologies at Porto Alegre (Brazil) World Social Forum, ETC
June 2005	ETC Group hosted seminar series on nanoscale technologies in Geneva geared towards civil society representatives
2005	Publication of three reports on nanotechnology and Intellectual Property at key dates, including the opening of the GlenEagles G8 summit, ETC
October 2006	ETC Group testifies at US Food & Drug Administration's public meeting on nanotechnology
January 2007	ETC launches Nano Hazard symbol contest. Winning symbol to be sent to major regulating agencies
April 2007	Open letter to the international nanotechnology community to reject proposed framework put forward by DuPont and environmental Defence, ETC

Source: Reproduced from Auplat & Zucker (2014)

Table 16. Référence points (nanosilver) +

2005	The Woodrow Wilson International Center for Scholars and the Project on Emerging Nanotechnology: the Nanotechnology Consumer Product Inventory (CPI) (Vance et al., 2015)
2007	National Institute of Advanced Industrial Science and Technology launched a consumer products inventory, Japan (Vance et al., 2015)
September 2011	Friends of the Earth published a report "Nano-silver: policy failure puts public health at risk". The report states that "Friends of the Earth United States is calling on the government to act now to seriously restrict the use of nanosilver in consumer, industrial and environmental products" p.3. Besides, it reports that the number of allergies might increase as a result of nanosilver intake
2009	Amis de la Terre USA : L'inquiétant accroissement de l'utilisation de l'argent et du nanoargent comme biocides et de leur dispersion dans l'environnement (R. Sengen) http://www.amisdelaterre.org/IMG/pdf/nanoargent.pdf
2012	the Danish Consumer Council and Ecological Council and the Technical University of Denmark's Department of Environmental Engineering created the inventory of products "The Nanodatabase" (Vance et al., 2015)

February 2013	ANEC/BEUC inventory of products claiming to contain nanosilver particles available on the EU market
December 2013	Avicenn explains the absence of declared nanosilver in the ANSES report "Éléments issus des déclarations des substances à l'état nanoparticulaire - Rapport d'étude, ANSES, novembre 2013". The explanation of this phenomena was that nanosilver had been integrated in products before arriving in France
May 2014	Friends of the Earth published a report "New report: Tiny ingredients, big risks" related to presence of nanomaterials in food products. This report suggests labeling the food if there are nanomaterials
December 2014	6 NGOs in the USA brought a lawsuit against the EPA claiming its inaction on regulation on consumer products containing nanosilver
September 2014	Friends of the Earth Australia published a factsheet concerning nanosilver. This factsheet explains environmental and health concerns related to nanosilver ¹¹⁸
February 2014	Center for Food Safety created an inventory of nanosilver applications in food
March 2016	Agir pour l'Environnement published 1 list of 200 food products which might contain nanoparticles on their website ¹¹⁹

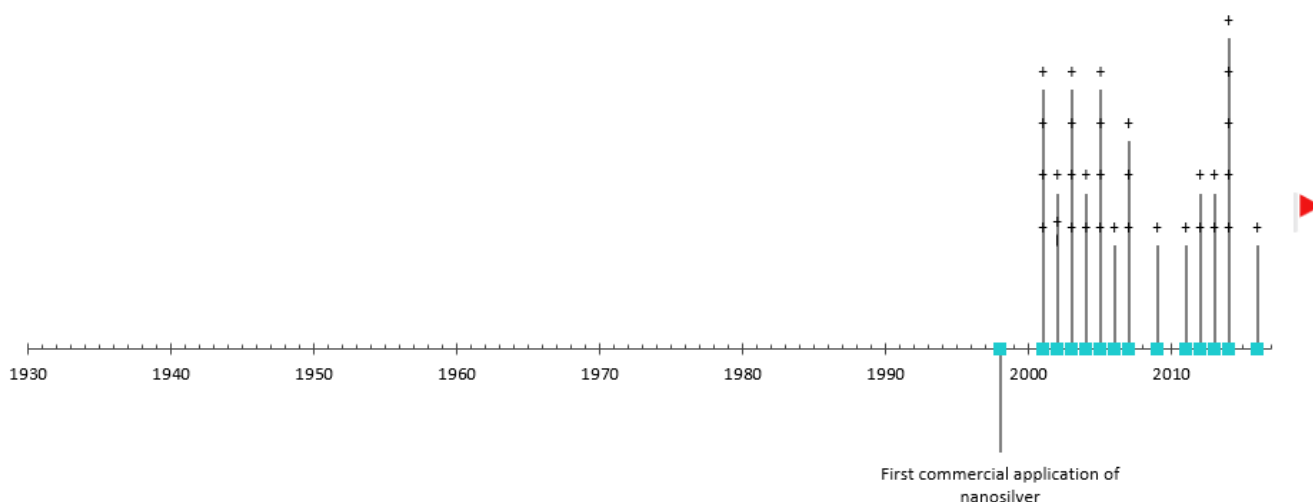


Figure 22. Event occurrences, NGOs related to nanosilver, + indicates one event
Source: Based on Table 15 and Table 16

Regarding BPA, WWF started the DetoX Campaign (Campaigning for safer chemicals) in order to bring adverse effects of chemicals (including BPA) to the public's attention in 2003. Contrary to this Campaign, the main message on the website of the American Chemistry Council is "BPA is safe". In 2013, the video "A Closer Look At Bisphenol A" published by BPA coalition discussed

¹¹⁷http://www.centerforfoodsafety.org/files/2014-12-16-dkt-1--pls--complaint_78869.pdf,

<http://veillenanos.fr/wakka.php?wiki=UsaNanoargent>, accessed in April 2017

¹¹⁸<http://emergingtech.foe.org.au/wp-content/uploads/2014/09/Nano-silver-Fact-Sheet.pdf>, accessed in April 2017

¹¹⁹<http://www.agirpourenvironnement.org/communiqués-presse/infonanoorg-mise-en-ligne-d-une-liste-de-200-produits-alimentaires-suspect-31026>, accessed in April 2017

other risk factors for cancer, obesity, diabetes besides BPA. Moreover, this video shows that BPA has to be consumed in large quantities to cause harmful effects. And it discusses benefits of BPA. Diffusing facts about BPA consumption, producers and their representatives give a positive image related to BPA. Besides, the ban on baby bottles allows to delimit the vulnerable group. The European Information Centre on BPA has been created by the association Plastics Europe (Covestro, SABIC, Trinseo, Hexion). The website provides information about BPA and dispel different myths of BPA (Table 17).

Table 17. Reference points (BPA) +

2003	WWF: DetoX Campaign
2008	RES can be defined as a challenger. In 2010, RES launched its first campaign against BPA. Since 2011, RES has published articles on BPA
2009	Plastics Europe has provided position papers related to BPA, among other sources, on the following website: http://www.bisphenol-a-europe.org
2009	The American Beverage Association (ABA) spent around \$19 million on " lobbying, including lobbying on, and presumably against, multiple bills that would protect consumers from BPA exposure." (p.11) "The beverage industry's products and containers are safe and pose no public health risk, including any alleged risk associated with BPA." (American Beverage Association) (Stone, Ruoff, Galland, & Passoff, 2010)
2010	The magazine "60 Millions de consommateurs", edited by National Institute of Consumption, has published a series of articles related to BPA
2011	UFC-Que Choisir can be defined as a challenger. Since 2009, UFC-Que Choisir has published several articles related to BPA
December 2012	"Differential Effects of Bisphenol A and Diethylstilbestrol on Human, Rat and Mouse Fetal Leydig Cell Function" Thierry N'Tumba-Byn, Delphine Moison, Marlène Lacroix, Charlotte Lecureuil, Laëtitia Lesage, Sophie M. Prud'homme, Stéphanie Pozzi-Gaudin, René Frydman, Alexandra Benachi, Gabriel Livera, Virginie Rouiller-Fabre , René Habert. This study concludes that a factor of 10 for potential interspecies variation is not sufficient. This might suggest that the TDI should be reevaluated (René Habert)
August 2012	BPA coalition was created in August 2012
March 2013	The video "A Closer Look At Bisphenol A" published by BPA coalitation discussing other risk factors for cancer, obesity, diabet... Besides, this video shows that it has to be consumed in large quantities to cause harmful effects. And this video discusses benefits of BPA: https://www.youtube.com/watch?v=z38a9bfHmjU
2013	Interview was conducted by MINES ParisTech with Gilles Garnier, Senator Annie David's Assistant. Gilles Garnier admitted that an industrial lobby was the strongest, but the interests of industry and those of the population could have coincided. Besides, he mentioned that the argument about job cuts had been used during the debate on BPA
	American Chemistry Council, the main message on the website "BPA is safe"
	European Information Centre on BPA was created by the association Plastics Europe (Covestro, SABIC, Trinseo, Hexion). The website provides information about BPA and dispel different myths of BPA

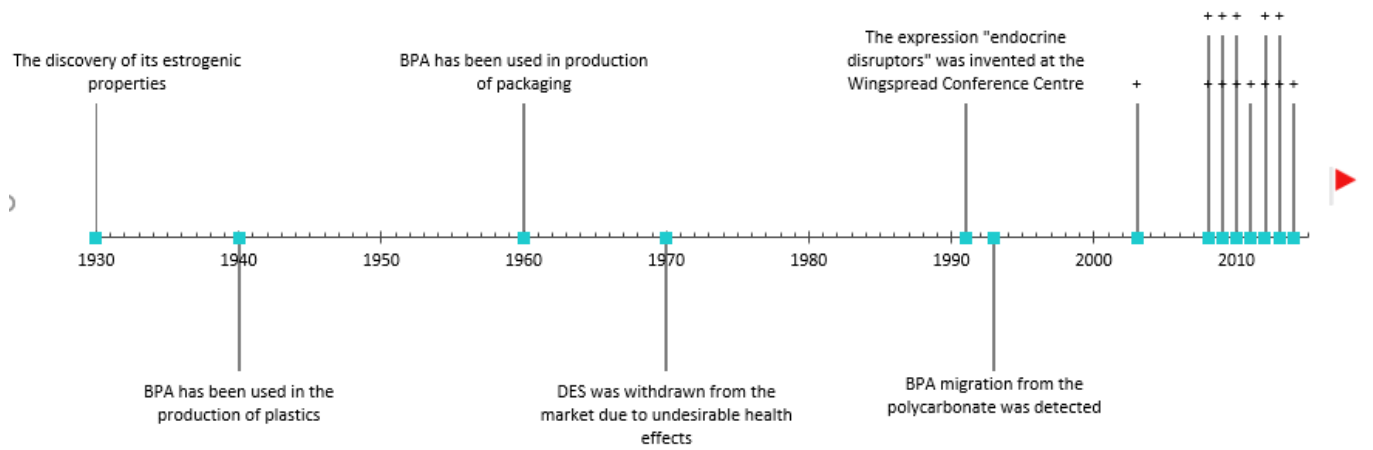


Figure 23. Event occurrences, NGOs related to BPA, + indicates one event
Based on Table 17

Chapter 5. Bisphenol A: background information and publications in scientific journals

The literature on the diffusion of innovation reviewed in Chapter 2 serves as a background for this research. The review has revealed that there is still need for literature that addresses the uptake of innovation in a situation of uncertainty regarding environmental and health risks. Prior research on the diffusion of innovation has explored the issue of uncertainty concerning performance and profitability of innovation (Jensen, 1982; Oren & Schwartz, 1988). Recent studies (Arora et al., 2014; Hossain, 2011; OECD, 2013) provide first evidence of drivers of nanotechnology. Very little research asks why a particular innovation is rejected after having been adopted before, or why the slowdown occurs. Understanding the slowdown in a situation of uncertainty about environmental and health risks can be crucial in designing future responsible and commercially successful nanotechnology innovations.

Given that the literature on the diffusion provides controversial evidence of the impact of wealth on diffusion rates (Chandrasekaran & Tellis, 2008; Dekimpe et al., 1998, 2000a, 2000b; Kauffman & Techatassanasoontorn, 2005; Putsis Jr. & Srinivasan, 2000; Tellis et al., 2003; van Everdingen et al., 2009), another stream of literature that might contribute to this research focuses on the relationship between economic growth and environmental degradation. It examines the possibility of the existence of an Environmental Kuznets Curve (EKC). The EKC hypothesize that several different measures of environmental degradation are inverted U-type function of economic development, that can be represented by income per capita (Stern, 2004). At a higher level of income people become more environmentally and health conscious. Besides, higher income countries have greater potential to reduce negative environmental impacts. This might cause reduction in consumption of potentially harmful product, its voluntary replacement or introduction of new regulations. Therefore, there might be a link between consumption of potentially dangerous products, their potential impact on

environment and economic growth/wealth. Relatively little published literature examines the validity of the Environmental Kuznets Curve hypothesis in a situation of uncertainty about environmental and health risks while it can provide new insight into drivers of innovation. For these reasons, we will study empirically the relationship between economic growth and the industrial intermediate good under uncertainty (Chapter 6).

This chapter begins with research questions of Chapter 6 and Chapter 7. Then, data collection problems are briefly discussed. Then, background information about bisphenol A and its use is presented. Following this, health and environmental concerns about BPA are discussed and bisphenol A consumption pattern is presented. Finally, details about the construction of scientific knowledge proxies related to the analysis are provided.

5.1. Research questions

In particular, Chapter 6 and Chapter 7 aim to study the impact of economic growth and the introduction of new scientific knowledge about risks by analyzing consumption of bisphenol A at international level and sales of polycarbonate in Japan. Chapter 6 and Chapter 7 make an attempt to answer five questions exploring two data sets with two different modeling techniques for each. First, we try to develop a classification of new scientific knowledge related to potential risks of BPA. We have used the PubMed search engine to collect the overall number of scientific articles available at the beginning of 2015. A combination of such keywords as bisphenol A with epidemiology, toxicity and endocrinology separately resulted in 1723 articles. We specifically exclude all literature not directly related to the potential risks of Bisphenol A. These articles will lead us to the following questions:

- Can scientific knowledge about bisphenol A be classified under different categories based on their conclusions on potential risk of BPA?

We will construct several variables that take into account publications related to the issue of bisphenol A based on their conclusions (Chapter 5).

Second, we will analyze annual data on BPA consumption. This data set contains information on the following regions: North America, South America, Western Europe, CIS and Baltic States, Middle East and Africa, Indian Subcontinent, Northeast Asia (including China, Japan and the Republic of Korea and Taiwan separately) and Southeast Asia for the 1990, 1995 and over the period of 2000-2013 for which data is available on an annual basis. It will be used to answer the following questions:

- Is there an Environmental Kuznets curve (EKC) for bisphenol A consumption?
- Does the introduction of new scientific knowledge about potential risks of BPA affect its consumption?¹²⁰

The second data set deals with quarterly data on sales value of polycarbonate (PC), polycarbonate producer price index and GDP per capita in Japan over the period of 1990-2013. It will be used to answer the following question:

- Does the volume of scientific articles about potential risks of BPA influence sales values of products containing BPA?

The analyses and results related to BPA study are presented in Chapter 6 and Chapter 7. The structure of Chapter 5, Chapter 6 and Chapter 7 is presented in Figure 24 below.

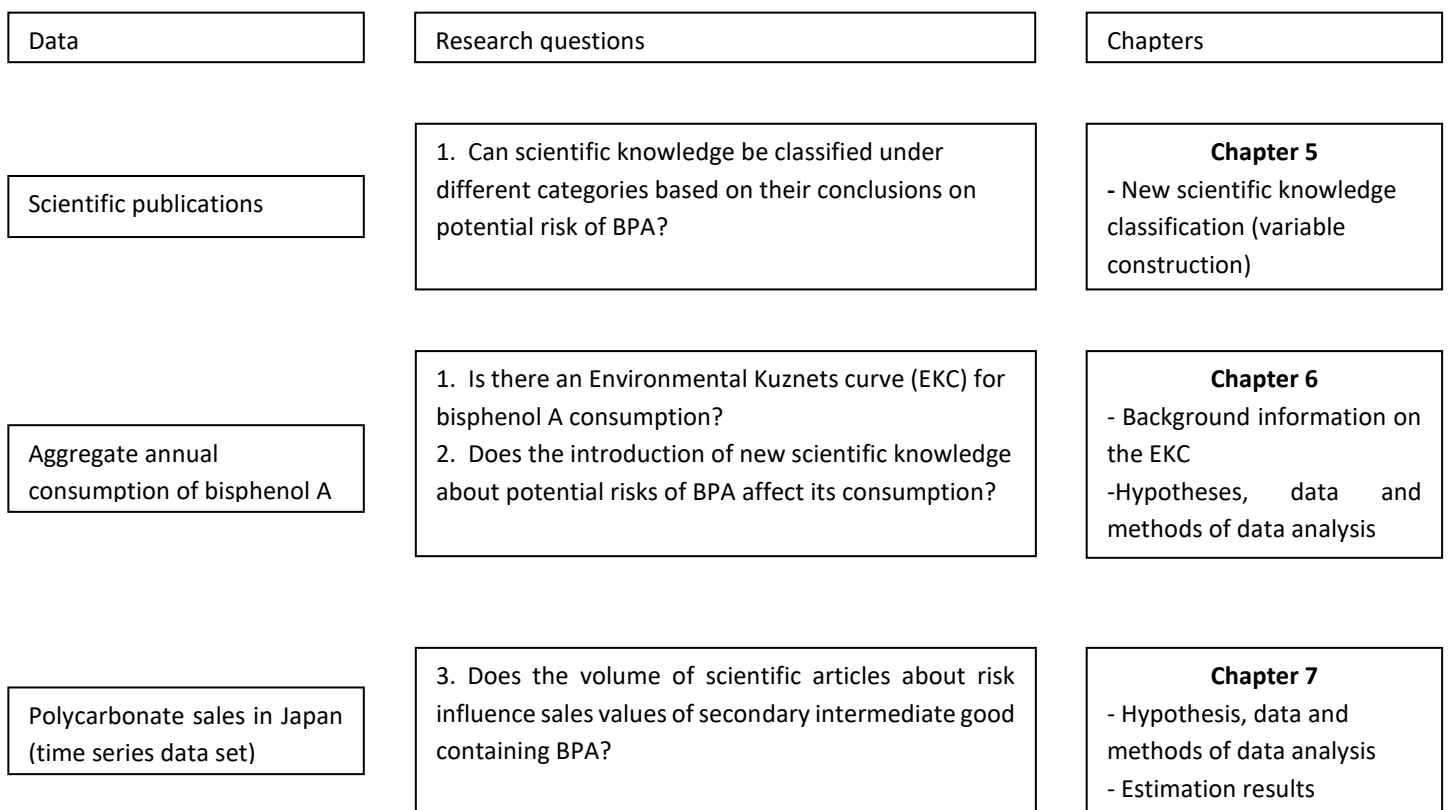


Figure 24. Structure of Chapter 5, Chapter 6 and Chapter 7
Source: Ostapchuk

5.2. Data collection

Before explaining the two main sources of data, it is worth mentioning that an iterative approach to deciding on an appropriate data sample has been applied (see Figure 25). While

¹²⁰ We examine different new scientific knowledge measures and their influence on BPA consumption.

the bisphenol A was initially chosen as a suitable one, an identification of the suitable data set was progressive. First, baby bottles made from BPA-based polycarbonate was chosen as a unit of analysis due to the notorious endocrine-disrupting properties of these bottles. However, for the reason of data unavailability, we selected other closely related units of analysis, namely aggregate level data on bisphenol A and polycarbonate consumption sales.

In searching for data on bisphenol A and polycarbonate, we contacted several federations (Fédération des Chambres Syndicales de l'Industrie du Verre, La Fédération de la Plasturgie et des Composites), public institutions (DGCCRF, Anses, Centre Européen des Consommateurs France, CREDOC) market research companies (GFK, PIE, ICIS), baby bottles producers (SGD, Philips Avent), statistical agencies (INSEE), etc. The list of contacts is presented in Appendix D. This process was extremely difficult and without success at the beginning (data was not sufficiently detailed/confidential/unavailable). Eventually, data on polycarbonate (PC) sales value was drawn from Datastream¹²¹ and data on BPA consumption was bought from the IHS Chemical Economics Handbook on Bisphenol A (Sriram et al., 2014). The sources of explanatory variables which are used in the analysis are presented in Chapter 6 and Chapter 7.

¹²¹<http://financial.thomsonreuters.com/en/products/tools-applications/trading-investment-tools/datastream-macroeconomic-analysis.html>

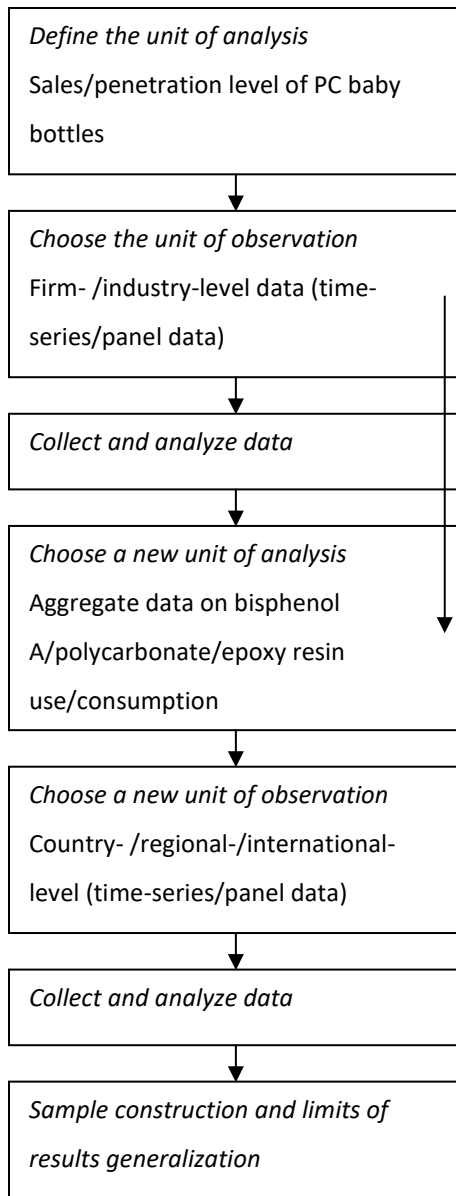


Figure 25. *Iterative approach*
 Source: Adapted from Thietart, 2014

The analysis of bisphenol A consumption at international level will be conducted applying different types of panel data methods including fixed effects and random effects methods which are described in detail in Chapter 5. The analysis of polycarbonate sales in Japan will be carried out using a vector autoregressive model given the availability of time series data set (chapter 6)¹²².

¹²² Survival analysis which is often employed to model the time-to-takeoff or time-to-slowdown of new product's sales growth at international level is not used here given the nature of the available data (relatively small sample size, different stages of bisphenol A consumption).

5.3. Bisphenol A use

The industrial chemical bisphenol A (BPA) is mainly used to produce polycarbonate plastic and epoxy resins which in turn are employed in the production of baby bottles, packaging, dental sealants, medical devices, optical media industry, automotive industry, sports equipment, electronics, electric industry, polyvinyl chloride (PVC), thermal paper, phenoplast and construction industry, etc^{123,124} (see Figure 26). Besides, bisphenol A can be found in optical lenses and window glazing (Møller, Fotel, & Larsen, 2012).

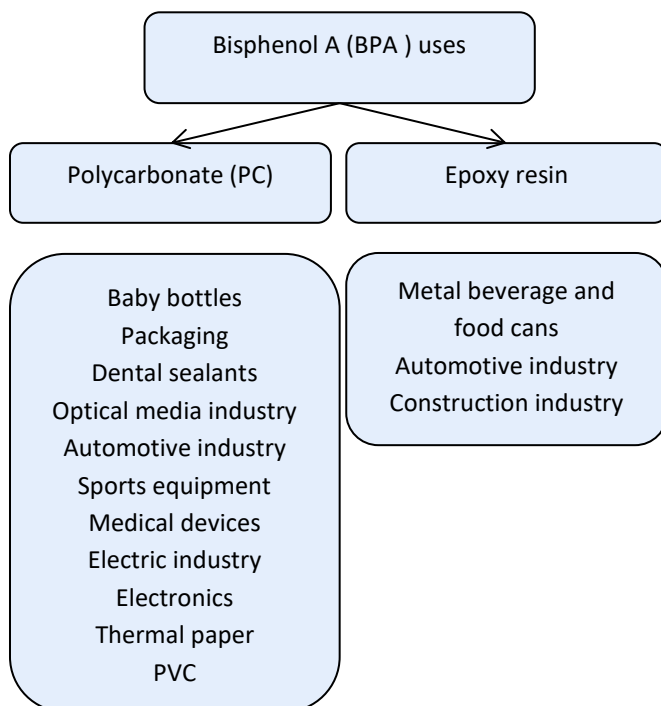


Figure 26. Main use of bisphenol A
Sources: Based on Brignon & Gouzy (2010)

The pie chart (Figure 27) is about polycarbonate use sectors. Three largest sectors in 2006 are optical media, electrical, electronic applications and assembly. More recent data suggests that the share of optical media sector in the EU was substantially lower in 2010 than the world share of optical media in 2005. The building and construction sector was the EU's largest sector in 2010. (PlasticsEurope, 2010). According to Sriram et al. (2014), the shares of automotive and medical applications continue increasing and the share of optical media continues decreasing. The latter can be explained by the decrease in the use of CDs.

¹²³ INERIS, Service National d'Assistance à la Substitution du Bisphénol A, www.ineris.fr/substitution-bpa/, accessed in June 2014

¹²⁴ <http://www.icis.com/chemicals/bisphenol-a/?tab=tbc-tab4>, accessed in May 2015

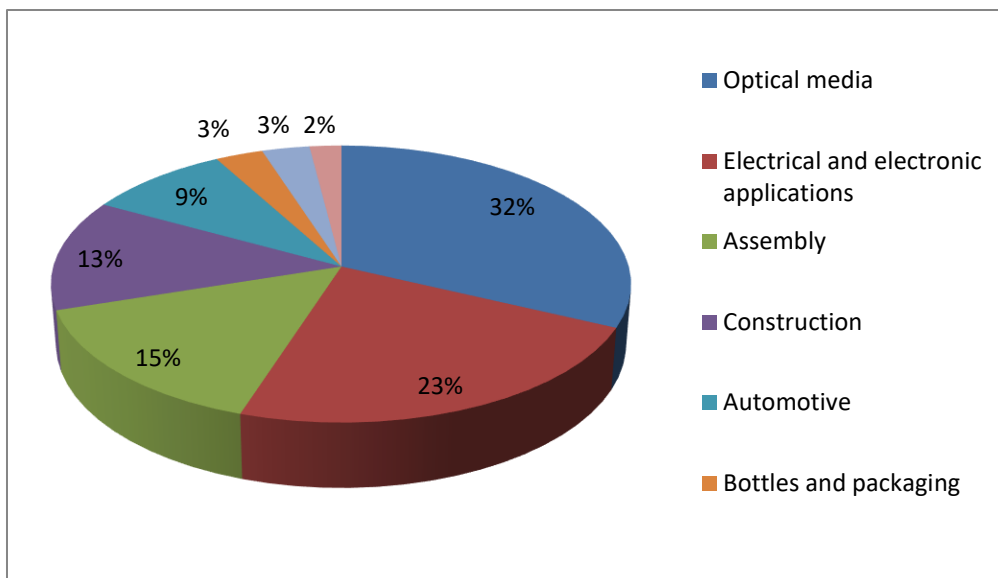


Figure 27. Polycarbonates-use sectors (world production of polycarbonate in 2006: 2.9 million tons)

Source: Brignon & Gouzy (2010) based on PlasticsEurope (2007)

Figure 28 deals with epoxy resin-use sectors in 2005. The figure shows that three world's largest sectors are insulation covers, electrical and electronic applications, bobbins and cops coating. In 2013, two largest sectors became coating application and electrical and electronic applications ("Epoxy Resins," 2014).

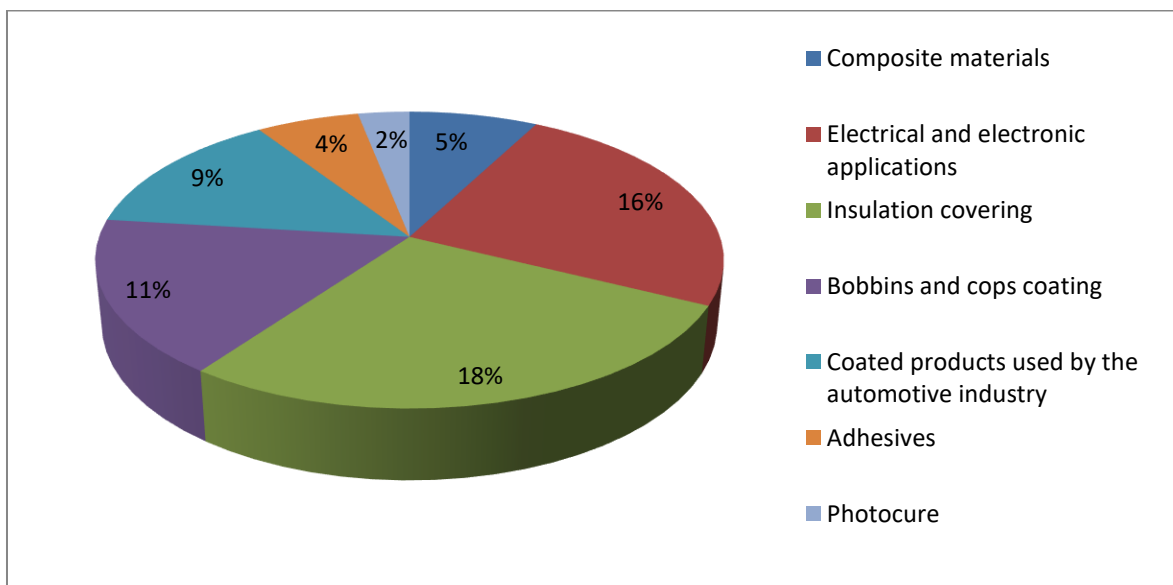


Figure 28. Epoxy resin-use sectors (world production of epoxy resin in 2005: 1.6 million tons)

Source: Brignon & Gouzy (2010) based on Plastics Europe (2007)

5.4. Bisphenol A in the value chain

Bisphenol A is produced from phenol and acetone through the hydrochloric acid-catalyzed condensation reaction. In addition to polycarbonate and epoxy resin, other applications of

BPA comprise flame retardants and different types of resins (Sriram et al., 2014), which are intermediate products in the value chain¹²⁵. Figure 29 presents bisphenol A value chain.

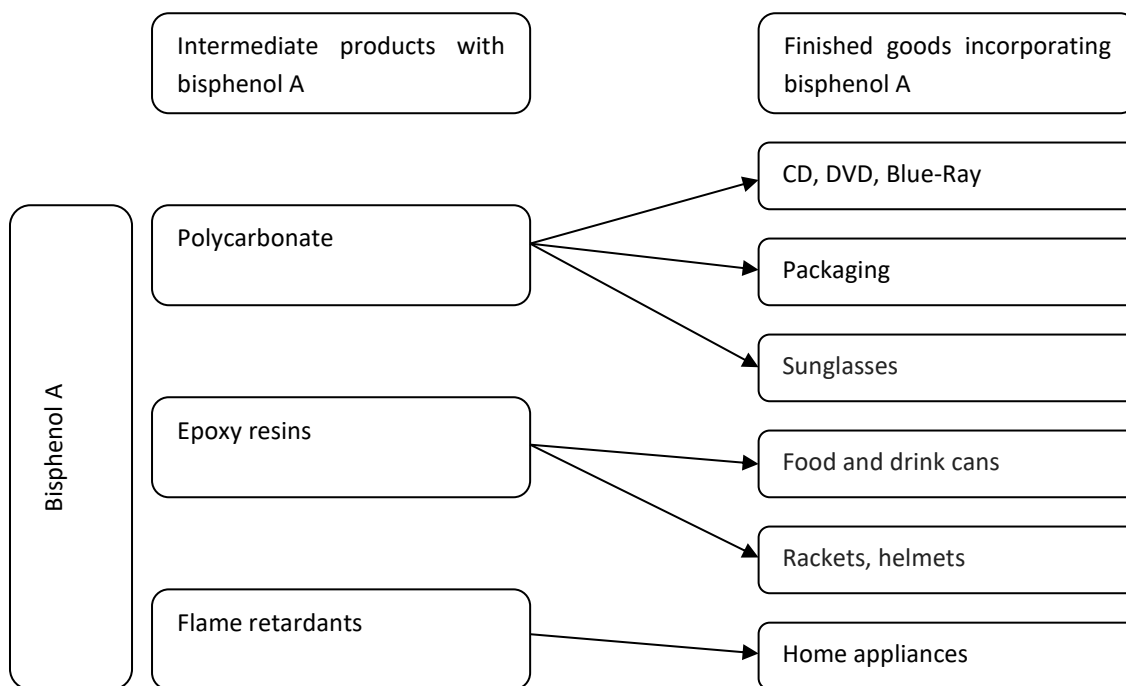


Figure 29. *Bisphenol A value chain: from bisphenol A to products containing BPA (selected products)*

Source: *Ostapchuk, based on (Brignon & Gouzy, 2010)*

5.5. Bisphenol A: health and environmental concerns

In 1993, some of the first publicly available evidence of “unsuspected estrogenic activity” of bisphenol A was revealed by Krishnan et al. (1993). The authors raised concerns about BPA release into the environment from polycarbonate (PC) goods. Since then, a large quantity of studies has investigated endocrine-disrupting properties of BPA. Bisphenol A may influence the processes regulated by endocrine system and as a result activate or stop hormonal responses (Flint, Markle, Thompson, & Wallace, 2012; Møller et al., 2012). Endocrine disruptors might cause “reduced fertility and increased progression of some diseases, including obesity, diabetes, endometriosis, and some cancer” (Yang, Kim, Weon, & Seo, 2015, p. 1). The reproductive toxicity of bisphenol A is a highly researched topic (Flint et al., 2012; Møller et al., 2012). Besides, a positive correlation between incident coronary artery and relatively high level of BPA concentration in urine has been found (Møller & DHI, 2012). BPA may leach into the environment during production, transportation, employment or waste

¹²⁵ Finished goods made from BPA based polycarbonate include CD, DVD, Blue-Ray, packaging, sunglasses. Some examples of finished goods produced from BPA based epoxy resin, which is used as a protective coating, are food and drink cans, rackets and helmets (Brignon & Gouzy, 2010).

disposal stages (Flint et al., 2012). Human beings are mostly exposed through ingestion, for example, through food and beverage cans, sport bottles, food containers. This source of exposure is recognized as a dominant one. The alternative routes of exposure, such as inhalation and dermal contact cannot be excluded, for example, through cashier receipts, dental resin composite. Human exposure to BPA via water and soil is anticipated to be low. However, BPA is found in soil, groundwater and house dust (Møller et al., 2012). Wildlife species exposed to BPA exhibit an effect on “brain, liver, gut, adipose tissue, endocrine pancreas, mammary gland and reproductive tract and function, etc.”, the effect is reported to be dose and age-dependent (Fenichel, Chevalier, & Brucker-Davis, 2013). Although, it is characterized as toxic, its bioaccumulative potential is low (Møller et al., 2012).

Canada was the first country that imposed a ban on infant feeding bottles containing polycarbonate and it preceded the EU which limited the use of BPA in baby bottles in 2011. According to Stone et. al (2010), in the USA, over 20 States restricted the use of polycarbonate containing BPA in baby bottles production in 2010 and, eventually, the U. S. Food and Drug Administration (FDA) prohibited its use in infant bottles in 2012 and infant formula packaging in 2013. Moreover, China, Malaysia, Argentina, Brazil and Ecuador banned the use of BPA in infant feeding bottles (Seltenrich, 2015). However, the main reason behind this ban indicated on the FDA website is “based on abandonment”. In addition, FDA emphasizes that this decision is not related to the safety issue. Similarly, one of the latest explanations of the European Food Safety Authority concerning safety states that there is no health risk to human (including pregnant women and the elderly) related to BPA due to the low level chemical exposure existing now. However, this scientific opinion was published in 2015 which is beyond the period of our analysis, and therefore it could not have had impact on the results of our study. The timeline for major events in bisphenol A history is presented in Figure 30.

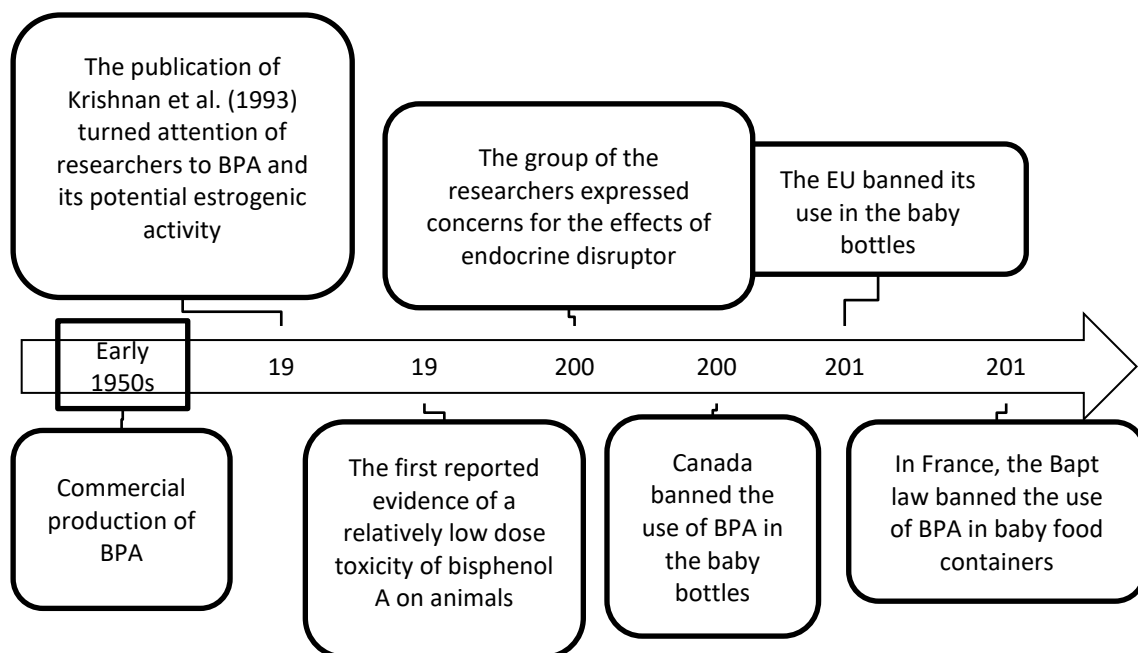


Figure 30. Timeline for major events: bisphenol A¹²⁶

Source: Ostapchuk, based on Krishnan et al. (1993), Stone et al. (2010) and Vogel (2009)

Several studies (Nakanishi, Miyamoto, & Kawasaki, 2007; Stone, Ruoff, Galland, & Passoff, 2010) provide evidence that some companies started replacing BPA in plastic baby bottles voluntarily due to concerns raised by the public. Furthermore, several companies have begun the replacement of food and beverage containers for specific products and a few more companies have made public commitments to phase out BPA from cans (Stone, Ruoff, Galland, & Passoff, 2010).

5.6. BPA consumption pattern

While several studies raised public concern over the impact of BPA on health and several bans on its use for production of specific goods were imposed, the world consumption of BPA rose from 2730 thousand metric tons in 2000 to 5169 thousand metric tons in 2013. This increase can be explained by economic growth and new applications of polycarbonate in medical and automotive industries (based on Sriram, Smith, & Feng, 2014). Figure 31 presents bisphenol A consumption in the following regions: North America, South America, Western Europe, Commonwealth of Independent States (CIS) and Baltic States, Middle East and Africa, Indian Subcontinent, Northeast Asia and Southeast Asia over the 1990-2013 period. It shows a large variation in the evolution of BPA consumption across these regions. Over the studied period, the minimum actual consumption of BPA is recorded in Central Europe in 2003 and the

¹²⁶ <https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000022414734>, accessed in June, 2016

maximum one is observed in China in 2013. Figure 31 shows that in 1990 North America, Western Europe and Japan are the largest consumers of BPA with BPA consumption higher than the overall mean over the studied period. However, at the end of the analyzed period these three regions weaken their positions of the largest consumers. The CIS countries, South America, the Indian Subcontinent and Central Europe remain comparatively low BPA consumption regions. During the studied period, they do not reach the global mean consumption over the period. According to the IHS report (2014), there is almost no capacity constraint over the studied period.

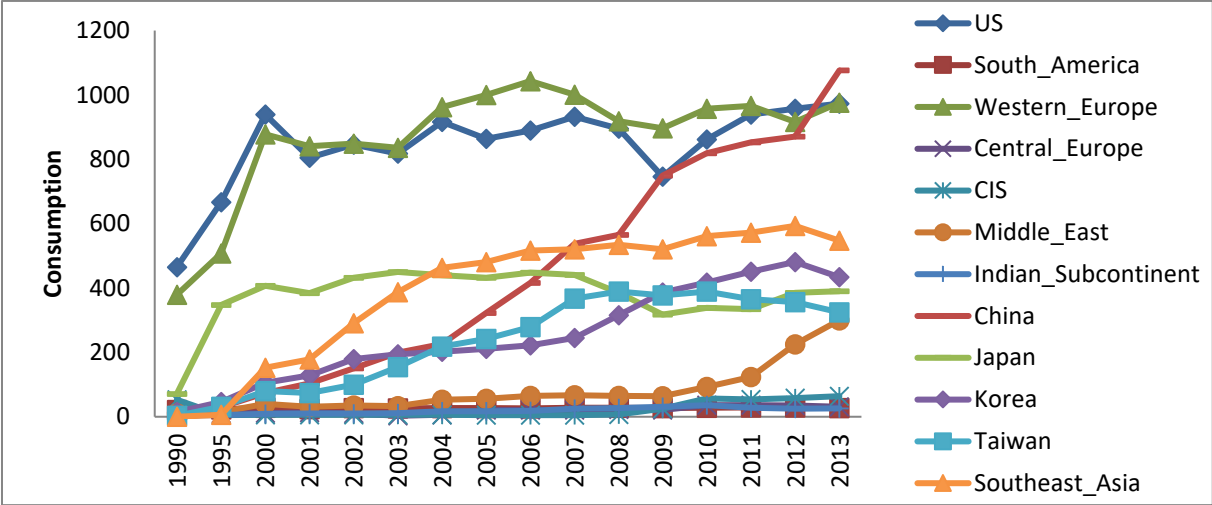


Figure 31. Annual consumption of BPA, 1990-2013, thousands of metric tons
 Source: Ostapchuk, based on the IHS report (2014)

5.7. New scientific knowledge: variable construction

Whereas various sources of information that might affect the consumption of bisphenol A are available nowadays, a primary channel of information related to potential risk remains scientific literature. Scientific reports on bisphenol A are accessible online through the publications of biomedical journals. Consumers and producers might not have full access to all published reports and articles, but digital libraries provide abstracts for most articles which are easily accessible to everyone and they often contain findings. Besides, scientific journals are available through public libraries in paper or digital formats. What is more, scientific findings are communicated through different media channels when an issue turns into a social problem (Jin & Han, 2014).

Some of the mass media (the press) also encourage the public to visit scientific databases for confirmation of the existence of literature exploring the bisphenol A problem. This suggests that one of the main sources of information on BPA that the media uses is scientific literature.

One of the search engines covering this issue, frequently referred to in the daily press, such as “Le Monde” is PubMed (Foucart, 2015). Indeed, PubMed¹²⁷ provides citations for a large quantity of life science and biomedical studies from the MEDLINE database and other scientific journals.

We therefore collected data on scientific BPA reports from the PubMed website which can be accessed directly by different stakeholders. We are interested in the global volume of scientific articles as they are accessible worldwide and published in English^{128,129}. The quantity of these reports available over the studied period serves as a proxy for available information to producers and final consumers of products containing BPA on potential risks of BPA. Therefore, the constructed variable is suitable for our analysis. First, epidemiology and toxicity (which corresponds to EP and TO abbreviations in the PubMed search engine) were the categories used for identifying bisphenol A studies¹³⁰. The two searches using the keyword “Bisphenol A” together with “EP” and “TO” separately were conducted separately and resulted in 122 and 1474 articles, respectively¹³¹. While “toxicity” and “epidemiology” were natural keyword choices given our interest in potential adverse effects of estrogenic substances, literature search based on these keywords excluded the one of the first articles mentioning the possible impact of polycarbonate on health, namely Krishnan et al. (1993). Thus, we corrected the set of keywords and another round of search was run containing keywords such as bisphenol A and endocrinology in addition to “EP” and “TO” searches. It resulted in 127 articles, including Krishnan et al. 1993.

The first step in the actual analysis consists in appending all these datasets and deleting the articles which appear more than once. After appending, 90 articles are detected as repeating ones and they are deleted, decreasing the data set to 1633 non-repeating articles. The second step consists in identifying the articles related to the issue of potential danger/risk to health/environment associated with BPA by reading the available abstracts. 1468 abstracts

¹²⁷<http://www.ncbi.nlm.nih.gov/pubmed>

¹²⁸ The assessment of the publications’ quality is beyond the scope of this study, we anticipate that potential and existing consumers can be affected by the volume of published scientific articles about a specific topic.

¹²⁹ English is chosen as it can be considered as the language of science. We assume that articles published in English represent the current state of knowledge concerning BPA. Due to the number of countries included in our analysis, we do not search for scientific publications in other languages. One of the possible limitations is an understanding of scientific articles published in English as the percentage of English speakers varies from country to country.

¹³⁰The abstracts and summaries were extracted on March, 2015.

¹³¹ All abstracts corresponding to this search were saved in text file. The FLink option was used to save Authors, PubDate(Year), PubDate(Month), Title and Summary in the csv format. This format does not include abstracts, but it is useful for our analysis to work with afterwards.

are manually analyzed covering the 1960 – 2013 period, given that international bisphenol A consumption is available until 2013.

We are interested in constructing annual variables containing information about potential risks of BPA in order to perform the analysis of bisphenol A at international level and monthly variables to conduct the analysis of the Japanese data¹³² (which is transformed into quarterly data afterwards). Articles with abstracts which are not about bisphenol A (either not containing the keyword bisphenol A or concerning one of the following product: DGEBA, Bis-GMA, BADGE¹³³, and substitutes of BPA) or with abstracts not directly related to the issue of risk (e.g., discussing existing methods for assessing the risk without mentioning potential dangerous/non-dangerous effects of bisphenol A or discussing the identification or validation of biomarkers) are disregarded. Although risk assessment incorporates exposure assessment, abstracts about exposure to BPA with no indication of absence or presence of potential danger are considered as not directly related and they are excluded from the analysis.

The remaining abstracts are assigned to three groups, namely “Risk”, “No risk” and “Uncertain”. The first group “Risk” consists of abstracts on potential risk/danger to health/environment associated with bisphenol A/BPA. The second group “No risk” is composed of the abstracts concluding that there is no potential risk to health/environment associated with BPA. The third group “Uncertain” comprises the abstracts which are about potential risk of BPA, but the findings of the research are not indicated in the abstract or their meaning is unclear (for example, if they state some effects without indicating whether they are harmful or not) or the author(s) could not reach a conclusion. Besides, this group includes comparative studies and the studies on combined-effects of BPA and other substances. We assign these studies to this group to avoid misinterpretation of the individual effect of bisphenol A as results of additive combination effects are usually reported. Additionally, the papers reviewing other studies on BPA risk are assigned to this group as their authors can be selective in the literature used (and sometimes their selection criteria are not well explained).

¹³² Date of publication is presented by two columns in the initial dataset: year and month. If month is absent, December is chosen as a month of publication as the article is available in the end of the year whatever the month of publication. If two months are indicated as months of publication, then the later one is chosen as the month of publication. For example, May-June, then June is chosen.

¹³³ DGEBA (or BADGE or bisphenol A diglycidyl ether) is the most commonly used epoxy resin made from Bisphenol A and epichlorohydrin (Brignon & Gouzy, 2010). BPA can be present as an impurity during the production of Bis-GMA (or bisphenol A-glycidyl methacrylate) dental materials (Brignon & Gouzy, 2010).

Given that the analysis and classification of the scientific abstracts is conducted by the author, a minor bias is possible in the interpretation of the meaning of the findings reported in the abstracts with respect to the presence or absence of risk (which might provoke additional uncertainty in our analysis). It can be partly because contradictory messages can be communicated. Thus, in order to detect such a potential bias, the abstracts were re-reviewed through a short questionnaire assessing how a sample of abstracts is interpreted by others (see Appendix E). None of the participants had an expert knowledge of BPA risks/danger before completing this questionnaire. The result suggests that 80 % of abstracts were evaluated in the same manner as the author did. The remaining 20% of abstracts were assigned by the majority to the different categories¹³⁴. The reason is that these abstracts were either comparative studies or reviews, they are categorized by the author of this article as “Uncertain” given that the authors of these abstracts chose the set of studies to review which might represent one side of the issue.

The use of our BPA variable which includes “Risk”, “No risk” and “Uncertain” groups helps to partially eliminate the potential bias. Therefore, we construct a variable, “BPA”, which includes scientific articles from group 1, 2 and 3, namely “Risk”, “No risk” and “Uncertain”. Thus, we do not consider the articles which are not directly related. We use “BPA” as a measure of scientific knowledge about potential risks of BPA in both studies (Chapter 5 and Chapter 6). Then, to complete our analysis, we use alternative measures of scientific knowledge, namely “Risk”, “No risk” and “Uncertain” (this step is only related to global consumption study presented in Chapter 5). We examine their influence on under-consumption of BPA by applying two approaches, namely PCA and lowess. The variables “BPA”, “Risk”, “No risk” and “Uncertain” are transformed in logarithm adding 1 to the data prior to transformation due to absence of the articles categorized under one of the categories mentioned above in the years 1990 and 1995.

According to this framework, over the 1960-2013 period, a cumulative number of papers classified under groups “Risk”, “No risk” and “Uncertain” is 464, 120 and 334, respectively (see Figure 32). The overall number of the evaluated abstracts is 1469.

¹³⁴ Twelve respondents participated in the questionnaire. Given that all participants are non-native English speakers, the question about their level of English proficiency is included in the questionnaire. 75% of respondents self-evaluated their level as “fairly confident user”. A group of participants were provided with 10 arbitrary chosen abstracts representing the main categories depicted by the author. The participants were asked to read each abstract and to choose whether each abstract was about potential risk(s)/no risk/impossible to choose with an option to explain their choice.

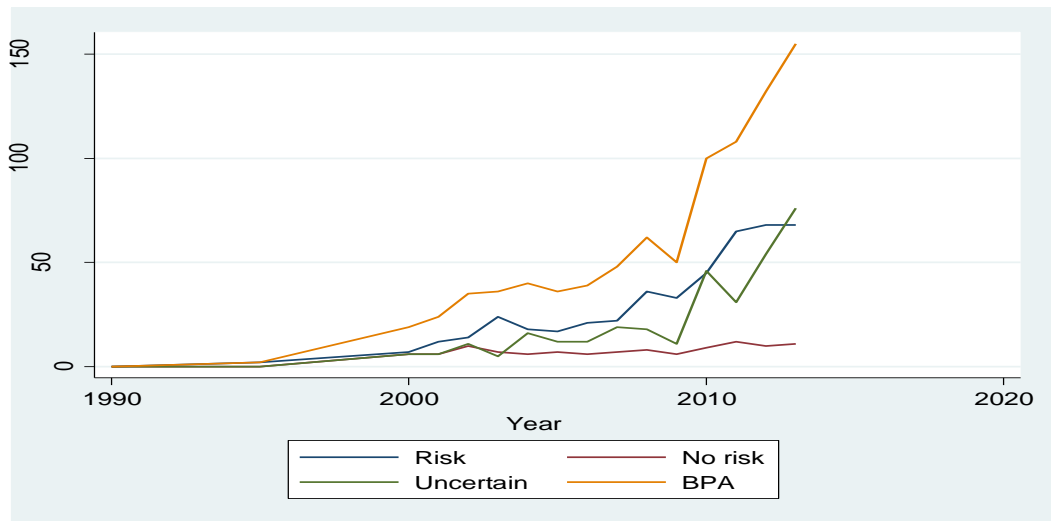


Figure 32. Quantity of scientific articles assigned to group “Risk”, “No risk”, “Uncertain”, “BPA”, 1990 – 2013

Source: Ostapchuk, based on the PubMed

Chapter 6. Bisphenol A consumption, economic growth and new scientific knowledge about risk

This chapter has two goals. The first one is to explore the link between bisphenol A consumption and economic growth. The second goal is to analyze the relationship between new scientific knowledge about risk on over- and under-consumption of bisphenol A. To construct a measure of over- and under-consumption of bisphenol A, we begin by estimating a reduced form model that includes income as explanatory variable. We extend this model by industry- and country-specific factors. The residuals from this model serve as an indication of over- and under-consumption of bisphenol A.

Increased understanding of the phenomenon of under-consumption may not only be useful for managers in their inventory planning, but also contribute to the emerging literature on the management of uncertainty. Given that the impact of risk and uncertainty on innovation is crucial to strategic planning (Olson et al., 2014) this study might also help to bridge the gap in the existing literature on this subject. Moreover, very little research is available regarding the issue of rejection of innovation in a situation of uncertainty about environmental and health risks. The under-consumption can be an alternative indicator of rejection at the decision stage or discontinuance at the confirmation stage in the Model of Five Stages in the Innovation-decision Process of (Rogers, 2003) or slowdown of a product's life cycle of (Golder & Tellis, 2004) at international level. This study helps to identify additional factors that influence adoption/rejection of innovation.

The chapter is organized as follows. First, background information on the Environmental Kuznets Curve is provided. Second, hypotheses regarding other factors influencing BPA consumption and under-consumption are formulated. Third, data on bisphenol A and the other variables is described and our methodology is discussed. Finally, estimation results are presented.

6.1. Background information on the Environmental Kuznets Curve

First, we investigate if the large variation in the consumption of bisphenol A can be explained by economic growth together with market-level, cultural and industry factors, information access and introduced policies. Second, we examine if under-consumption of bisphenol A can be associated with new scientific knowledge about potential risks of BPA.

There is a large empirical literature on the link between environmental degradation and income that started with the article of Grossman and Krueger in 1991 (Gene M Grossman & Krueger, 1991). It was one of the first articles examining the Environmental Kuznets Curve. The quantity of articles analyzing this relationship has been increasing since the publication of their paper¹³⁵.

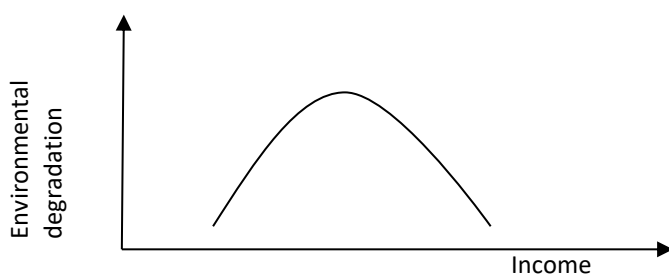


Figure 33. *Environmental Kuznets Curve (an inverted U-type link)*

Source: Dinda (2004)

The Environmental Kuznets Curve represents an inverted U-type link between economic growth and environmental degradation that is a long run relationship (Figure 33). Environmental quality decreases as income per capita increases up to a threshold where the environmental quality impact improves with higher income. Different environmental quality indicators are used in the empirical literature to test the hypothesis, namely air quality (sulfur dioxide, carbon dioxide), water quality (oxygen regime, pathogenic contamination, heavy metals), water use, waste, pesticide use, etc (Dinda, 2004; G. M. Grossman & Krueger, 1995; D. Katz, 2015; Stanchi, 2014). One of the explanations of the inverted U-type relationship is the process of economic development from agricultural to industrial economy, and then to service and information economy. The process is often accompanied by growing level of environmental consciousness, introduction of new environmental policies, higher environmental spending and technologies that are less harmful to environment (Arrow et al.,

¹³⁵ The ScienceDirect search using "Environmental Kuznets Curve" keywords results in 1814 articles, March 2016

1995; Panayotou, 2003). Thus, higher income might be associated with environmental improvements.

The theoretical framework behind the empirical studies on Environmental Kuznets curve can be based on a simple one-sector model that entails a consumption of a product and an abatement of its side-product. The model of Andreoni & Levinson (2001) begins with the idea that an agent maximizes utility that depends on consumption of one good and its byproduct that is pollution. The byproduct depends positively on consumption and negatively on “environmental effort” that is pollution reduction effort (Andreoni & Levinson, 2001, p.271). The maximization is subject to resource (income) constraint that can be expended on consumption and pollution abatement/prevention. Using Cobb-Douglas framework (abatement function), the authors show that an inverse U-type relationship between income and pollution/side-product/environmental degradation is possible if pollution abatement has increasing returns to scale. The authors explain Environmental Kuznets curve (EKC) by technological relationship between consumption and pollution given that consumption is a source of pollution and pollution abatement spending improves the situation. If abatement exhibits increasing returns to scale, high-income agents can consume more with less side-effects. At higher level of income, a society has a greater ability to abate the impact of environmental degradation. New technologies can offer great benefits to society, but they could pose serious environmental and health risks. Their side-effects might be unknown in the early stages of product life cycle. Increasing scientific evidence of potential undesirable effects of new product might have an important effect on the rise of public concerns. If the environment is considered as a normal good, increase in income may boost higher environmental expenditure and environmental regulations (Dinda, 2004; Smulders & Bretschger, 2000). Otherwise, the production/generation of byproducts can be limited/reduced by the choice of consumption of the main product (or input) by producers and final consumers which might result in less harm (Gene M Grossman & Krueger, 1991). As income increases, people become more concerned about environment and health which might put more pressure for environmental and health regulations (Dasgupta, Laplante, Wang, & Wheeler, 2002; Dinda, 2004; Ghimire & Woodward, 2013). Andreoni & Levinson (2001) do not question the necessity of environmental regulations. The authors state that before introducing new regulations, a link between byproducts and income should be studied.

Relatively little is known about the link between GDP per capita and BPA consumption per capita. Sriram et al. (2004) indicates that consumption of bisphenol A is affected by demand for epoxy resin and polycarbonate which is influenced by “overall health of economy”. GDP can serve as a proxy for the state of economy. GDP per capita or GNP per capita is often used as a proxy for country’s wealth (Chandrasekaran et al., 2013; Chandrasekaran & Tellis, 2008; Tellis et al., 2003). Most of the studies on the diffusion of new products find a positive link between time of adoption and income (Horbach, Chen, Rennings, & Vögele, 2014).

In addition to potential environmental risks, major potential health risks are associated with BPA ingestion, for example, through contaminated food from the plastic packaging containing BPA. A reduction in BPA consumption can be associated with the choice of consumers/producers to decrease undesirable side-effects by limiting its usage or replacement by other products. An input/resource, such as BPA, can be used as an indicator of potential environmental degradation. Therefore, we would like to test the hypothesis that BPA use might first increase as income increases given that BPA is a normal good, and then decrease with a rise in income per capita (together with scientific evidence of potential risks of BPA and health/environmental concerns), that is an inverted U-shaped relationship. However, (Dinda, 2004) states that the inverted U-pattern can be observed if a direct relationship between environmental indicator/byproducts and health is widely recorded and known. Therefore, uncertainties surrounding potential environmental and health risks might result in other form of BPA-income relationship. Thus, we will analyze the relationship between bisphenol A consumption and economic growth. To examine BPA-income link, we analyze panel dataset on BPA consumption at international level, rather than environmental emission levels due to unavailability of data.

Another explanation of the EKC is the Displacement Hypothesis (Dinda, 2004) that is closely related to international trade. According to this hypothesis, the EKC reflects a replacement of dirty industries from more developed to less developed countries where environmental policies are less severe. One of the policies that can be relevant to this analysis is a ban on BPA use in production of baby bottles (we have discussed this ban in Chapter 5). This ban might lead to the displacement of production of BPA to less developed countries. While we do control for introduction of bans introduction on BPA use in production of baby bottles in several regions, we do not take into account international trade factor in the analysis given

that most of the bans were introduced in the end of studying period, thus the displacement effect could not be observed (in addition to lack of data on baby bottles).

6.2. Hypotheses: impact of economic growth and other factors on BPA consumption

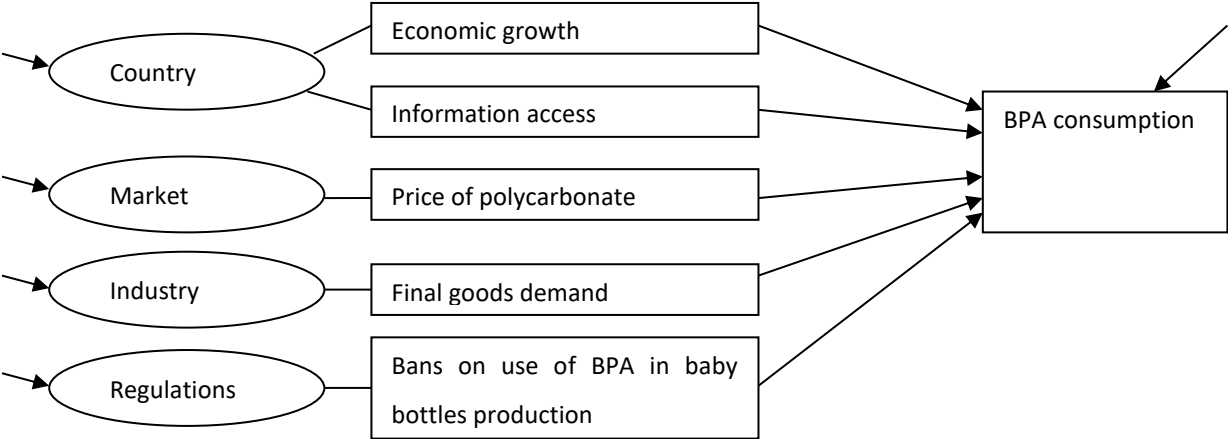


Figure 34. A conceptual framework for the factors influencing BPA consumption (Model)
Source: Ostapchuk

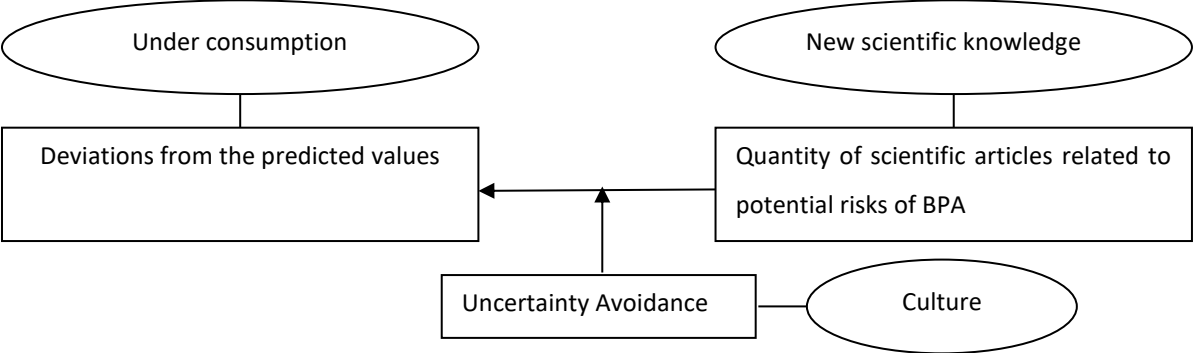


Figure 35. A conceptual framework for the impact of new scientific knowledge on under consumption of bisphenol A
Source: Ostapchuk

We begin this subsection by developing a conceptual framework for a cross-regional analysis (Figure 34). It is based on the empirical studies examining the Environmental Kuznets curve together with the literature on the international diffusion of innovation. The reason is that we use BPA consumption as a dependent variable. BPA is an industrial intermediate good which can be used as an indicator of environmental quality of an undesired environmental impact. Most of the EKC literature use different environmental indicators as dependent variables.

Most of the diffusion of innovation literature use sales of product to construct dependent variables. The set of independent variables includes economic, market-level, cultural and industry factors, information access and introduced policies. We focus on the studies which investigate factors affecting different stages of the product life cycle (Chandrasekaran & Tellis, 2008; Chandrasekaran, Arts, Tellis, & Frambach, 2013; Dekimpe, Parker, & Sarvary, 2000a, 2000b; Kauffman & Techatassanasoontorn, 2005; Tellis, Stremersch, & Yin, 2003). The reason is that over the studied period the majority of regions are in the transition from the growth to the maturity stage with respect to BPA use as we have discussed in Chapter 4. We thereafter develop a set of hypotheses that will help us to evaluate the impact of economic growth and other drivers on BPA consumption, and then the volume of new publications on its over- and under-consumption. The hypotheses are presented in Table 18.

Table 18. Hypotheses for effect of factors influencing BPA consumption

Variable	Reasoning	Hypothesized effect on BPA consumption
Country variables		
GDP growth	Discussed in the previous subsection.	H1. BPA use might first increase as income per capita increases given that BPA is a normal good, and then decrease with a rise in income per capita
Information access	Two sides of information access should be considered. First, level of information access in industry has a positive effect on BPA consumption as it spreads information about its potential applications and the process of their production, new products containing BPA, thus, raising awareness about numerous products. That is why it might be expected that new products are consumed more in regions where media intensity is higher (Chandrasekaran & Tellis, 2008; Tellis et al., 2003). However, information access together with economic growth influences social policy decisions and introduction of environmental regulations (Dinda, 2004). However, introduced bans are currently related to some of the products containing BPA.	Therefore, H2. Consumption of bisphenol A per capita is positively affected by the level of information access
Industry-specific variable		

Variable	Reasoning	Hypothesized effect on BPA consumption
<p>Possession of CD and DVD players (used as proxies for CD/DVD use)</p> <p>Passenger Cars in Use</p>	<p>Bisphenol A is an input, therefore it depends on the demand for final goods (passenger cars, packaging and CD/DVD).</p>	<p>H3. The higher the demand for final goods, the higher consumption of bisphenol A.</p>
Market		
<p>Price variable (we use polycarbonate transparent price as a proxy of BPA price given that BPA is used in the production of polycarbonate)</p>	<p>Polycarbonate and epoxy resin are relatively inexpensive material (for example, compared to glass). A relative increase in price may lead to decrease of input attractiveness (Chandrasekaran et al., 2013). However, the cost of these intermediate inputs (PC and ER) produced using BPA is negligible in the production cost of the final good. Besides, material substitution can be very costly. Therefore, undramatic price changes should not change BPA consumption significantly. Besides, Jiang et (2015) explain a lower volatility of plastics by the fact that they can be easily put in storage and changes in price can be postponed until the crude oil market stabilizes.</p>	<p>H4. Higher price slightly decreases BPA consumption.</p>
Regulatory policies		
<p>Bans</p>	<p>While the bans on bisphenol A use in the EU, China, Brazil, Malaysia and the USA intend to limit its use in several applications, the consumption of bisphenol A related to the banned applications should decrease as a consequence of the introduced policies. While we expect negative effects of these policies on the use of BPA in baby bottles production, the size of these effects on overall consumption of BPA might be really insignificant due to voluntary replacement of BPA and the other countries before the bans introduction and wide usage of BPA. Moreover, these bans do not concern the majority of BPA applications. On the other hand, the bans on some of the applications might suggest that the other applications are relatively safe (as they haven't been banned) together</p>	<p>H5. The effect of policies on BPA use in baby bottles productions in the EU, China, Brazil, Malaysia and the US on aggregate consumption of BPA is ambiguous</p>

Variable	Reasoning	Hypothesized effect on BPA consumption
	with new uses of plastic and, as a result, an overall BPA consumption may increase	

Source: Ostapchuk

6.3. Hypotheses: under- and over-consumption of bisphenol A

The goal of the model is not only to assess impacts of economic growth on BPA consumption, but also to explain the variation in BPA consumption due to macroeconomic and industry-specific factors controlling for time-effects at international level. Following Ghimire & Woodward (2013), over and under-consumption of BPA can be measured as deviation from the predicted values (fitted values) from the basic model. Contrary to their model, macroeconomic factors are included in the basic model given their importance in explaining the variations in BPA consumption. If the region's actual consumption is below the fitted value from the basic model, it may indicate under-consumption of bisphenol A (if the model is correctly specified)¹³⁶. If it is above the fitted value, it may show overconsumption of BPA. The more negative the deviation from the predicted values, the larger under-consumption. It might suggest that a region uses less of bisphenol A in order to reduce environmental and health effects of bisphenol A.

Under-consumption can be an alternative indicator of rejection at the decision stage or discontinuance at the confirmation stage in the Model of Five Stages in the Innovation-decision Process of (Rogers, 2003), or slowdown of product's sales growth in the product's life cycle theory of Golder & Tellis (2004) at international level. Slowdown is a turning point of a product's life cycle and it is "the beginning of a period of level, slowly increasing, or temporarily decreasing product sales after takeoff" (Chandrasekaran & Tellis, 2007b; Ranganath, 2012). It is suggested that consumers might be disillusioned with innovations as a consequence of new scientific knowledge about their safety (hazard) and harmful side-effects (Rogers, 2003).

Following our discussion on the role of new scientific knowledge in Chapter 1 and Chapter 3, we introduce another hypothesis,

H6: The higher the number of scientific articles related to potential risk of BPA in a situation of uncertainty about environmental and health risk, the greater the under-use of BPA.

¹³⁶ "The results of regression analysis are conditioned upon the chosen model" (Gujarati, 2004, p. 74)

At the knowledge stage, a decision-making unit discovers that an innovation exists and how it works. At the confirmation stage, the decision-making unit may reverse the decision to adopt or reject the innovation if new evidence which conflicts with previous findings of innovation is introduced causing the decision maker to reconsider the innovation. Knowing about an innovation or receiving new information about it does not necessarily lead to the decision and/or confirmation stages. Characteristics of the decision-maker are important at this stage of the decision-making process (Rogers, 2003). One of the characteristics is culture. Prior international studies have focused on such cultural variables as uncertainty avoidance index, industriousness, religiosity, number of ethnic groups (Chandrasekaran & Tellis, 2008; Dekimpe et al., 2000a, 2000b; Tellis et al., 2003).

Based on the fact that bisphenol A is associated uncertainty about potential environmental and health risks, the uncertainty avoidance index is of particular interest to this study. As we have discussed in Chapter 2, it refers to the capacity of a society to tolerate uncertain conditions. Given that such country characteristics as economic and information access variables are included in the basic model together with country and time fixed effects, at this stage we examine an effect of specific cultural variable on the relationship between new scientific knowledge and under-consumption. We expect that regions with higher uncertainty avoidance use less products and intermediate goods under uncertainty as they are less willing to take potential risks (a positive relationship between uncertainty avoidance and under-consumption of BPA). We also hypothesize that uncertainty avoidance will have a moderating effect on the relationship between scientific knowledge about potential risk and over and under-consumption of bisphenol A in the situation of uncertainty about environmental and health risk. Thus,

H7: There will be a positive interaction between under-consumption of BPA, quantity of scientific articles related to potential risks of BPA and uncertainty avoidance. Specifically, higher uncertainty avoidance will be associated with a more positive relationship between scientific knowledge about potential risk and under-use of BPA. Figure 34 presents a conceptual framework for the impact of new scientific knowledge on under consumption of bisphenol A.

6.4. Methodology: bisphenol A modeling

This subsection discusses the empirical methodology of this chapter. A summary of the methodology is presented in Table 19, followed by detailed description of each step.

Table 19. Summary of the empirical methodology

Steps	Methods
5.4.1. Reduced form model	<ul style="list-style-type: none"> - the pooled OLS, - the fixed effect estimation procedure, - the random effect estimation procedure, - the Breusch-Pagan Lagrange multiplier test, - the Sargan-Hansen version of the test for random effect vs fixed effect, - the test for heteroscedasticity, - the comparison of RE GLS with robust standard errors and the Feasible Generalized Least Squares with heteroscedastic error structure if heteroscedasticity is present, - the local scatter plot smoothing technique
$Bisphenol_{it} = \beta_0 + \beta_1 Inc_{it} + \beta_2 Inc_{it}^2 + \beta_3 Inc_{it}^3 + \alpha_t Year + (u_i + v_{it})$ <p>where $Bisphenol_{it}$ denotes consumption of bisphenol A per capita on the log scale in region i at time t, Inc_{it} is the log of GDP in region i at time t, Year is a set of dummy variables, β_0 is a constant, $\beta_1, \beta_2, \beta_3$ are elasticity coefficients, α_t is a vector of coefficients of year dummy variables, u_i is an unobserved time-invariant region effect that impacts BPA consumption and v_{it} is an idiosyncratic error.</p>	
5.4.2. Extended form model: additional predictors selection	<ul style="list-style-type: none"> - PCA - the Wald test - cross validation
<p><i>Information access:</i> possession of broadband internet enabled computer; possession of personal computer; possession of satellite tv system; possession of cable tv</p> <p><i>Industry-specific variables:</i> possession of cd player; possession of dvd player/recorder, passenger cars in use</p> <p><i>Market variable:</i> PC transparent price</p>	
Extended form model: different estimation approaches	<ul style="list-style-type: none"> - the fixed effect and random effect (including the Breusch-Pagan Lagrange multiplier test and the Sargan-Hansen test adjusted to allow for the presence of heteroscedasticity), - the heteroscedasticity test
$Bisphenol_{it} = \beta_0 + \beta_1 Inc_{it} + \beta_2 Inc_{it}^2 + \beta_3 Inc_{it}^3 + \alpha_t Year + \beta_4 X_{it} + (u_i + v_{it})$ <p>X: country characteristics, market characteristics industry characteristics, regulations</p>	
5.4.3. Over- and under-consumption of bisphenol A: test for endogeneity	Regional totals for R&D expenditure at world level as an instrumental variable for global volume of scientific articles
Over- and under-consumption of bisphenol A: analysis	<ul style="list-style-type: none"> - PCA - local scatter plot smoothing technique

Steps	Methods
5.4.4. Policy analysis	Method selected for the extended model
$Bisphenol_{it} = \beta_0 + \beta_1 Inc_{it} + \beta_2 Inc_{it}^2 + \beta_3 Inc_{it}^3 + \alpha_t Year + \beta_4 X_{it} + DD2011 + DD2012 + (u_i + v_{it})$ DD2011=1 if the region belongs to the EU, China, Brazil or Malaysia after 2011, 0 otherwise DD2012 =1 if the entity is the US after 2012, 0 otherwise	

Source: Ostapchuk

6.4.1. Reduced form model

With the aim of exploring the impact of economic growth on BPA consumption, we start with a reduced form model of the Environmental Kuznets curve (which includes only income, its quadratic and cubic terms as explanatory variables):

$$Bisphenol_{it} = \beta_0 + \beta_1 Inc_{it} + \beta_2 Inc_{it}^2 + \beta_3 Inc_{it}^3 + \alpha_t Year + (u_i + v_{it}) \quad (1)$$

where $Bisphenol_{it}$ denotes consumption of bisphenol A per capita on the log scale in region i at time t , Inc_{it} is the log of GDP in region i at time t , $Year$ is a set of dummy variables, β_0 is a constant, $\beta_1, \beta_2, \beta_3$ are elasticity coefficients, α_t is a vector of coefficients of year dummy variables, u_i is an unobserved time-invariant region effect that impacts BPA consumption and v_{it} is an idiosyncratic error.

Year dummies are included for each but one year in the analysis. They capture the effect of common time-varying variation that can be driven, for instance, by recession. The unobserved region fixed effect includes factors influencing BPA consumption that are time-invariant (or very slow to change), such as region location, demographic characteristics, etc (Wooldridge, 2013). Then we will extend this model by country (information access), industry and market characteristics (Chapter 6.4.2 and 6.4.6).

The Environmental Kuznets curve is an inverted U-shaped relationship which corresponds to the case where $\beta_1 > 0, \beta_2 < 0, \beta_3 = 0$ in model (1). However, the other shapes are possible (Dinda, 2004):

$\beta_1 = 0, \beta_2 = 0, \beta_3 = 0$ no relationship between BPA consumption and economic growth

$\beta_1 > 0, \beta_2 = 0, \beta_3 = 0$ a positive linear relationship between BPA consumption and income

$\beta_1 < 0, \beta_2 = 0, \beta_3 = 0$ a negative linear relationship between BPA consumption and income

$\beta_1 < 0, \beta_2 > 0, \beta_3 = 0$ a U-shaped curve (Figure 36. *U-shaped curve*)

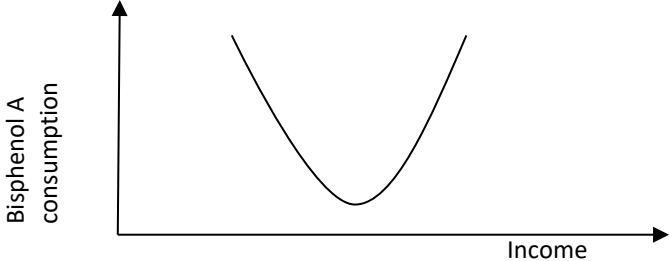


Figure 36. *U-shaped curve*
 Source: Adapted from Dinda (2004)

$\beta_1 > 0, \beta_2 < 0, \beta_3 > 0$ a N-shaped curve (Figure 37)

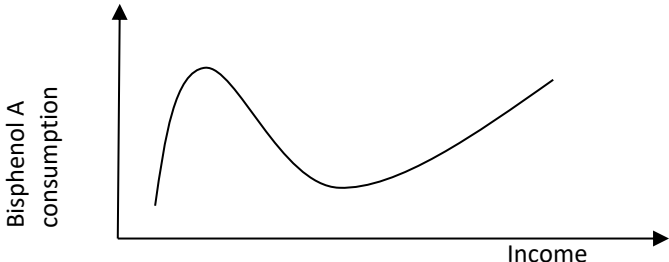


Figure 37. *N-shaped curve*
 Source: Adapted from Dinda (2004)

$\beta_1 < 0, \beta_2 > 0, \beta_3 < 0$ an inverted N-shaped curve (Figure 38)

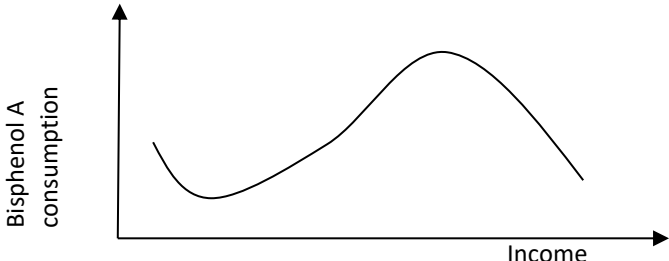


Figure 38. *Inverted N-shaped curve*
 Source: Adapted from Dinda (2004)

Several authors (Dinda, 2004; Koop & Tole, 1999) state that random effect (RE) estimation is appropriate to estimate the relationship between environmental degradation and economic growth based on a panel data. However, the majority of empirical studies on the Environmental Kuznets curve applying panel data methods estimate both random- and fixed effect (Stern, 2004). Both methods can be applied to the panel data with unobserved region effects. The fixed effect (FE) estimator is a pooled ordinary least squares (OLS) estimator based on the time-demeaned data. One of the main assumptions is that u_i is correlated with one or several explanatory variables. It allows to eliminate u_i . If we assume that there is no

correlation between u_i and explanatory variables, the fixed effect transformation will lead to inefficient estimators. Under the assumption of uncorrelated unobserved effect (with explanatory variables), the random effect model can be estimated by random effect generalized least squares (Wooldridge, 2013). Formal tests for differences in the coefficients on the variables which vary over time allow to select random effect or fixed effect after their estimation. The Sargan-Hansen version of test for random effect vs fixed effect can be conducted. It can be considered as a test for overidentifying restrictions¹³⁷. This test can be adjusted to the presence of heteroscedasticity (Wooldridge, 2002) as this problem can arise with random effect or fixed effect models estimation. Regression disturbances are heteroscedastic if their variances are not constant across observations (Greene, 2012, p. 308). The OLS standard errors, t statistics and F statistics are invalid if the assumption of homoscedasticity is violated (Wooldridge, 2013). The literature on EKC shows the heteroscedasticity is often present (Stern 2004, Katz 2015, Ghimire). A modified Wald test for groupwise heteroscedasticity in the residuals can be run to test for heteroscedasticity¹³⁸ as discussed in (Greene, 2000). In the presence heteroscedasticity, corrective procedure should be applied. One of the potential solutions is the White heteroscedasticity consistent estimator that allows to get a correct estimator for the variance in the presence of heteroscedasticity. However, its performance in small size samples is questioned (Greene, 2012). Another solution is the Feasible Generalized Least Squares (FGLS) with heteroscedastic error structure (Greene, 2012; D. Katz, 2015). To find out whether the RE GLS with robust standard errors is preferred to FGLS with heteroscedastic error structure, we can apply a leave one out cross validation or a k-fold cross validation. Under K-fold cross validation, the data is separated into k subsets. A subset of the data is used to fit the model and the other part of it (a validation set) is used to evaluate the performance of the model. “For the kth part (...), we fit the model to the other K-1 parts of the data, and calculate the prediction error of the fitted model when predicting the kth part of the data. We do this for k=1, 2, ..., K and combine the K estimates of prediction error” (Hastie, Tibshirani, & Friedman, 2009, p. 242).

Besides, the usual pooled OLS can be used to estimate the relationship between BPA consumption and economic growth. However, if v_{it} is uncorrelated with our explanatory variables, but u_i is correlated with the explanatory variables, heterogeneity bias arises as a

¹³⁷ <http://fmwww.bc.edu/repec/bocode/x/xtoverid.html>, accessed in 2016

¹³⁸ <http://www.stata-journal.com/sjpdf.html?articlenum=st0004>, accessed in 2016

result of biased and inconsistent parameters. Then, the fixed effect model can be used. If u_i is uncorrelated with the explanatory variables, cross-section data can be used and the random effect model can be estimated by the pooled OLS. However, it is possible only if a sufficiently large cross-sectional dataset is available. Besides, time dimension is ignored in this case. If a panel data set is used, the random effect generalized square procedure (RE GLS) is preferred than the pooled OLS procedure, as RE GLS is usually more efficient (Wooldridge, 2013). The Breusch-Pagan Lagrange multiplier test can be applied to test for the existence of random effects (Baltagi, 2008). Additionally to the fixed effect and random effect, estimation by the pooled OLS can provide further details of the nature of the biases if the unobserved effect is left partially or entirely in the error term (Wooldridge, 2013).

Additionally, we use lowess in order to compare the results provided by parametric and nonparametric techniques. Lowess is associated with a nonparametric regression with less underlying assumption about the functional form of the relationship between economic growth and BPA consumption per capita. Lowess is a local scatter plot smoothing technique, " $(x_i, y_i), i = 1, \dots, n$, in which the fitted value at x_k is the value of a polynomial fit to the data using weighted least squares" where the weight for (x_i, y_i) depends on the position of x_i , namely the closer x_i to x_k , the smaller the weight (Cleveland, 1979).

6.4.2. Extended form model

Another econometric criticism leveled at the EKC studies with panel data is misleading results of OLS as a possible consequence of the presence of unit root. Besides, a test for stationarity is rarely performed in the studies with longitudinal data (Ghimire & Woodward, 2013; Stern, 2004). The existence of non-stationary variables might suggest the need for testing for cointegration. Given that several years are missing in our dataset (1991-1994, 1996-1999) and relatively short time-series, we do not run the test for the presence of the unit root.

Therefore, to estimate the reduced form model of the Environmental Kuznets curve we will proceed in the following way: (1) the pooled OLS, (2) the fixed effect estimation, (3) the random effect estimation, (4) the Breusch-Pagan Lagrange multiplier test, (5) the Sargan-Hansen version of the test for random effect vs fixed effect, (6) the test for heteroscedasticity, (7) the comparison of RE GLS with robust standard errors and the Feasible Generalized Least Squares with heteroscedastic error structure if heteroscedasticity is present, (8) the local scatter plot smoothing technique.

With the aim of constructing a measure of over- and under-consumption of BPA taking a relatively small sample size into account, we estimate the extended version of the EKC. Many empirical studies on the EKC estimate the impact of additional factors on environmental quality (environmental indicators), such as a democracy and a trade openness in addition to the reduced form of the EKC (Dinda, 2004; Ghimire & Woodward, 2013; Stern, 2004). However, the results of these studies are contradictory (Dinda, 2004). Given that our goal is not an estimation of the impact of specific factors, we do not include the democracy and trade openness in the next step. Following (Ghimire & Woodward, 2013), over and under-consumption of bisphenol A can be measured as deviation from the predicted values (fitted values) from the basic model. Contrary to their model, macroeconomic factors are included in the basic model given their importance in explaining the variations in BPA consumption. Thus, in order to explain the variations in BPA consumption at international level macroeconomic, information access and industry-specific factors will be included in the extended model together with time-effects.

We have multiple proxies to measure information access and industry-specific factors which can be used as explanatory variables. This is one of the sources of a multicollinearity problem (exact linear relationship between explanatory variables). For example, a percentage of households possessing internet enabled computers can be closely related to a percentage of households having personal computers. There is no need to include both measures in the model. One of the possible solutions to the problem of multicollinearity is to select a plausible subset of the explanatory variables (Jolliffe, 2002). Given the small sample size and together with the multicollinearity issue, we use a principal component analysis (PCA) to choose a subgroup of predictors. We perform a PCA for the entire sample taking into account all available variables. Then, we estimate the model with the chosen subgroup of predictors together with macroeconomic variables and time dummies applying both fixed effect and random effect. Afterwards, we test the hypothesis that the coefficients on each of these variables are 0 performing Wald test separately for each variable. Additionally, we apply cross-validation procedures to different subsets of variables chosen by the PCA to avoid a potential over-fitting in model selection. It might occur if a model contains an excessive number of factors compared to the size of the dataset (Bilger & Manning, 2015) or if irrelevant variables are included in the model which might have undesirable consequence for the variance of the estimators (Wooldridge, 2013). As soon as the best model in terms of inference and prediction

is chosen, we conduct the heteroscedasticity test and apply the corrective procedure if it is needed. The deviations from this model are used as a measure of over- and under-consumption of BPA. Therefore, to estimate the extended form model of the Environmental Kuznets curve we will proceed in the following way: (1) the principal component analysis¹³⁹, (2) the fixed effect and random effect estimation of the extended model (including the Breusch-Pagan Lagrange multiplier test and the Sargan-Hansen test adjusted to allow for the presence of heteroscedasticity), (3) the Wald test, (4) the cross-validation, (5) the heteroscedasticity test.

6.4.3. Over- and under-consumption of bisphenol A

Before proceeding further (relationship between the quantity of scientific articles related to potential risk of BPA and under-use of BPA), testing for endogeneity is necessary. The concern about endogeneity arises from the fact that a substantial BPA consumption may attract the attention of scientists to the issue of potential risk and as result the overall quantity of scientific reports may increase. In the presence of endogeneity, alternative instruments for scientific knowledge should be chosen to get consistent estimators (for example, in the case of the pooled OLS estimation procedure) or alternative methods should be applied (Gujarati & Porter, 2009). Besides, the results of scatter plots can be misinterpreted. To test for endogeneity, we need an exogenous variable that is not included in the extended model, that is uncorrelated with v_{it} and is correlated with the scientific knowledge (Wooldridge, 2013). We use regional totals for R&D expenditure¹⁴⁰ at world level as an instrumental variable for global volume of scientific articles given that this measure of scientific knowledge varies over time (but not over regions). First, we choose between random effect and fixed effect instrumental variable approaches. Instrumental variable approach allows to treat the explanatory variable as endogenous. As soon as an estimation method is chosen, to test for endogeneity, we compare the following models: the first one treats the quantity of scientific knowledge as endogenous and the second one treats it as exogenous and identifies whether the difference is statistically significant. The test statistics can be adjusted for

¹³⁹ At this step, we choose a subgroup of proxies which are used in our analysis. Additionally, we conduct the Wald test and cross-validation procedures to variables chosen by the PCA.

¹⁴⁰ <http://data.uis.unesco.org/Index.aspx?queryid=74>, accessed in January 2016

heteroscedasticity. The variable is endogenous if the hypothesis that “the specified endogenous regressors can actually be treated as exogenous” is rejected¹⁴¹.

Taking into account previous findings, the next step is to test the hypothesis about the impact of new scientific knowledge on under-consumption of bisphenol A. Given the relatively small sample size and our particular interest in under-consumption of bisphenol A, we do not proceed with a multiple regression analysis using the residuals as a dependent variable from the extended model contrary to (Ghimire & Woodward, 2013). Instead, we rank our regions in order of uncertainty avoidance index. Then, we break them in four equal sized groups from the lowest to highest. Afterwards, we plot these residuals which measure over- and under-consumption against the logarithm of scientific articles related to potential risks of BPA for each group separately. Additionally, we apply a robust locally weighted scatter plot smoothing technique (lowess) to analyze the relationship between under-consumption of bisphenol A and new scientific knowledge.

6.4.4. Policy analysis¹⁴²

Finally, we evaluate the impact of the bans on the BPA use in baby bottles production on aggregate consumption of BPA. We do not expect a substantial improvement in the performance of our model due to policy variables introduction in the model. Besides, policy evaluation is not of primary importance in this study given a wide variety of applications compared to the number of banned applications over the studied period. That explains why we have not evaluated the policy earlier. Policy analysis with panel data requires a construction of a binary variable which equals one if region/country is affected by a ban on BPA use in the baby bottles production in year t and in the subsequent years (equals to 0 otherwise). The regions/countries affected by bans are called treatment group and the ones that are not affected are called control group. In our study the EU, China, Brazil and Malaysia saw the introduction of the ban on the BPA use in 2011 (Møller et al., 2012). Given that the majority of the EU countries are included in Western and Central Europe in our dataset, these two regions are considered as affected. Therefore, DD_{2011} denotes a dummy variable which equals 1 if the region belongs to the EU, China, Brazil or Malaysia after 2011, 0 otherwise.

¹⁴¹ <http://EconPapers.repec.org/RePEc:boc:bocode:s456501>, <http://www.repec.org/bocode/i/ivreg2.html>, accessed in January 2016

¹⁴² We use “the panel data version of the difference-in-difference estimator” (Wooldridge, 2009, p. 464)

Using the same procedure, DD2012 is constructed which equals 1 if the entity is the US after 2012. To evaluate the policy, we include DD2011 and DD2012 in the extended model in addition to the chosen explanatory variables. We use a simple policy evaluation approach that does not take into account the wideness of the scope and the strength of the legislation. To control for other changes that are not connected to this ban, we include year dummies as previously. The model can be estimated by the method selected for the extended model.

To summarize, we will start with a reduced form model of the Environmental Kuznets curve. Next, a subset of predictors will be selected to construct a parsimonious model and the extended version of the EKC will be estimated. Then, the deviations from this model are obtained and used as a measure of over- and under-consumption of BPA. In addition, the test for endogeneity of the quantity of scientific articles is conducted. Next, we analyze the impact of new scientific knowledge on under-consumption of bisphenol A. Finally, to complete our analysis, we evaluate the impact of the bans on the BPA use.

6.4.5. Data sources

For the analysis of the impact of economic growth on bisphenol A consumption per capita together with the effect of new scientific knowledge on under-consumption of BPA at international level, the panel data on aggregate consumption of BPA is used. The data on BPA consumption was bought from the Chemical Economics Handbook: Bisphenol A (2014). The sample includes 9 world regions, namely North America, South America, Western Europe, Central Europe, CIS and Baltic States, Middle East and Africa, Indian Subcontinent, Northeast Asia (including China, Japan and Republic of Korea and Taiwan separately) and Southeast Asia for 1990, 1995, and the years 2000-2013. Given that 4 countries are presented separately, we analyze 12 entities. The list of the countries –consumers of BPA included in the regions mentioned above is presented in Table 58 in Appendix F. It is based on the information provided in the Chemical Economics Handbook: Bisphenol A and a correspondence with the authors of the IHS report (2014). Given that data is available for these regions, explanatory variables were constructed accordingly using country-level data.

The data on explanatory variables is collected/bought from a variety of sources (World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe, etc). The data sources for each variable and their units of measurement are presented in Table 20.

Table 20. Data sources

Variable	Units	Source
Bisphenol A consumption	thousands of metric tons 1990, 1995, 2000-2013, annual	Chemical Economics Handbook: Bisphenol A, IHS Chemical
GDP per capita (except Taiwan); GDP per capita (Taiwan)	current US\$, 1960-2013, annual current US\$, 1991-2014, annual	World Bank Data extracted in January 2016 http://eng.stat.gov.tw/ct.asp?xItem=37408&CtNode=5347&mp=5 Data extracted in July 2015
Productivity	US\$ per person employed, 1990-2014	Passport/ Euromonitor International from International Labour Organisation (ILO)/Eurostat/national statistics Data extracted in July, 2015
<u>Information Access</u> Possession of Broadband Internet Enabled Computer; Possession of Personal Computer; Possession of Satellite TV System; Possession of Cable TV	% of households, 1990-2014, annual % of households, 1990-2014, annual % of households, 1990-2014, annual % of households, 1990-2014, annual	Passport/Euromonitor International Data extracted in December, 2014
<u>Cultural variables</u> Uncertainty Avoidance Index (uai);	scores, a 100-point scale, time-invariant	Geert Hofstede, Gert Jan Hofstede, Michael Minkov, Cultures and Organizations: Software of the Mind. Revised and Expanded 3rd Edition. New York: McGraw-Hill USA, 2010
Possession of CD Player; Possession of DVD Player/Recorder	% of households, 1990 – 2014 % of households, 1990 - 2014	Passport/Euromonitor International from national statistics Data extracted in December, 2014
Passenger Cars in Use	thousands units, 1990 – 2014	Passport/ Euromonitor International from European Automobile Manufacturers' Association (ACEA)/International Road Federation (IRF)/Eurostat/national statistics Data extracted in December, 2014
DD2011 DD2012	Policy analysis dummies that measure policies impact in the EU, China, Brazil, Malaysia and the US, respectively	constructed (discussed above)
PC transparent price (available only for Europe); Exchange rate US dollar (EUR/USD)	PC transparent (EUR/t)	PIE: Plastics Information Europe, Data extracted in July, 2015
<u>Gross Domestic Expenditure on R&D (GERD)</u>	current '000 PPP\$, 1996-2013	http://data.uis.unesco.org/Index.aspx?queryid=74 Data extracted in January, 2016

Variable	Units	Source
Regional totals for R&D expenditure at world level over the period of 1996-2013		
Population	total	World Bank Data extracted in January, 2016
New scientific knowledge	abstracts	PubMed (constructed) The abstracts were extracted in March, 2015

Sample construction

To perform the analysis, a panel data set is constructed from the set of variables mentioned above and it is reshaped to the log form for 1990, 1995, 2000-2013 as data for the dependent variable, namely consumption of BPA, is available only for these years. Two missing values are detected in the IHS data set. They concern the consumption in Central Europe and Southeast Asia in 1990 and they are given as “-”. For practical reasons, they are substituted by 0.001 given that the BPA consumption in these regions is comparatively very low in 1995 and the consumption in the other regions (except the US and Western Europe) is low as well. BPA consumption per capita in entity i at time t is computed by dividing aggregate consumption of bisphenol A in entity (region or country) i at time t by the average population in entity i at time t . GDP per capita is extracted for the 1990-2013 period, mainly from the World Bank statistics. Taiwan’s GDP per capita is absent from this data source. To replace the missing values, Taiwan’s GDP is obtained from a national data source¹⁴³. For a few countries 1990 GDP data is missing in the World Bank dataset and they are replaced by following non-missing value related to these countries available in the dataset. Average annual GDP per capita for each entity is computed. Observations on 1992-1994, 1996-1999 are excluded due to unavailability of the consumption data for these years. Besides, average annual values for the study regions are computed for the following groups of variables: information access, possession of CD and DVD players (they are used as proxies for CD/DVD use), productivity and cultural variables. A mean price of polycarbonate¹⁴⁴ has been calculated, which corresponds to the European average annual price which serves as a proxy for a world average bisphenol A price due to data unavailability. Exchange rate (EUR/USD) is used from PIE website to convert PC prices in USD. Bisphenol A is used for production of polycarbonate, so changes in prices of

¹⁴³ <http://eng.stat.gov.tw/ct.asp?xItem=37408&CtNode=5347&mp=5>, accessed in July 2015

¹⁴⁴ Data on price of BPA and ER is not available. To compensate for this data lack, we purchase polycarbonate price in Europe from PIE: Plastics Information Europe.

polycarbonate depend on BPA price changes. We expect that potential differences in prices across regions converge with time as the BPA price is defined at global level, and therefore it does not significantly influence a conclusion drawn from the data. Total annual measures for each region are constructed for the passenger cars in use. Missing data in observations for one or several countries is substituted for empty values that permit to compute mean or total values properly without taking into account these countries¹⁴⁵. We expect that countries belonging to one region have similar characteristics due to geographic proximity, therefore rare missing values of one or several countries should not change significantly annual mean values.

The authors of the IHS report (2014) have indicated that Tajikistan, Malta and Kosovo are included in the calculation of the BPA aggregate consumption in the following regions¹⁴⁶: the CIS countries, Western Europe and Central Europe, respectively. We exclude these countries from the computation of mean or total values of the independent variables for the respective regions due to insufficient data.

Gross Domestic Expenditure on R&D (GERD) at world level is available for the period of 1996-2013. We use it as an instrumental variable for global volume of scientific articles to test for endogeneity of scientific knowledge. Given that the measure of scientific knowledge varies over time (but not over regions), we need an instrument that varies only over time. GERD at world level meets the requirements of instrumental variable approach and our data set. The observations corresponding to 1990 and 1995 are missing. The first one is left empty and the second one is replaced by the value of 1996. We do not expect the large difference in GERD between the year 1995 and the year 1996.

We transformed the following variables in logarithmic forms: GERD, GDP per capita, BPA consumption per capita, passenger cars in use per capita. This is in line with the literature on the EKC.

Policy analysis requires data on a treatment group affected by the introduction of a ban on BPA use in the baby bottles production and a control group not affected by the ban (all other entities) before and after the policy implementation (Wooldridge, 2009). Dummy variables for policy analysis are constructed as indicated in the methodology part.

¹⁴⁵ It deals with how Stata treats missing values as we use Stata13 to perform this analysis.

¹⁴⁶ Data is not available separately for these countries.

6.4.6. Descriptive statistics on bisphenol A consumption and new scientific knowledge measures

Table 21 and Table 22 below present the descriptive statistics of BPA consumption per capita and the measures of new scientific knowledge about risks related to BPA. The data shows important variations across regions. The minimum BPA consumption over the study periods occurs in Central Europe and Southeast Asia in 1990 which is the first year included in the sample. Some missing values for 1990 are replaced by 0,001. However, these values do not differ substantially from the values of these two regions in the next period (which corresponds to the year 1995) for the mentioned regions.

Average per capita BPA consumption over the studied period ranges from $3.06e-12$ metric tons in 1990 to .017 metric tons in 2008 with the mean value of .002 (Table 21, Table 22 and Figure 39 below). Republic of Korea and Taiwan are the countries with the highest BPA consumption per capita during the 1990-2013 period, with .017 and .010 metric ton, respectively. Southeast Asia turned out to be the region with the lowest per capita consumption (Table 59 in Appendix G). Table 22 below shows an increase in the mean level and the standard deviation of BPA consumption per capita and GDP per capita until the year 2008. Between 1990 and 2013, the mean level of GDP per capita increased from 8638 to 22363 current US\$, with the mean value of 16658 (Table 59 in Appendix G). China is the entity with the lowest GDP per capita in 1990 and Western Europe is the entity with the largest GDP per capita in 2008. Are these increases in BPA consumption per capita mainly caused by economic growth?

Table 21 shows the differences in 4 categories of new scientific knowledge proxies over the years: all articles related to BPA, articles about potential risks of BPA, articles in which BPA related risks are uncertain, and articles stating no risk of BPA. A considerable increase in the quantity of all groups of articles related to BPA risk is documented. In 1990 no articles related to potential risk of BPA were published. In 1995 the number of articles which belong in the "Risk" category increased and it reached its maximum in 2012 and 2013 (the same quantity of articles fitting in this category was published). The highest volume of "Uncertain" BPA studies was published in 2013 and the highest number of articles which corresponds to the "No Risk" category became available in 2011. Given that these articles and abstracts are available online in English, they are accessible worldwide, therefore there is no need to classify them by countries. Table 23 shows that the uncertainty avoidance index varies from very low (China)

to very high (Japan). Descriptive statistics of the other variables used in the analysis are provided in Appendix G.

Table 21. Descriptive statistics of bisphenol A consumption and new scientific knowledge measures over the 1990, 1995, 2000-2013 years

Variable	Obs	Mean	Std. Dev.	Min	Max
Consumption (thousands of metric tons)	192	297.994	326.460	0	1076
Consumption per capita (metric tons)	192	.002	.0034528	3.06e-12	.017
BPA	192	55.375	43.830	0	155
No Risk	192	6.938	3.239	0	12
Uncertain	192	20.188	20.694	0	76
Risk	192	28.25	21.881	0	68

Source: Ostapchuk, based on IHS Chemical and PubMed

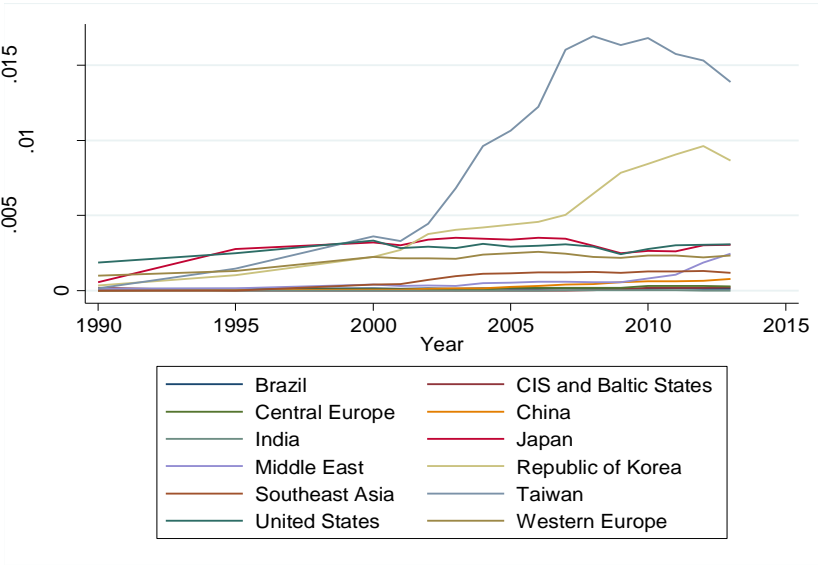


Figure 39. Bisphenol A consumption per capita over the 1990, 1995, 2000-2013 years
Source: Ostapchuk, based on IHS Chemical

Table 22. Evolution of BPA consumption per capita and GDP per capita

Year	BPA consumption per capita					Year	GDP per capita				
	Obs	Mean	Std. Dev.	Min	Max		Obs	Mean	Std. Dev.	Min	Max
1990	12	.0004	.0006	3.06e-12	.0019	1990	12	8638.18	9367.74	316.22	25123.63
1995	12	.0008	.0010	5.20e-06	.0028	1995	12	12620.33	13360.81	381.52	42522.07
2000	12	.0013	.0015	8.54e-06	.0036	2000	12	12823.07	13302.45	452.41	37299.64
2001	12	.0013	.0014	9.33e-06	.0033	2001	12	12254.69	12720.27	460.82	37273.62
2002	12	.0015	.0017	9.17e-06	.0045	2002	12	12576.3	12884.66	480.62	38166.04
2003	12	.0017	.0022	9.92e-06	.0068	2003	12	13786.83	14027.4	557.90	39677.2
2004	12	.0020	.0028	.0000151	.0096	2004	12	15221.54	15216.28	640.60	41921.81
2005	12	.0021	.0031	.0000149	.0106	2005	12	16270.2	15632.31	729.00	44307.92
2006	12	.0023	.0035	.0000155	.0122	2006	12	17200.59	15959.47	816.73	46437.07
2007	12	.0027	.0045	.0000176	.0160	2007	12	18859.55	16870.97	1050.03	50375.56
2008	12	.0029	.0048	.0000226	.0169	2008	12	19985.56	17360.09	1022.58	53593.93
2009	12	.0028	.0048	.0000255	.0163	2009	12	18828.33	16461.77	1124.52	47414.51
2010	12	.0030	.0049	.0000292	.0168	2010	12	20456.61	16783.51	1387.88	48374.05
2011	12	.0030	.0047	.0000224	.0157	2011	12	22338.68	17654.19	1471.66	52475.69
2012	12	.0031	.0046	.0000198	.0153	2012	12	22313.51	17541.27	1449.67	51456.66
2013	12	.0030	.0042	.0000203	.0138	2013	12	22363.99	17095.61	1455.10	52980.04

Source: Ostapchuk, based on IHS Chemical and World Bank

Table 23. Uncertainty avoidance index (UAI) by entity

Entity	UAI	Entity	UAI	Entity	UAI
South America	76	Middle East	70	Southeast Asia	38.17
CIS and Baltic States	70.75	Republic of Korea	85	Taiwan	69
Central Europe	81.67	Indian Subcontinent	40	United States	46
China	30	Japan	92	Western Europe	68.52

Source: Ostapchuk, based on Hofstede (2001)

6.5 Results

6.5.1. Reduced form model

We first examine the relationship between economic growth and consumption of bisphenol A by plotting BPA consumption per capita on the log scale against GDP per capita on the log scale (Figure 40). The preliminary data analysis suggests that the relationship is nonlinear, which justifies a further application of the polynomial regression model. The overall trend is upward. Besides, two potential outliers are detected which are connected to two missing values substituted by 0.001 and transformed to logarithm. We will conduct our analysis neglecting these outliers and then we will carry it out without these points to see whether results change. The obtained estimation results for the reduced form model and their

discussion are presented in Appendix G¹⁴⁷. Figure 41 represents the relationship over the studied period and the resulting line of the prediction for consumption. To briefly summarize, the obtained results do not support the EKC hypothesis since they show the existence of an inverted N shape relationship between consumption of bisphenol A on the log scale and economic growth.

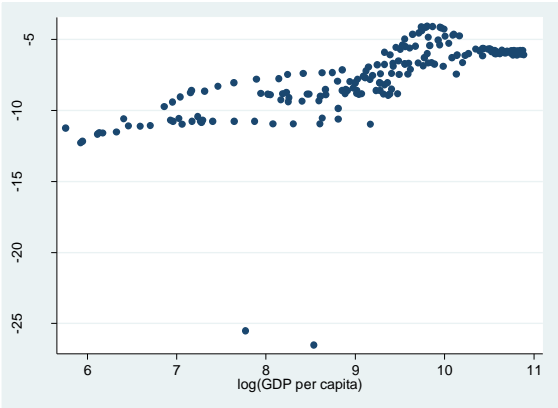


Figure 40. Scatter plot of BPA consumption per capita against GDP per capita on the log scales
Source: Ostapchuk, based on World Bank and IHS Chemical

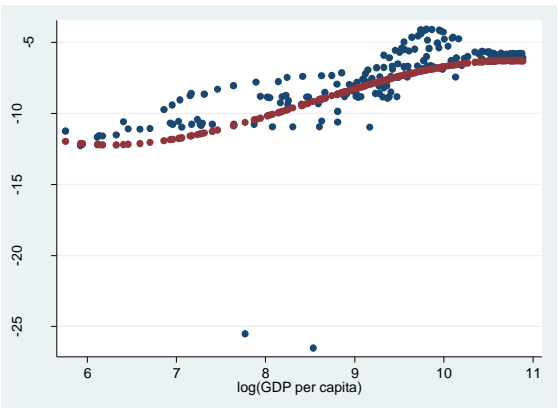


Figure 41. Scatter plot of consumption of bisphenol A per capita against GDP per capita on the log scales (blue circles) and the resulting line of the prediction for consumption from a reduced form model (red circles)
Source: Ostapchuk, based on World Bank and IHS Chemical

6.5.2. Extended form model: additional predictors selection (principal component analysis)

The main purpose of carrying out principal component analysis in this research is to select a subset of predictors to construct a parsimonious model and to analyze the strength and the patterns of the links between potential explanatory variables and the dependent variable. The

¹⁴⁷ Estimates of the basic model are intermediate results as the model can suffer from omitted variable bias. However, a vast number of empirical studies on the EKC use reduced-form models. A reduced-form model is considered to be useful in measuring both direct and indirect effects of economic growth ((D. Katz, 2015; Saboori et al., 2012b)

chosen variables will be used in the construction of the measure of over- and under-consumption of BPA. Our dependent variable is bisphenol A consumption per capita. The set of explanatory variables additionally to GDP per capita includes multiple items to measure information access (possession of broadband enabled computers, possession of personal computers, possession of satellite TV system possession of cable TV), industry-specific factors (possession of CD players, possession of DVD players which are used as proxies for CD/DVD and number of passenger cars and price. Besides, we test the impact of productivity on BPA consumption. A sufficiently large number of economic indicators that are correlated with indicators of demand for inputs may exist (Bourbonnais & Usunier, 2013). Several of them are related to the situation on the labor market (productivity, labor force participation) which is interconnected with production and, eventually, with demand for other inputs. These measures can be positively correlated with GDP per capita. However, we do not expect an exact correlation between GDP and productivity. Other potential sources of multicollinearity are the relationship between economic indicators and demand for final goods (Bourbonnais & Usunier, 2013).

Figure 42 and Figure 43 present the biplots for the variables mentioned above. Our main purpose is to define the strength of the association between the available measures of explanatory variables. Besides, we can identify the existing patterns among the variables. According to the first biplot, the first two components together explain approximately 70% of the total variance in all variables included in the analysis. The second biplot shows the first and the third components and it explains more than 60% of the total variance in all variables included in the analysis. We do not show additional correlation plots of the variables as the scree plot shows that the appropriate number of principal components is 3. Due to different measurement units of our variables, scaling is performed to make the data more comparable. According to Figure 42, the information access variables (Cable_TV, Computer, Internet and Satellite_TV) are positively correlated with each other and with BPA consumption per capita (Conc_pc). Except for possession of satellite TV system (Satellite_TV), all variables are clustered together (Cable_TV, Computer, Internet). Given that the possession of cable TV variable is closer to the circle of correlations and consumption per capita, it is an appropriate measure of media intensity. The shorter the distance of a variable to the correlation circle, the better the variable can be reconstructed from the two dimensions (Abdi & Williams, 2010). The industry-specific factors are well represented by the first two dimensions and positively

correlated with BPA consumption per capita (CD, DVD and Cars_Use_pc). Between the procession of CD and DVD proxies, the possession of CD player is closer to the dependent variable as a result it is chosen as the most suitable measure. Besides, cars use will be included in the further analysis. A positive link between the possession of CD player and consumption of bisphenol A per capita is suggested by PCA.

The first plot (Figure 42) shows that the correlation between productivity (ProductivityPass) and consumption per capita is very low. However, the second plot (Figure 43) shows that there might be a positive correlation between these two variables (the distance to the circle of correlation is relatively low). But the distance between consumption per capita and the circle together with the distance between productivity and the circle suggests that these two variables are worse represented by these two dimensions (Figure 42). GDP per capita is, on average, positively correlated with BPA consumption per capita according to two plots presented below.

The first biplot (Figure 42) shows a low importance of price (PC_USD) for the first two dimensions. As can be seen from the first plot, the price variable is close to the origin, so it confirms its relatively low importance for these two components. However, the second plot (Figure 43) shows that the price is closer to the circle, so it is better represented. It can be concluded that the price is not much correlated with BPA consumption per capita (as the angle between these two variables is almost a right one). It can be explained either by the sample construction and unavailability of prices for each entity separately or by the low price volatility. Therefore, we will not include it in the further analysis.

Turning to the positions of the observations on the Individual factor map, the right side of Figure 42 shows the various subsets of observations (Jolliffe, 2002). It can be seen that areas occupied by different entities overlap slightly, but separation occurs in terms of second component. The observations on the right side correspond to large consumers of bisphenol A (from the bottom to the top: the Republic of Korea and Taiwan, Japan and the US, and Western Europe), and the ones on the left correspond to less "important" consumers. Moreover, we can see that the observations corresponding to Taiwan and the Republic of Korea which are the largest consumers are closely positioned (right bottom corner). Thus, the plot presents essentially regional differences in BPA consumption per capita.

To conclude, the following explanatory variables are chosen for further analysis: possession of cable TV, possession of CD player, passenger cars in use and productivity.

Extended form model: the Wald test and different estimation approaches

When the chosen subgroup of predictors is added to the reduced model, the Sargan-Hansen version of the test for random effect vs fixed effect suggests that the RE GLS is an appropriate estimation procedure (P-value = 0.2126). Afterwards, in order to examine the relevance of these additional variables, the Wald tests are conducted together with cross-validation procedures. In addition to the possession of CD player, its quadratic term is included in the model to examine the shape of the relationship. The results are presented in Table 24. The Wald tests suggest that there is strong evidence against the hypotheses that coefficients on the possession of Cable TV and the quadratic term of the possession of CD player are 0. We fail to reject the hypotheses that coefficients on the possession of CD players, productivity and cars in use are 0. Both leave one out and repeated k fold cross validations suggest that the extended model that includes the possessions of cable TV and CD player is appropriate (pseudo R^2 is .53976887 and overfitting measure is 9.33 with lower in sample shrinkage statistics). The results are presented in Table 25. Therefore, we will include these two variables in the extended model.

In the case of the extended model, the Breusch and Pagan Lagrangian multiplier test for random effects fails to reject the hypothesis that variances across entities is 0 which suggests that the random effect estimation procedure is preferred to the pooled OLS. The formal test for fixed vs random effects adjusted for the presence of heteroscedasticity, which suggests that random effect is appropriate. Besides, a modified Wald statistic for groupwise heteroskedasticity suggests the presence of heteroskedasticity (there is strong evidence against the hypothesis that $\sigma_i^2 = \sigma^2$, $\text{Prob} > \chi^2 = 0.0000$). The results of these tests are presented in Table 27. As in the case of the reduced form, corrective measures are needed. We compare the performance of robust random effect estimation procedure with FGLS with heteroskedastic error structure by running leave one out and k-fold cross-validations (Table 28).

The results of the model estimated by the approaches mentioned above are presented in Table 26. According to leave one out and k fold cross-validations, the model estimated by FGLS is preferred (the pseudo R^2 for this model is higher and overfitting measure is lower). Besides, the extended model performs better than the reduced one (the pseudo R^2 is higher and the overfitting measure is lower for the extended model). Besides, the improved in sample

shrinkage (the difference in shrinkage statistics is 2,4) demonstrates the appropriateness of inclusion of these two variables).

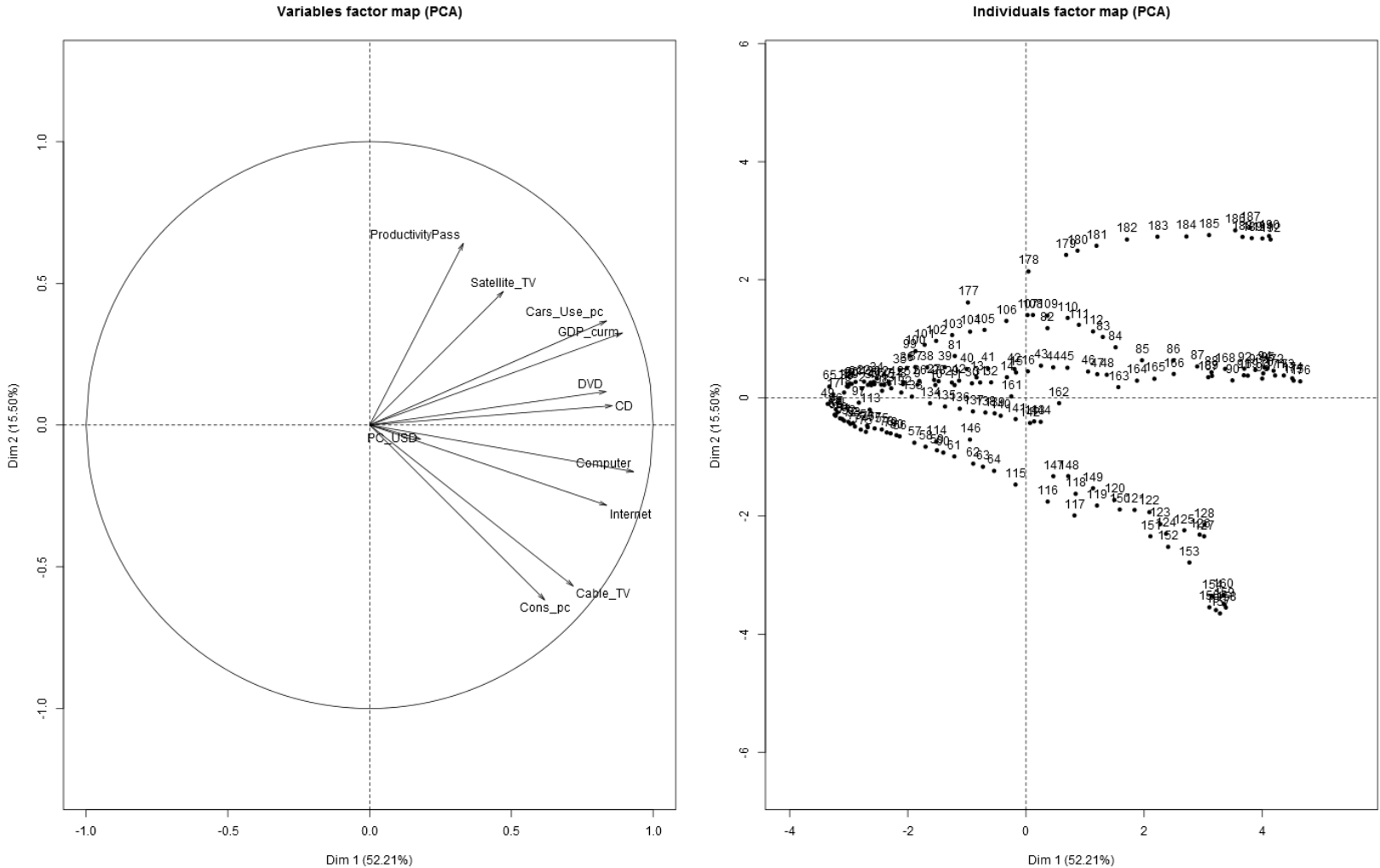


Figure 42. Principal component analysis, biplot, components: 1 and 2, the selected variable, 1990-2013.
 Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

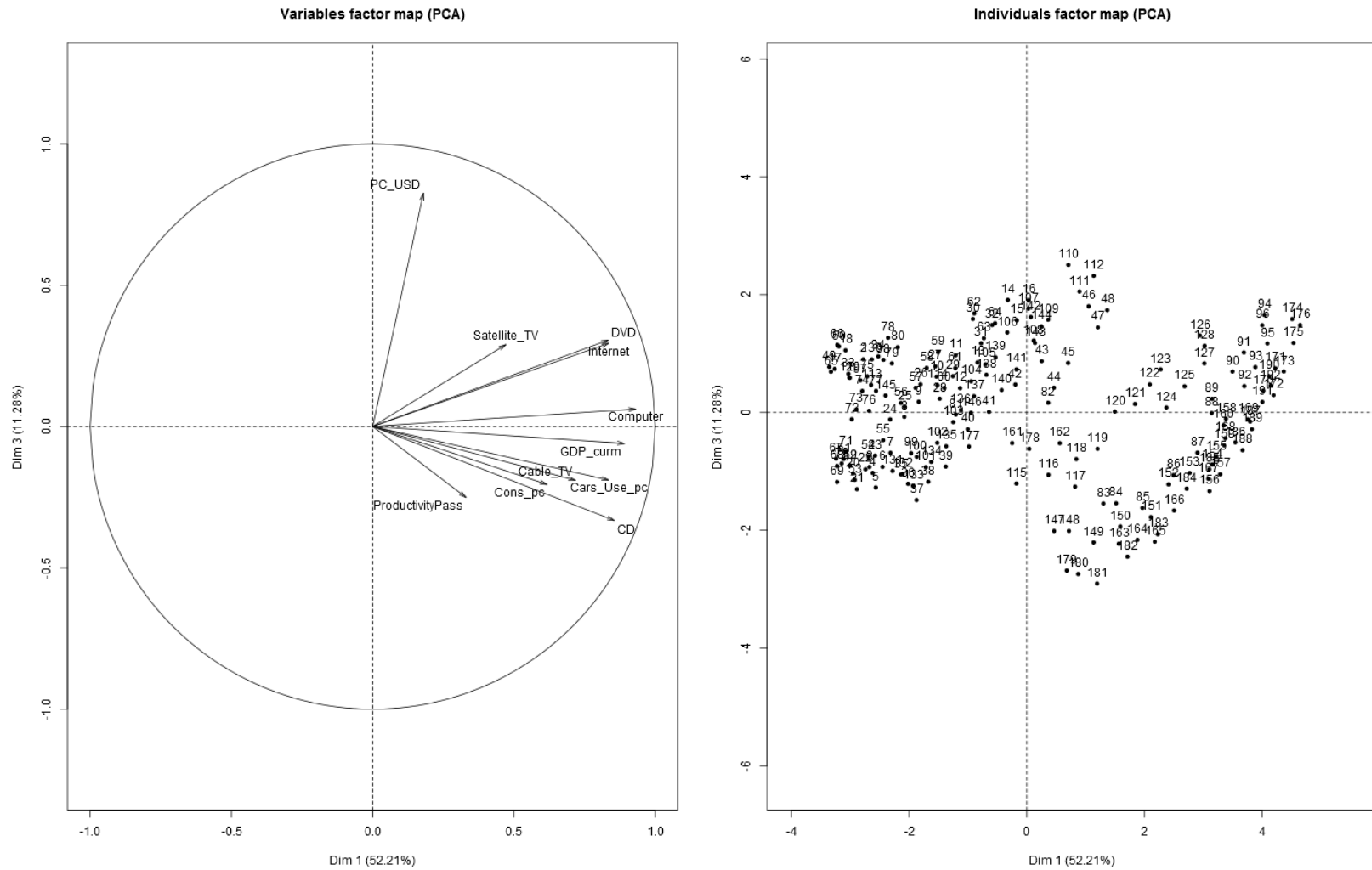


Figure 43. Principal component analysis, biplot, components: 1 and 3, the selected variable, 1990-201.
 Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

The coefficients on the log of GDP per capita, quadratic and cubic terms are statistically significant at 1% level of significance. The estimated turning points are \$456 and \$26015. The introduction of these variables influences the estimated turning points. China and India had per capita GDP level below \$456 and Japan, the US and Western Europe crossed the second turning point. The obtained results confirm the existence of the inverted N-shaped relationship between consumption of bisphenol A on the log scale and economic growth (Table 26). Figure 44 shows the relationship that corresponds to the studied period and the resulting line of the prediction for consumption.

The coefficient of the possession of cable TV is positive and statistically significant at 1 % level of significance. The semielasticity of BPA consumption per capita with respect to the possession of cable TV is 3,1 (Table 26). The interpretation is that, on average, 1% increase in possession of cable TV among the households is associated with 3,1 % increase in annual consumption of bisphenol A per capita holding other factors fixed. There are two reasons why BPA consumption is responsive to the possession of cable TV. First, BPA is used in the production of polycarbonate which is used in the production of TVs. Second, a level of information access has a positive effect on BPA consumption as it spreads information about an enormous number of products made out of bisphenol A. This effect can be slightly diminished by the media that disseminates the information about potential risk of BPA related to several applications of BPA. The coefficient of the possession of CD players is statistically insignificant at 10% level of significance. However, the sign is positive as it is expected, and it is shown by PCA analysis. Year dummies are included in the model. The deviations from this extended model estimated by FGLS are used to construct a measure of over- and under-consumption of BPA.

Table 24. Extended model: the Wald tests

Hypothesis	Result
CD = 0	$\chi^2(1) = 2.54$ Prob > $\chi^2 = 0.1112$
CD ² = 0	$\chi^2(1) = 3.91$ Prob > $\chi^2 = 0.0481$
InCars_Use_pc = 0	$\chi^2(1) = 0.35$ Prob > $\chi^2 = 0.5537$
In_productivity = 0	$\chi^2(1) = 1.02$ Prob > $\chi^2 = 0.3115$
Cable_TV = 0	$\chi^2(1) = 11.02$ Prob > $\chi^2 = 0.0009$

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Table 25. Extended model. Cross validation

Additional variable	Cross-validation type	Results
Cable_TV, CD, CD ² , InCars_Use_pc	Leave-One-Out	Root Mean Squared Errors 1.98 Mean Absolute Errors 1.00 Pseudo-R2 .50
Cable_TV, CD, CD ² , In_productivity	Leave-One-Out	Root Mean Squared Errors 1.90 Mean Absolute Errors .98 Pseudo-R2 .53
Cable_TV, CD, In_productivity, InCars_Use_pc	Leave-One-Out	Root Mean Squared Errors 1.98 Mean Absolute Errors 1.00 Pseudo-R2 .49
CD, CD ² , InCars_Use_pc	Leave-One-Out	Root Mean Squared Errors 2.16 Mean Absolute Errors 1.21 Pseudo-R2 .40
Cable_TV, CD	Leave-One-Out	Root Mean Squared Errors 1.88 Mean Absolute Errors .95 Pseudo-R2 .54
Cable_TV, CD, InCars_Use_pc	Leave-One-Out	Root Mean Squared Errors 1.94 Mean Absolute Errors .964 Pseudo-R2 .51
Cable_TV, CD, In_productivity	Leave-One-Out	Root Mean Squared Errors 1.90 Mean Absolute Errors .95 Pseudo-R2 .53
Cable_TV, In_productivity, InCars_Use_pc	Leave-One-Out	Root Mean Squared Errors 1.96 Mean Absolute Errors .99 Pseudo-R2 .50
In_productivity, InCars_Use_pc	Leave-One-Out	Root Mean Squared Errors 2.03 Mean Absolute Errors 1.09 Pseudo-R2 .46
Cable_TV, CD, CD ² , InCars_Use_pc	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample 12.39 (3.13) In sample 0.06 (1.43) Overfitting 12.32 (3.30) Standard errors are in parentheses

Additional variable	Cross-validation type	Results		
Cable_TV, CD, CD ² , ln_productivity	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample In sample Overfitting Standard errors are in parentheses	11.02 0.05 10.96	(3.74) (1.50) (3.94)
Cable_TV, CD, ln_productivity, lnCars_Use_pc	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample In sample Overfitting Standard errors are in parentheses	13.30 0.10 13.19	(3.56) (1.46) (3.68)
CD, CD ² , lnCars_Use_pc	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample In sample Overfitting Standard errors are in parentheses	14.74 0.02 14.69	(3.51) (1.74) (3.84)
Cable_TV, CD	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample In sample Overfitting Standard errors are in parentheses	9.39 0.04 9.33	(3.40) (1.52) (3.70)
Cable_TV, CD, lnCars_Use_pc	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample In sample Overfitting Standard errors are in parentheses	11.75 0.08 11.66	(3.19) (1.48) (3.40)
Cable_TV, CD, ln_productivity	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample In sample Overfitting Standard errors are in parentheses	10.52 0.06 10.44	(3.75) (1.54) (3.97)
Cable_TV, ln_productivity, lnCars_Use_pc	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample In sample Overfitting Standard errors are in parentheses	12.74 0.13 12.61	(3.41) (1.44) (3.55)
ln_productivity, lnCars_Use_pc	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample In sample Overfitting Standard errors are in parentheses	13.63 0.12 13.51	(3.37) (1.55) (3.56)

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Table 26. Extended form model of the Environmental Kuznets curve, selected results.
Dependent variable: log of BPA consumption per capita

VARIABLES	Model 1				
	POLS	Model 1 FE	Model 1 RE	Model 1 RE robust	Model 1 GLS
	(1)	(2)	(3)	(4)	(5)
lnGDP_curm	-36.80*** (12.96)	-41.36*** (14.76)	-36.80*** (12.96)	-36.80 (23.43)	-23.16*** (7.396)
ln2GDP_curm	4.394*** (1.556)	4.860*** (1.800)	4.394*** (1.556)	4.394 (2.712)	3.030*** (0.868)
ln3GDP_curm	-0.166*** (0.0617)	-0.183** (0.0736)	-0.166*** (0.0617)	-0.166 (0.102)	-0.124*** (0.0334)
Cable_TV	0.0427*** (0.0124)	0.0436** (0.0190)	0.0427*** (0.0124)	0.0427*** (0.0120)	0.0310*** (0.00388)
CD	-0.0184 (0.0202)	-0.0572* (0.0309)	-0.0184 (0.0202)	-0.0184 (0.0335)	0.00654 (0.00572)
Time dummies	Yes	Yes	Yes	Yes	Yes
Constant	85.15** (35.52)	100.8** (40.49)	85.15** (35.52)	85.15 (63.66)	44.17** (20.56)
Observations	192	192	192	192	192
R-squared		0.404			
Number of En_entity	12	12	12	12	12

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Table 27. Extended form model. Tests for random effects, fixed vs random effects and heteroscedasticity

Test	Result
Breusch and Pagan Lagrangian multiplier test for random effects $H_0: \text{Var}(u) = 0$	$\bar{\chi}^2(01)=22.22$ Prob > $\bar{\chi}^2 = 0.0000$
Test of overidentifying restrictions: fixed vs random effects (robust), Sargan-Hansen statistic	$\chi^2(11) = 12.590$ Prob > $\chi^2 = 0.3210$
Modified Wald test for groupwise heteroscedasticity in fixed effect regression model $H_0: \sigma_i^2 = \sigma^2$ for all i	$\chi^2(12)$ = 13665.20 Prob > χ^2 = 0.0000

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Table 28. Extended form model. Cross-validation results

Model, method	Cross-validation type	Results	
Extended model, RE GLS robust	Leave-One-Out	Root Mean Squared Errors	1.88
		Mean Absolute Errors	.95
		Pseudo-R2	.54
Extended model, FGLS	Leave-One-Out	Root Mean Squared Errors	1.85
		Mean Absolute Errors	.77
		Pseudo-R2	.56
Extended model, RE GLS robust	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	9.39 (3.40)
		In sample	0.04 (1.52)
		Overfitting	9.33 (3.70)
		Standard errors are in parentheses	
Extended model, FGLS	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	-4.38 (0.95) -
		In sample	6.81 (0.68)
		Overfitting	2.28 (1.09)
		Standard errors are in parentheses	

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

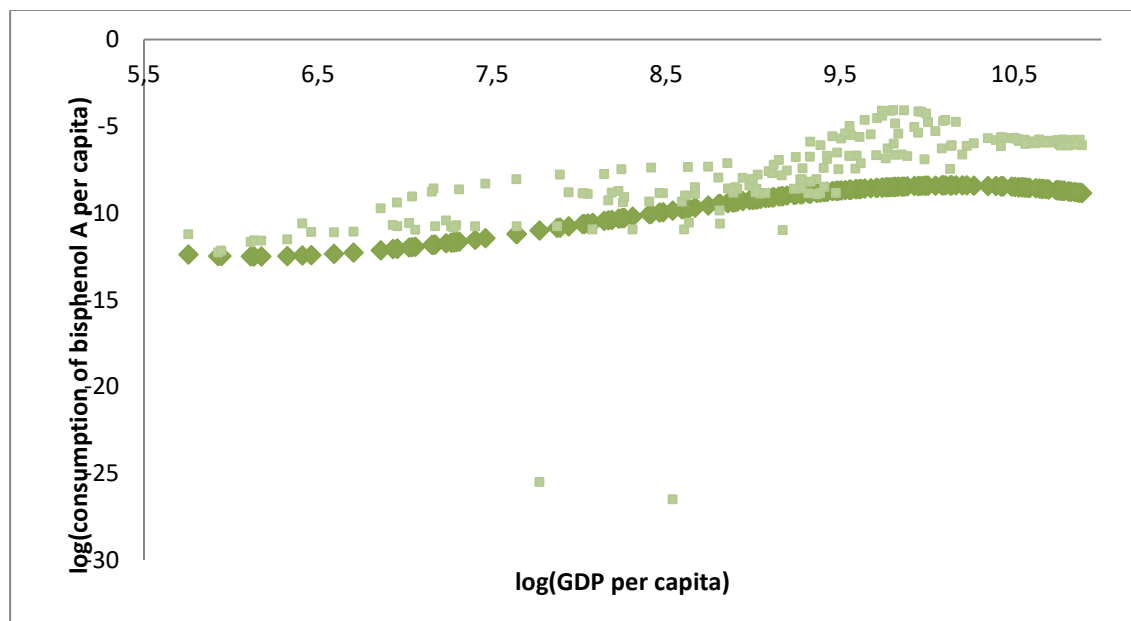


Figure 44. Scatter plot of consumption of bisphenol A per capita against GDP per capita on the log scales (squares) and the resulting line of the prediction for consumption of bisphenol A from an extended form model (rhombus)

Source: Ostapchuk, based on World Bank and IHS Chemical

6.5.3. Over- and under-consumption of bisphenol A: test for endogeneity

Before proceeding further, we will test for endogeneity. As we have mentioned in the methodology part, the concern about endogeneity arises from the fact that a substantial BPA

consumption may attract the attention of scientists to the issue of potential risk and as result the overall quantity of scientific reports may increase. We use regional totals for R&D expenditure¹⁴⁸ at world level on the log scale as an instrumental variable for global volume of scientific articles given that this measure of scientific knowledge varies over time (but not over regions). Correlation between regional totals for R&D expenditure at world level on the log scale and global volume of scientific articles on the log scale is 0,9314. The formal test for fixed vs random effects adjusted for the presence of heteroscedasticity suggests that the fixed effect instrumental variable approach is appropriate (the Sargan-Hansen statistic is 0,000). Therefore, we estimate the extended model using regional totals for R&D expenditure at world level as the instrument by fixed effect instrumental variable approach (FE IV) with robust standard errors including the weak identification test and the endogeneity tests. The results of FE IV are presented in Table 64 in Appendix G.

The Cragg-Donald Wald F statistics exceeds the critical value. Thus, there is strong evidence against the hypothesis that the estimator is weakly identified. Our instrument is not weak. The issue of weak instruments may arise even if correlation is significant. The result of endogeneity test of endogenous regressor suggests that there is weak evidence against the null hypothesis (Chi-sq P-val = 0.8950). The null hypothesis is that “the specified endogenous regressors can actually be treated as exogenous”. Therefore, there is no contemporaneous endogeneity and we can continue our analysis of the relationship between over- and under-consumption of bisphenol A.

Over- and under-consumption of bisphenol A: analysis

The correlation between the predicted and the observed BPA consumption is 0,7633. If we compare the mean estimated using FGLS with the actual observed mean on the log scales, we can see that the values are very close (-7,50 and -7,74 respectively). The deviations from the predicted consumption are used as a measure of over- and under-consumption of bisphenol A. The average over- and under-consumption on the log scale is -0,23 with entities' over- and under-consumption ranging from -17,00 to 3,06. On average, entities which over-consume BPA over the studied period are China, the Middle East, the Republic of Korea, Taiwan and Western Europe, and those which under-consume are Brazil, CIS and Baltic State, Central Europe, India, Japan, Southeast Asia and the US. However, only one entity over-consumes

¹⁴⁸ <http://data.uis.unesco.org/Index.aspx?queryid=74>, accessed in January 2017

constantly over the studied period (China) and another one under-consumes constantly (the USA). The descriptive statistics of residuals are presented in Table 65 in Appendix G.

Next, we examine the relationship between new scientific knowledge about potential risks of BPA, the over- and under-consumption of bisphenol A, and uncertainty avoidance. As we have mentioned in the methodology, we rank our entities in order of uncertainty avoidance from the lowest to highest. We break them in four equal sized groups. The first group (with the lowest UAI in the sample: $UAI < 43$) includes China, India and Southeast Asia. The second group ($43 \leq UAI < 69,5$) includes Taiwan, the US, Western Europe. The third group ($69,5 \leq UAI < 78$) consists of Brazil, CIS and Baltic States. Central Europe, the Republic of Korea and Japan are part of the fourth group ($UAI > 78$). For each group, we plot the deviations from the predicted values against global quantity of scientific articles 'BPA' on the log scale, we combine them on Figure 45. If the actual consumption is below the fitted value from the basic model ($residuals < 0$), it may indicate under-consumption of bisphenol A. If it is above the fitted value ($residuals > 0$), it may show over-consumption of BPA. The more negative the deviation from the predicted values, the larger under-consumption. As it is seen from the graph (the plot below represents the UAI for each group of regions, from the lowest to highest), the greater uncertainty avoidance, the more negative the deviations (which represents under-consumption of bisphenol A) and the smaller over-consumption as the quantity of scientific articles increases suggesting higher under-consumption of bisphenol A. Figure 45 shows that under-consumption (the dots under the red line) reaches the lowest level (that is the highest under-consumption) for the entities with the highest level of uncertainty in our sample. On average, under-consumption increases as the quantity of articles and the uncertainty avoidance increase. Thus, the uncertainty avoidance modifies the intensity of the relationship. Figure 46 shows the difference in the relationship between over-/under-consumption and the quantity of scientific knowledge for the groups with the lowest and the highest uncertainty avoidance index. This graph confirms the results which we have discussed above. However, the patterns of behavior are different for each group. Figure 66a - Figure 66b in Appendix G present robust locally weighted regressions (lowess). Figure 66a in Appendix G shows that a downturn in the over-consumption begins at a certain level of the quantity of scientific articles (between 32 and 53 published studies which is relatively high) for the entities with the lowest uncertainty avoidance. Figure 66b in Appendix G shows the relationship for the entities with the highest uncertainty avoidance. On the graph it can be seen, that the under-consumption

increases at relatively low level followed by a period of constant under-consumption. On average, lowess captures the downward trend in the data that is a positive relationship between under-consumption and the quantity of articles.

Hence, the hypothesis of under-consumption of bisphenol A and the number of scientific articles related to potential risk of BPA in a situation of uncertainty about these risks cannot be rejected. Moreover, it can be concluded that the results support the hypothesis that uncertainty avoidance will have a moderating effect on the relationship between scientific knowledge about potential risk and over- and under-consumption of bisphenol A in a situation of uncertainty about environmental and health risk. However, further application of parametric technique would be desirable if larger and more detailed dataset existed.

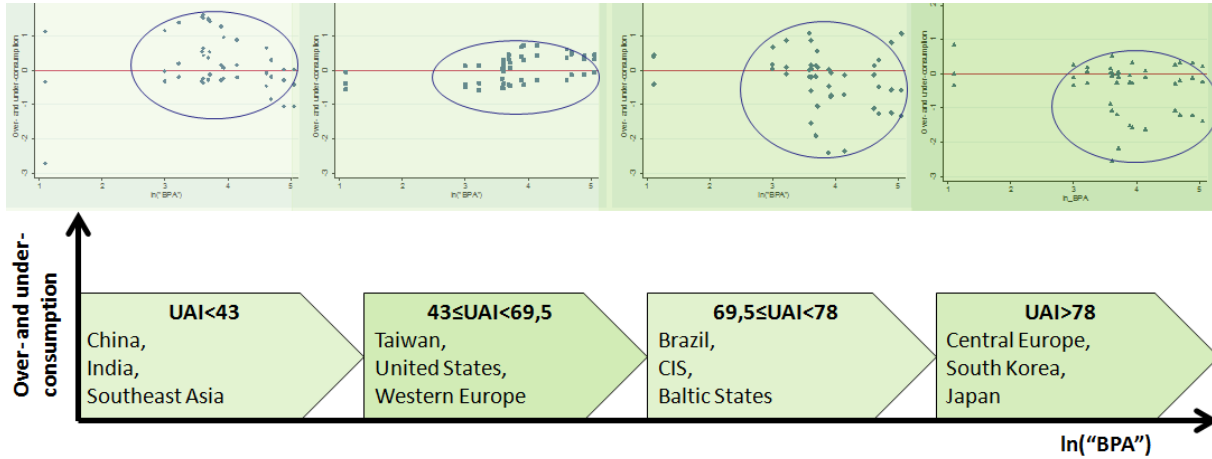


Figure 45. Scatter plot: over- and under-consumption of bisphenol A against “BPA” for four groups according to their uncertainty avoidance
 Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

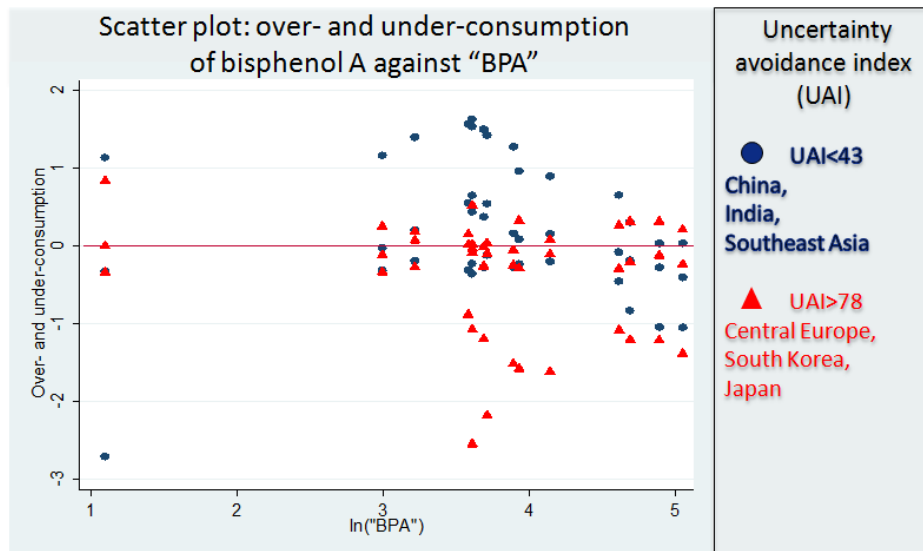


Figure 46. Scatter plot: over- and under-consumption of bisphenol A against "BPA" for two groups: the one with the lowest uncertainty avoidance and the one with the highest uncertainty avoidance

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

As it was previously mentioned, two outliers were detected which are connected to the substitution of two missing values. To evaluate the impact of the outliers on the results obtained previously, first, we will re-estimate the reduced and extended models without these points (replacing them by missing values), second, we will conduct the cross-validation procedures and third, we will compare lowess results plotting the quantity of articles on the log scale against consumption of bisphenol A per capita on the log scale. Results are presented in Appendix G. The results show that the pattern of the relationship between the number of new scientific knowledge and over- under-consumption of bisphenol A on the log scales is roughly the same. We conclude that the models without these outliers perform slightly better, although the pattern of behavior has not changed significantly with the presence of outliers.

6.5.4. Policy analysis

In this subsection, in order to evaluate the impact of the bans on the BPA use in baby bottles production on aggregate consumption of BPA, we conduct a policy analysis. Given that the policy evaluation is not a main goal of our analysis, the policy binary variables have not been introduced earlier in the analysis. Moreover, their introduction decreases the extended model performance as k-fold out cross-validation indicates (overfitting statistics are higher, see Table 29 below). Nevertheless, the impact of bans on some applications of BPA on aggregate level

of bisphenol A consumption is an interesting question and it might have an important implication for policymaking. First, we carry out the principal component analysis with bans dummies. Fig. A1 suggests that there is a weak relationship between the ban introduced in the US (BanUS) and consumption of bisphenol A per capita (Cons_pc) as can be hypothesized while these two variables are well represented by these two components. This is not a surprising result given that voluntary replacement of bisphenol A component in baby bottles has preceded the ban on BPA use in the bottles. It confirms the information provided on the FDA website about the abandonment of bisphenol A use in infant formula packaging¹⁴⁹. In addition, we test the hypothesis that the coefficient on the US ban dummy is 0 by performing the Wald test. We fail to reject the hypotheses that the coefficient on the US ban is 0 ($\text{Prob} > \chi^2 = 0.8239$). Therefore, we will estimate the extended model including only the dummy on 2011 bans by FGLS. The results are presented in Table 30. Column 1 corresponds to the model based on the dataset with the replaced missing values. The coefficient on the ban introduction on the BPA use in the baby bottles production in the EU, China, Brazil and Malaysia in 2011 is statistically insignificant at 10% level of significance (Table 30). While the coefficient is statistically insignificant, it is positive.

The increase in the consumption of aggregate level of bisphenol A per capita can be explained by the shift from production of baby bottles to other products with BPA as an input using the same equipment. Another reason is the effect of green light to other applications which are not banned. Besides, the displacement hypothesis can be another reason for increased consumption of BPA. It suggests that a baby bottles production (that uses BPA) can be displaced to the country with less strong regulations and less concerned consumers (and higher demand for plastic baby bottles). However, unavailability of data does not allow to evaluate the hypothesis about the effect of this ban on the use of bisphenol A for baby bottles production. One of the hypotheses states that the consumption of bisphenol A related to the banned applications should decrease as a consequence of the introduced policies. Besides, the introduction of bans might suggest that bisphenol A is the process of complete replacement by alternatives which will be achieved in the long run. The reasoning behind this process is that producers might anticipate that bisphenol A use will be banned completely in the future or consumers can be dissatisfied with other products containing bisphenol A

¹⁴⁹ <http://www.fda.gov/NewsEvents/PublicHealthFocus/ucm064437.htm>, accessed in 2015

following the introduction of the first ban on one of its usages. Other potential explanations include growth in demand for other products containing BPA or external shocks. Given that our sample is relatively short, we are not able to test this hypothesis.

Table 29. Extended model. Cross validation

Additional variable	Cross-validation type	Results	
Extended model, 192 observations,	Leave-One-Out	Root Mean Squared Errors	1.85
		Mean Absolute Errors	.78
		Pseudo-R2	.56
Extended model, Ban2011 192 observations	Leave-One-Out	Root Mean Squared Errors	1.85
		Mean Absolute Errors	.73
		Pseudo-R2	.56
Extended model, Ban2011, BanUS 192 observations	Leave-One-Out	Root Mean Squared Errors	1.85
		Mean Absolute Errors	.73
		Pseudo-R2	.56
Extended model, 192 observations,	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	-4.38 (0.95)
		In sample	-6.81 (0.68)
		Overfitting	2.28 (1.09)
		Standard errors are in parentheses	
Extended model, Ban2011 192 observations	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	-5.00 (1.13)
		In sample	-7.63 (0.61)
		Overfitting	2.44 (1.15)
		Standard errors are in parentheses	
Extended model, Ban2011, BanUS 192 observations	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	-4.98 (1.14)
		In sample	-7.61 (0.60)
		Overfitting	2.44 (1.16)
		Standard errors are in parentheses	

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Table 30. Policy evaluation. Dependent variable: log of bisphenol A consumption per capita

VARIABLES	Model 1 FGLS PA
lnGDP_curm	-23.58*** (7.409)
ln2GDP_curm	3.081*** (0.869)
ln3GDP_curm	-0.126*** (0.0334)
Cable_TV	0.0310*** (0.00391)
CD	0.00668 (0.00573)
Ban2011	0.0356 (0.370)
Time dummies	Yes
Constant	45.30** (20.61)
Observations	192
R-squared	
Number of	12
En_entity	

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

6.5.5. Alternative measures of scientific knowledge

Previously we have used “BPA” as a measure of scientific knowledge about potential risks of bisphenol A. Next, we use separately the following alternative measures of scientific knowledge: “Risk”, “No risk”, “Uncertain”. Appendix G presents the lowess results for the relationship between the articles categorized under the groups “Risk”, “No risk”, “Uncertain” and under-consumption for the entities with the lowest and the highest uncertainty avoidance indexes. It is concluded that the pattern of the relationship does not change for these entities (with slight changes in downturn points). It can be concluded that “BPA” measure or equivalent is a suitable measure that can be used in the analysis in a situation of uncertainty regarding environmental and health risks. This is confirmed by PCA. This measure includes all articles that are related to potential risks of bisphenol A without distinguishing if they are about the presence of risk or its absence. It might suggest that uncertainty provokes controversies which become important or interesting to be reported in scientific journals or ordinary newspapers (or on television). As soon as the issue appears in print again, it reminds about the existing controversies and the communicated message can be disregarded or

misunderstood (misinterpreted) in the situation of uncertainty about environmental and health risks.

6.7. Conclusions

We analyzed bisphenol A consumption per capita, its over- and under-consumption at international level taking into account economic growth, state policies, polycarbonate prices in the European Union as a proxy for BPA prices, main final products use, information access, socioeconomic and cultural factors. Using annual panel data for the following regions North America, South America, Western Europe, CIS and Baltic States, Middle East and Africa, Indian Subcontinent, Northeast Asia (including China, Japan and the Republic of Korea and Taiwan separately) and Southeast Asia for the 1990, 1995 and 2000-2013 years, we explored the impact of economic growth on BPA consumption per capita through the estimation of the EKC. We constructed a measure of over- and under-use of consumption and empirically examined the impact of new scientific knowledge related to potential risks on BPA under-consumption which might have implications on production and marketing decisions making and planning. Rather than an inverted U-shaped relationship between consumption of bisphenol A per capita and economic growth, we found an inverted N-shaped relationship which did not support the EKC hypothesis. The Feasible Generalized Least Squares estimation procedure was a suitable approach to estimate the model given the presence of heteroscedasticity. Several additional explanatory variables were chosen to assess the consumption of bisphenol A per capita at cross-regional level. We employed a principal component analysis, the Wald test and cross validation procedures to select a subset of the predictor variables for a cross-regional analysis of BPA. We demonstrated the usefulness of CD player possession as proxy for final goods demand together with cable TVs in explaining BPA consumption. The underlying mechanism behind the inverted N-shaped relationship between BPA consumption and GDP in a situation of uncertainty about environmental and health risk of bisphenol A can be explained by direct (voluntary) limitation on BPA consumption, technological enhancement that allows to use less polycarbonate, changes in input mix that is a substitution of potentially dangerous inputs by less dangerous inputs. These decisions can be provoked by new scientific knowledge about potential risk. Unfortunately, wide usage of BPA and unavailability of detailed data do not allow to test how potential changes in technological improvement and input-mix impact polycarbonate consumption. Besides, the

limited existence of substitutes in the past eliminates the need to include them in the analysis over the studied period. Therefore, we do not consider this limitation as a serious one. However, the model can be extended by other factors which influence BPA consumption to avoid omitted variable bias if the size of the data set and availability of data on other explanatory variables permit. For example, an environmental awareness and/or awareness about potential risks of BPA might play an important role in the relationship between BPA consumption and economic growth.

The growing concerns over endocrine-disrupting properties of BPA resulted in a large number of scientific publications about BPA risks and in bans on its use in several products. In this study we constructed several new scientific knowledge measures by evaluating the relevance of 1469 abstracts containing keyword “bisphenol A” from PubMed. First, we used the volume of scientific papers about risk related to the use of BPA as a measure of new scientific knowledge to examine the relationship between under-consumption of BPA, new scientific knowledge and uncertainty avoidance. The hypothesis that the higher the number of scientific articles related to potential risks of BPA, the greater the under-use of BPA, could not be rejected. The result supported the hypothesis that uncertainty avoidance had a moderating effect on the relationship between scientific knowledge about potential risk and over and under-consumption of bisphenol A in a situation of uncertainty about environmental and health risk. However, further application of parametric technique would be desirable if larger and more detailed dataset existed. Despite the different measures of scientific knowledge, the pattern of the relationship did not change for these entities (with slight changes in downturn points). Any of the measures (“BPA”, “Risk”, “No risk”, “Uncertain”) could be used in the analysis in the situation of uncertainty regarding environmental and health risks. However, it was suggested using “BPA” measure or its equivalent in future studies in the situation of uncertainty about environmental and health risks. This result might suggest that the increasing quantity of articles with the divergent conclusions and the underlying controversy matter rather than articles concluding that there is risk.

The concern about endogeneity arose from the fact that a substantial BPA consumption could attract the attention of scientists to the issue of potential risk and as a result the overall quantity of scientific reports could increase. We conducted a formal test of a simultaneity problem. We estimated the extended model using regional totals for R&D expenditure at world level as the instrument by the fixed effect instrumental variable approach with robust

standard errors including the weak identification test and the endogeneity tests. No contemporaneous endogeneity was detected.

Additionally, we evaluated the impact of the bans on BPA use in baby bottles production¹⁵⁰ on aggregate consumption of BPA. The coefficient on the ban introduced in the US and consumption of bisphenol A per capita is positive, but it is statistically significant. Positive sign could be explained by voluntary replacement of bisphenol A component in baby bottles that had preceded the ban on BPA use in the bottles. We found that the average aggregate consumption of bisphenol A per capita had significantly increased due to the ban introduction on the BPA use in the baby bottles production in the EU, China, Brazil and Malaysia in 2011. The increase in the consumption of aggregate level of bisphenol A per capita could be explained by the shift from production of baby bottles to other products with BPA as an input using the same equipment. Another reason could be the effect of green light to other applications which were not banned. Besides, the displacement hypothesis could be another reason for increased consumption of BPA. The displacement hypothesis is also related to international trade which is one of the drivers that explains the EKC. We do not include this factor in the analysis which can be one of the limitations of this study.

One of our results suggests that certain factors might have different influence at the same stage in the absence of uncertainty and in its presence. For example, Golder & Tellis (2004) have found that a decrease in income can be associated with an increase in probability of slowdown. Contrary to these findings, we have found that higher income might be associated with a decrease in consumption of product in a situation of uncertainty about environmental and health risks. At higher level of income, people become more concerned about environment and health and as a result production/generation of byproducts can be reduced by the choice of consumption of the main product (or input).

¹⁵⁰ The ban that was introduced over the studied period

Chapter 7. Assessing the influence of economic growth and new scientific knowledge about risk on polycarbonate consumption in Japan

Despite the growing importance of scientific publications related to potential risk of bisphenol A (BPA), the link between new scientific knowledge of the potential BPA risk, economic growth and consumption of a secondary intermediate good containing BPA, namely, polycarbonate (PC)¹⁵¹ is poorly documented. Specifically, this chapter has two goals. First, our goal is to study if an inverted N-shaped relationship between is valid both for individual country consumption of polycarbonate and global consumption of bisphenol A. Second, our goal is to explore the role of scientific articles about potential risks of BPA in polycarbonate consumption in a situation of uncertainty about risks. We conduct analysis for Japan, one of the first countries that started replacing BPA voluntarily. As we have mentioned previously, Japan has the highest uncertainty avoidance index among regions analyzed. Moreover, BPA consumption in Japan has crossed the turning point which is characterized by a decrease in sales together with a higher income (see Chapter 6). Given the availability of quarterly data on sales value of polycarbonate and producer price index (PPI) of polycarbonate from Datastream, we use the Vector Error Correction Model (VECM) of the polycarbonate sales in volume at constant prices (2010), GDP per capita in Japan, its quadratic term together with the global volume of scientific articles related to BPA risks. Our goal is to analyze polycarbonate sales in Japan following the introduction of new scientific knowledge about potential risk of BPA.

This chapter is organized as follows. First, data on polycarbonate sales and the other variables is described and our methodology is discussed. Then, estimation results for polycarbonate sales in Japan are presented, followed by conclusion.

¹⁵¹ BPA is used in PC production and both of them are intermediate goods.

7.1. Data and methodology

7.1.1. Data

Japan started the voluntary replacement of bisphenol A in the late 1990s before an interim scientific conclusion on a point related to risk was drawn by the Japanese Committee on Health Effects of Endocrine Disrupting Substances (Nakanishi et al., 2007). The authors report that in 1998 around 300 local municipalities changed tableware made from polycarbonate used in schools and in 1999 around 500 municipalities were about to replace the tableware. Additionally, they provide evidence that epoxy resin films were partially substituted for PET films in the coating of beverage cans and PVC producers decreased substantially the quantity of BPA in the production. The fast BPA replacement in Japan was triggered by social concerns. Potential risks of bisphenol A reinforced the negative public attitude towards the chemicals which had been formed earlier as a result of the dioxin pollution. Dioxin emissions originating from a large quantity of waste incinerators in Japan turned society's attention to endocrine disrupting chemicals (Malisch & Kotz, 2014; Tajimi et al., 2005). Under these circumstances, does the volume of scientific publications on BPA play any role in the determination of polycarbonate (PC) sales? Following our discussion about potential side-effects of BPA and reduction in its use as a result of changes in income together with scientific evidence of potential risks to environment and health in the previous chapters, is there an inverted U-pattern link between polycarbonate consumption and economic growth? How does consumption of polycarbonate in Japan respond to variations in quantity of new scientific knowledge about potential risks of bisphenol A?

We study the impact of income and the volume of new scientific publications related to risk of bisphenol A on consumption of polycarbonate in Japan with a VECM model using quarterly data on sales value of polycarbonate, its price index, GDP per capita, its quadratic term and the global volume of publications for the following period: 1990:Q1 – 2013:Q4. BPA is used in PC production and PC is an intermediate good as well as BPA. In 2013 about 70% of BPA consumption occurred in PC production (Sriram et al., 2014). While the PC sales and new scientific knowledge diffusion processes deal with time, the time series analysis is appropriate for depicting a dynamic behavior of joint movement of these variables.

Seasonality and sample construction

Datastream provides non-seasonally adjusted monthly data on the sales value of polycarbonate (Japanese Yen) and the domestic producer price index for polycarbonate (PPI, index, 2010=100) in Japan. Besides, Datastream gives non-seasonally adjusted quarterly data on Gross Domestic Product per capita, GDP¹⁵² (total at market prices, constant prices, Japanese Yen, 2010 prices) in Japan. Sriram et al. (2014) indicate that consumption of bisphenol A is affected by demand for epoxy resin and polycarbonate which are in turn influenced by the “overall health of the economy”. To construct a parsimonious model, the choice of the variables is based on the empirical literature on diffusion of innovation, intermediate and final goods demand (Bourbonnais & Usunier, 2013; Chandrasekaran et al., 2013; de Freitas & Kaneko, 2011; Horbach et al., 2014; Tellis et al., 2003) and the Environmental Kuznets Curve.

Given that PPI data is available since 1990, all datasets are extracted over the period of 1990-2013. The volume of global publications is initially available on a monthly basis. Therefore, the quantities of articles related to the potential risks of BPA are counted on a monthly basis and then converted to a quarterly basis as GDP is available on a quarterly basis. Total quarterly sales value and mean quarterly PPI are constructed as well. Seasonal adjustment (SA) for quarterly sales value, PPI and GDP was carried out using the BV4.1 procedure¹⁵³ given that many economic time-series possess seasonal patterns. Several authors (Milanovic et al., 2015; Shi, Liu, Chen, & Zhang, 2014) observe variations in BPA concentrations in surface water over the seasons which might be explained by changes in man’s activity which suggests the need to account for a possibility of seasonality .



Figure 47. Original quarterly GDP per capita series (dashed line) and seasonally adjusted quarterly GDP per capita (blue line), Japanese Yen, 1990-2013

Source: Ostapchuk, based on Datastream

¹⁵² The data was extracted on February, 2015

¹⁵³ <https://www.destatis.de/EN/Methods/TimeSeries/TimeSeriesAnalysis.html>, accessed on July, 2015

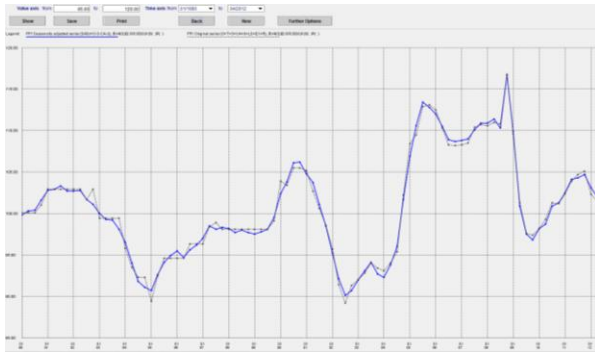


Figure 48. Original quarterly PPI (dashed line) and seasonally adjusted quarterly PPI (blue line), index, 2010=100, 1990-2013

Source: Ostapchuk, based on Datastream



Figure 49. Original quarterly sales value of PC (dashed line) and seasonally adjusted quarterly sales value of PC (blue line), Japanese Yen, 1990-2013

Source: Ostapchuk, based on Datastream

Figure 47 - Figure 49 show the quarterly data on 3 variables. The preliminary evaluation of data series shows the existence of a structural break (a sudden change in 2008-2009 which corresponds to the recession of 2008-2009) which may lead to structural changes in the process. The Chow test of structural change for the potential break date is presented in the last subsection of this chapter.

Given the after-break sample is relatively short (it includes only 26 periods), the estimation of this part separately¹⁵⁴ will lead to misleading results, therefore we will not proceed with estimation of the post-break sample. Besides, the goal of the current analysis is to describe the data rather than generate forecasts. Thus, a pre-break sample is only analyzed. Moreover, the recession may change attitude towards potential risk.

Figure 47 - Figure 49 also suggest the existence of a unit root for all variables of interest. Formal test for stationarity of time-series using the augmented Dickey-Fuller and Phillips-Perron tests are presented further below for the period from 1990 to the end of 2007 given

¹⁵⁴ It is one of the methods to deal with structural breaks

that in the presence of structural breaks, the Dickey-Fuller tests result in biased statistics (Enders, 2004).

Given the unavailability of polycarbonate sales in volume, we transform quarterly sales value to sales in volume at constant prices (2010). We use quarterly PPI to eliminate a direct effect of changes in prices on sales value and compute sales of polycarbonate in volume at constant prices at time t ($Sales_t$):

$$Sales_t = \frac{Sales\ value_t * 100}{PPI_t} = P_{2010} * Q_t$$

where $Sales\ value_t$ is a sales value of polycarbonate at time t , PPI_t is a PPI at time t , P_{2010} is a price of polycarbonate at period t and Q_t is sales of polycarbonate. $Sales_t$ per capita is computed by dividing $Sales_t$ in Japan by the average population¹⁵⁵ at time t (million people). Figure 50 presents a locally weighted smoothing scatter plot of seasonally adjusted GDP per capita on the log scale and sales of polycarbonate per capita on the log scale. A preliminary data analysis suggests that the relationship between centered GDP per capita on the log scale and sales of polycarbonate per capita on the log scale is nonlinear. Besides, Figure 50 suggests that the analysis with squared term only can be conducted avoiding the cubed term given the shape of the relationship. Data on the logarithmic scale is used in the analysis. As we have mentioned earlier, the variable “BPA” is transformed in logarithm adding 1 to the data prior to transformation. To avoid a perfect collinearity between GDP per capita on the log scale and its squared term, we perform a mean centering.

¹⁵⁵ Extracted from Datastream, October 2014

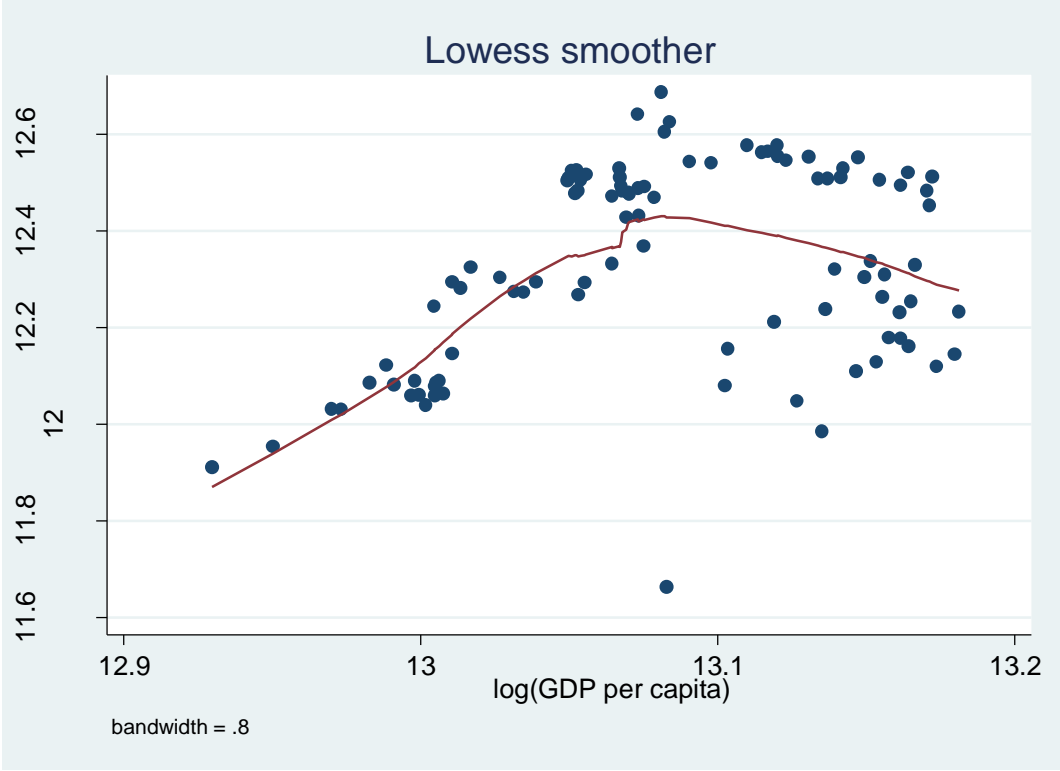


Figure 50. *Locally weighted smoothing scatter plot of seasonally adjusted GDP per capita on the log scale and sales of polycarbonate per capita on the log scale, 1990-2016*
 Source: Ostapchuk, based on Datastream

Descriptive statistics

Table 31 provides summary statistics and description of the variables employed in the sample over 1990:Q1 – 2007:Q4. The lowest sales are observed in the first quarter of 1990 and the highest one is observed in fourth quarter of 2005. The lowest GDP per capita is documented in the first quarter of 1990 and the highest one is observed in the fourth quarter of 2007.

Table 31. Summary statistics of the key variables on the log scale, 1990:Q1 – 2007:Q4

Variable	Obs	Mean	Std. Dev.	Min	Max	Description
Log(Sales)	72	12.3755	.2021	11.9116	12.6870	Log of sales of polycarbonate in volume at constant prices (2010) per capita ¹⁵⁶ (per million people)
Log(GDPc)	72	-.02169	.0561	-.1527	.0899	Log of GDP per capita centered on mean
Log(BPA)	72	1.2104	1.0212	0	2.8904	Log of the volume of scientific articles

¹⁵⁶ In our analysis, we use Sales per million people. However, in our discussion, we name it per capita as the results can be easily transformed in per capita terms.

Variable	Var	Skewness	Kurtosis	p5	p25	p50	p75	p95
Log(Sales)	.0408	-.7034	2.1237	12.0323	12.2556	12.4814	12.5223	12.6055
Log(GDPc)	.0032	.0881	2.4285	-.1092	-.0720	-.0180	.0118	.0793
Log(BPA)	1.0428	.0028517	1.4104	0	0	1.3863	2.2499	2.5649

*SA stands for seasonally adjusted

Source: Ostapchuk, based on Datastream and PubMed

The mean sales of polycarbonate on the log scale is 12.38. The inter-quartile range is 0.26, the skewness statistic is -0.70 and kurtosis is 2.12. The kurtosis is slightly lower than the value of kurtosis for normally distributed data which corresponds to 3. The distribution is slightly skewed to the left, and the median sales value, 12.48, is slightly higher than mean sales value. The mean seasonally adjusted GDP centered on mean per capita of the sample on the log scale between 1990:Q1 – 2007:Q4 is -.02. The inter-quartile range is 0.08, the skewness statistic is 0.09 and kurtosis is 2.43. The distribution of data on GDP is right-tailed with median, -.02, very close to the mean value.

The mean number of articles related to the potential risk of BPA on the log scale over the period 1990:Q1 – 2007:Q4 is 1.21 which is lower than median, 1.38. The distribution of articles is right-tailed. The skewness statistic is 0.003 compare to 0.74 for BPA in levels¹⁵⁷ and kurtosis is 1.41 compared to 2.34 for BPA in levels.

As highlighted previously, visual analysis of the untransformed data on the natural scale shows that each variable is nonstationary. Figure 71-Figure 74 (Appendix H) show the transformed variables. Table 32 presents the augmented Dickey-Fuller and Phillips-Perron tests statistics for data on the log scale. Dickey-Fuller test result suggests that we cannot reject the hypothesis of existence of a unit root at 10% level of significance for all variables, while Phillips-Perron test suggests that that we cannot reject the hypothesis of the existence of a unit root at 10% level for all variables except the squared term of GDP and the quantity of scientific articles. Therefore, all series are non-stationary according to the illustrations and the augmented Dickey-Fuller test, and the data is transformed on the log scale into first differences. Both tests imply that we can reject the hypothesis of the existence of a unit root at 10% level of significance for all variables in differences.

¹⁵⁷ One of the approaches to deal with skewed data is to perform a logarithmic transformation (Jones et al., 2012).

Table 32. Stationarity tests (log scale) with constant and trend terms, 1990:Q1 – 2007:Q4

Variables	Augmented Dickey-Fuller, 4 lags	Phillips-Perron	Variables	Augmented Dickey-Fuller, 5 lags	Phillips-Perron
Log(Sales)	-0.712	-1.763	Δ SA_Sales	--4.700***	-7.769 ***
Log(GDPc)	-2.083	-3.058	Δ SA_GDP	-3.323 *	-6.600***
(Log(GDPc)) ²	0.517	-4.725***	Δ SA_PPI	-3.746 **	-8.926 ***
Log(BPA)	-1.816	-6.498***	Δ BPA	-5.118 ***	-21.989 ***

Critical values for augmented Dickey-Fuller test are 1%=-4.11, 5%=-3.48, 10%=-3.17.

Critical values for Phillips-Perron test are 1%=-4.104, 5%=-3.479, 10%=-3.167

***denotes statistical significance at 1% level

**denotes statistical significance at 5% level

*denotes statistical significance at 10% level

Source: Ostapchuk, based on Datastream and PubMed

Given that all our series on the logarithmic scales are non-stationary, we cannot exclude the possibility to have a stationary linear combination of variables. Our multiple equation model suggests that there can be maximum three linearly independent cointegrating vectors as we have 4 variables. Hence, the Johansen methodology to test for cointegration is suitable as it can take into account multiple cointegrating vectors (cointegration and the Johansen methodology are further discussed in the methodology subsection).

7.1.2. Methodology

7.1.2.1. Modeling multiple time series

The VAR/VECM framework is particularly relevant as it allows to consider variables as endogenous. It allows to estimate the variation in each variable due to fluctuations in each of the endogenous variable. Our principal hypothesis is that changes in polycarbonate consumption are associated with fluctuations in economic growth. Besides, we cannot exclude the possibility that changes in sales are directly associated with changes in the volume of scientific articles.

Initially, the Vector Auto Regression (VAR), Vector Error Correction (VECM) models and cointegration approaches were used in macroeconomics. They summarize a conjoined movement of two or more series, which allows to describe them and perform a forecast if it is needed (Stock & Watson, 2001). More recently, these approaches have been applied to financial data and to study the interrelationship between agriculture and fuel markets (McPhail, 2012; Qiu, Colson, Escalante, & Wetzstein, 2012; Zhang, Lohr, Escalante, & Wetzstein, 2009). Hao et. al (2015) apply VECM to investigate linkages between soybean, corn, animal farming, ethanol industry and a hardly evitable supply shock related to these industries in the form of drought. (Jiang et al., 2015) analyze the relationship among plastics, crude oil,

corn and the US corn-related policies using VECM. Moreover, these approaches are used in the analysis of fossil fuel markets (McPhail, 2011) and ethanol demand (de Freitas & Kaneko, 2011; Zhang et al., 2009)¹⁵⁸.

Besides, Bourbonnais & Usunier (2013) proposes the VAR/VECM as a useful model in the industrial sector to predict sales of intermediate goods by including sales, price and stock¹⁵⁹ of the good. Dekimpe & Hanssens (1995); Freo (2005); Joshi & Hanssens (2010) apply VAR to study different marketing effects on sales.

We can start with the following first-order reduced VAR:

$$x_t = A_0 + A_1x_{t-1} + e_t$$

where A_0 is ($n \times 1$) matrix of intercept term, $A_i = (n \times n)$ matrices of coefficients, x_t is ($n \times 1$) vector (Log(Sales), Log(GDPc), (Log(GDPc))², Log(BPA)) and e_t is ($n \times 1$) vector of error terms.

It can be transformed into the vector error correction model which is equivalent to cointegrating representation according to a Granger representation theorem¹⁶⁰:

$$\begin{aligned} \Delta x_t &= x_t - x_{t-1} = A_0 + \pi x_{t-1} + e_t \\ \pi &= -(I - A_1) \end{aligned}$$

where the rank of $(A_1 - I)$ is the quantity of cointegrating vectors.

The pretesting of the variables on the logarithmic scales using plots and the formal tests, namely the Augmented Dickey-Fuller and Phillips-Perron tests, reveal that they are non-stationary with the same order of integration, which is $I(1)$. It implies that these variables can be cointegrated (Enders, 2004). "Cointegration is a linear combination of nonstationary variables. These variables must be integrated of the same order. If x_t has n components, there may be as many as $n-1$ linearly independent cointegrating vectors" (Enders, 2004, p. 322).

7.1.2.2. Testing for cointegration: the Johansen methodology

Given that our model contains 4 non-stationary variables, there can be up to three cointegrating vectors. Therefore, Engle and Granger procedure is unsuitable as this approach does not allow to estimate each cointegrating vector individually if more than one vector exists. The Engle and Granger procedure is suitable for two-variables system. Therefore, we

¹⁵⁸ The results of these studies are not discussed here as they are considered as irrelevant to this study.

¹⁵⁹ While maintaining sufficient product availability is crucial to meet demand, it is likely that the level of polycarbonate production capacity is adequate as capacity constraint on BPA over the studied period is not observed (as we have discussed in Chapter 4). Thus, the unavailability of data on polycarbonate stock does not pose a problem.

¹⁶⁰ If our variables are non-stationary and we take first difference to deal with unit root processes, we may misspecify the equation in case there is a cointegrating relationship

apply the Johansen methodology as described in Enders (2004). This procedure contains three steps.

Step 1: Having implemented the test for the order of integration of each variable included in the model, the lag length should be identified using a VAR in levels. We start with the longest length seemed appropriate for a parsimonious model and then we verify if it can be decreased. Each additional lag involves the estimation of four additional parameters for each equation and associated loss of degrees of freedom. The most widely used criteria for the lag length are Akaike Information Criterion (AIC) and the Schwartz Bayesian Criterion (SBC) (Enders, 2004).

$$AIC = T\log|\Sigma| + 2N$$

$$SBC = T\log|\Sigma| + N\log(T)$$

where $|\Sigma|$ is a determinant of the variance-covariance matrix of the residuals, N is total quantity of estimated parameters and T is quantity of observations. Then, the model with minimal values should be chosen given that the models with identical quantity of observations were compared.

Step 2: The VECM should be estimated by Johansen's maximum likelihood method and then the rank of π should be defined. If rank of π equals 0, there is no cointegration and the VAR in changes should be estimated. If $\pi = n$, then the variables included in the model are stationary and an untransformed VAR model should be estimated. If $\pi = 1$ and $n \geq 2$ then there is one cointegrating vector. If $\pi = k$ and $1 < k < n$, then there are k cointegrating vectors. To test for the number of cointegrating vectors (the cointegrating rank of x_t), maximum eigenvalue and trace test can be conducted. Then, several post-estimation tests can be carried out (test for normally distributed residuals, autocorrelation in the residuals and test for stability).

Step 3: Further, to investigate the interrelationship among the variables, "innovation accounting" (impulse response functions and forecast error variance decomposition) can be performed which is discussed in the section below.

The first stage consists of three parts. First, we apply the Johansen procedure for the reduced specification of the EKC on the logarithmic scale over the period of 1990-2007 (see Figure 51), which includes the following variables: $\log(\text{Sales})$, $\log(\text{GDPc})$, $(\log(\text{GDPc}))^2$. A vast number of empirical studies on the EKC use reduced-form models. A reduced-form model is considered to be useful in measuring both direct and indirect effects of economic growth ((D. Katz, 2015; Saboori, Sulaiman, & Mohd, 2012b). However, it can suffer from the omitted variable bias.

Second, the Johansen procedure will be implemented for the extended model on the logarithmic scale over this period, which in addition to $\log(\text{Sales})$, $\log(\text{GDPC})$, $(\log(\text{GDPC}))^2$ includes $\log(\text{BPA})$. Due to unavailability of quarterly data on other industry-specific factors and a small sample size, in order to construct a parsimonious model, we will not include other potentially relevant variables in the analysis (information access, trade, technological progress, other external shocks, etc). Third, the performance of both models (reduced and extended) will be compared over the period of 1990-2007 (rather short period of comparison was chosen given a relatively small pre-break sample size). As soon as we have chosen a model that performs better, we perform an innovation accounting (stage 2). This stage corresponds to step 3 of the Johansen methodology. Then, we perform a formal test for a structural break (stage 3).

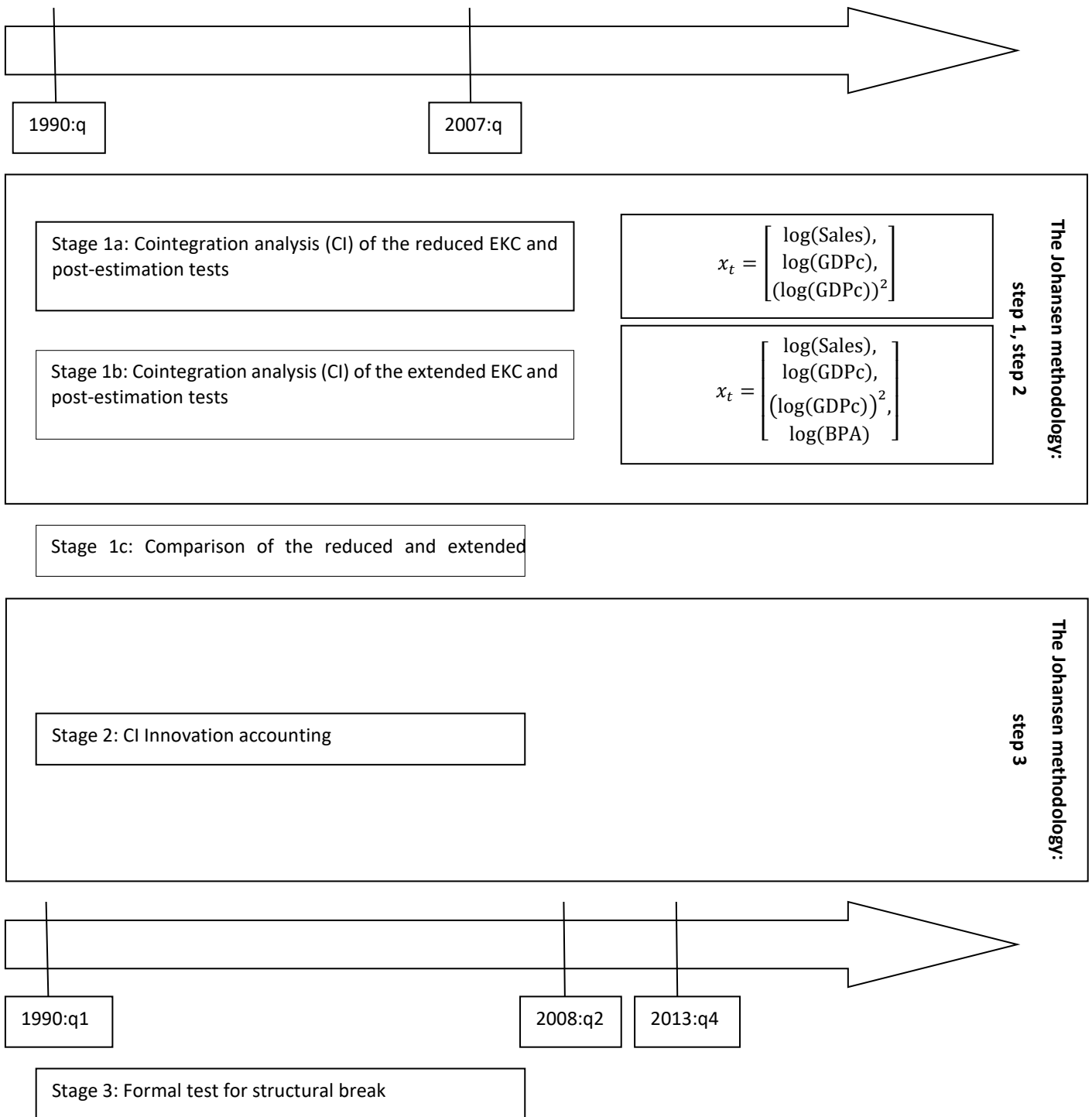


Figure 51. The stages of the analysis involving the reduced and extended models
Source: Ostapchuk

7.2. Estimation results

Stage 1a: Estimation results for the reduced model on the log scale, 1990:Q1 – 2007:Q4

The first step of the Johansen methodology¹⁶¹ involves defining the order of integration of each variable (the results are presented above, see Table 6.2) and estimating a VAR without difference transformation to determine the lag length. Lag length is tested for the following VAR:

$$x_t = A_0 + A_1 x_{t-1} + A_2 x_{t-2} + \dots + A_p x_{t-p} + \epsilon_t$$

where A_0 is $(n \times 1)$ matrix of intercept term, $A_i = (n \times n)$ matrices of coefficients, x_t is $(n \times 1)$ vector $(\log(\text{Sales}), \log(\text{GDPc}), (\log(\text{GDPc}))^2)$ and ϵ_t is $(n \times 1)$ vector of error terms and p is a lag length.

Table 33. Lag order selection, 1990 – 2007¹⁶²

Selection-order criteria

Sample: 1991q1 - 2007q4		Number of obs: 64						
Lag	LL	LR	df	P	FPE	AIC	HQIC	SBIC
0	474.873				7.9e-11	-14.746	-14.7062	-14.6448
1	799.127	648.51	9	0.000	4.2e-15*	-24.5977*	-24.4382*	-24.1929*
2	804.059	9.8635	9	0.362	4.7e-15	-24.4706	-24.1915	-23.7622
3	809.273	10.428	9	0.317	5.4e-15	-24.3523	-23.9536	-23.3403
4	818.067	17.588	9	0.040	5.5e-15	-24.3458	-23.8276	-23.0303
5	829.879	23.625*	9	0.005	5.1e-15	-24.4337	-23.7958	-22.8146
6	833.183	6.6081	9	0.678	6.2e-15	-24.2557	-23.4982	-22.333
7	838.34	10.314	9	0.326	7.2e-15	-24.1356	-23.2586	-21.9093
8	844.538	12.395	9	0.192	8.2e-15	-24.0481	-23.0514	-21.5181

Endogenous: $\log(\text{Sales}), \log(\text{GDPc}), (\log(\text{GDPc}))^2$

Exogenous: $_cons$

Source: Ostapchuk, based on Datastream and PubMed

Akaike's information criterion (AIC), Schwarz's Bayesian information criterion (SBIC) and the Hannan and Quinn information criterion (HQIC) indicate the same lag length despite the small sample size (Table 33). AIC and SBIC are the most widely used approaches for parsimonious model selection (Enders, 2004). As a result, we include 1 lag in the Vector Error Correction model to determine the number of cointegration vectors.

¹⁶¹ Stage 1a and stage 1b: each stage involves step 1 and step 2

¹⁶² We use Stata 13 to perform our analysis

Table 34 .Johansen tests for cointegration

Trend: constant, Number of obs=71					
Sample: 1990q3 - 2007q4 , Lags=1					
maximum rank	parms	LL	eigenvalue	trace statistic	critical value 5%
0	3	809.89655	.	103.4044	29.68
1	8	855.17322	0.72068	12.8510*	15.41
2	11	859.83709	0.12311	3.5233	3.76
3	12	861.59874	0.04841		
maximum rank	parms	LL	eigenvalue	max statistic	critical value 5%
0	3	809.89655	.	90.5533	20.97
1	8	855.17322	0.72068	9.3277	14.07
2	11	859.83709	0.12311	3.5233	3.76
3	12	861.59874	0.04841		

Source: Ostapchuk, based on Datastream and PubMed

Johansen test for cointegration indicates that there is 1 cointegrating relationship between these three variables (the rank of $\pi = 1$). The results are presented in Table 34.

We reject the null hypothesis of no cointegration (zero cointegrating equation). Therefore, we proceed with estimation of VECM by applying the Johansen’s maximum likelihood method.

$$x_t = A_0 + A_1 x_{t-1} + e_t$$

$$x_t - x_{t-1} = A_0 + A_1 x_{t-1} + e_t - x_{t-1}$$

$$\Delta x_t = A_0 + (A_1 - I)x_{t-1} + e_t$$

$$\Delta x_t = A_0 + \pi x_{t-1} + e_t$$

π is the error-correction term, rank of π is r (which equals 1). π can be expressed as $\alpha\beta'$. Both α and β are $(n \times r)$ with rank r where α is the speed of adjustment and $\beta(s)$ are coefficient(s) in the cointegrating equation.

Having estimated the following model, we test the hypothesis that a trend term in the cointegrating relationship equals 0 using a likelihood-ratio test. We fail to reject this hypothesis at 1% level of significance (p-value equals 0.85), therefore, we eliminate the linear trend in the cointegrating equation. Next, we test the hypothesis of no trends in the untransformed (undifferenced) data. We fail to reject this hypothesis at 1% level of significance (p-value equals 0.85). Finally, we test the hypothesis that there is no trend and constant at 1% level of significance (p-value equals 0). We reject this hypothesis at 1% level of significance. Eventually, we estimate a model with 1 lag and an unrestricted constant. The result of adjustment coefficient vector is presented in Table 35.

Table 35. VECM results, reduced form, 1 lag, 1 cointegrating equation

Equation	Adjustment coefficient vector	Constant
log(Sales)	0.0239041 (0.0189)	0.000158 (0.00783)
log(GDPc)	0.00969*** (0.00273)	5.25e-05 (0.00113)
(log(GDPc)) ²	-0.00384*** (0.000312)	0.00112*** (0.000129)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Ostapchuk, based on Datastream and PubMed

The equilibrium relationship is

$$\log(\text{Sales}) = 12.2990 + 4.3896 * \log(\text{GDPc}) - 48.4656 * (\log(\text{GDPc}))^2$$

(0.3736) *** (4.7631) ****

Having estimated the following model, several tests are run to assess the model adequacy, namely test for autocorrelation in residuals, normally distributed residuals and stability of the estimates.

The post-estimation reveals that the hypothesis of normally distributed residuals cannot be rejected at 1% level of significance. The Jarque-Bera test, the Lagrange-multiplier test and the Eigenvalue stability condition are presented in Table 36 below. The test for autocorrelation suggests that the hypothesis of no autocorrelation cannot be rejected at 1% level of significance. A process can be considered stable as the remaining eigenvalue lies inside the unit circle (there are n-r unit eigenvalues).

Table 36. Post-estimation tests, reduced form

Jarque-Bera test

Equation	chi2	df	Prob > chi2
log(Sales)	1.781	2	0.41037
log(GDPc)	1.646	2	0.43908
(log(GDPc)) ²	5.622	2	0.06016
All	9.049	6	0.17084

Lagrange-multiplier test

Lag	chi2	df	Prob > chi2
1	7.1131	9	0.62535
2	5.8575	9	0.75409

H0: no autocorrelation at lag order

Eigenvalue stability condition

Eigenvalue	Modulus
1	1
1	1
.7953	.7952

Source: Ostapchuk, based on Datastream and PubMed

The results confirm the existence of long-run relationship between consumption of polycarbonate and economic growth in Japan where log of GDP has a positive relation with sales of polycarbonate and the squared term of GDP has a negative relationship with sales. The results are consistent with our expectations. The coefficients on the log of GDP and its quadratic terms are statistically significant at 1% level of significance. The coefficients can be seen as elasticities. If the equilibrium is achieved, on average, a 1% increase in GDP per capita is associated with 4,39 % increase in polycarbonate sales per capita (per million) until a particular level of GDP. Then, a 1% increase in GDP per capita is associated with 48,47 % decrease in polycarbonate sales per capita (per million). The turning point of centered logarithm of per capita GDP is 0,0452 which corresponds to about 500 thousands Japanese Yen. The results support the EKC in long-run as they show the existence of an inverted U-type relationship between consumption of polycarbonate and economic growth. According to the Phillips-Perron test for unit root, we can reject the hypothesis of the existence of a unit root at 1% level of significance for the cointegrating equation ($Z(t)=-6.097$). The graphical representation (Appendix H) confirms the existence of inverted U-type relationship (given a small sample, we focus on the pattern of the relationship, but not on the precise size of parameters).

The speed of adjustment coefficient in sales equation is not statistically insignificant at 1% level of significance. It implies that sales change in response to its disturbance term and its short run dynamics does not change in response to a deviation from long run equilibrium¹⁶³. The speed of adjustment coefficients in GDP and its squared term equations are both statistically significant. Therefore, only these two variables respond to a deviation from equilibrium and correct it. However, relatively small values of these coefficients (speed of adjustment) suggest that the responses of GDP and its squared term to the previous period's deviation from the long-run equilibrium are relatively low.

The equilibrium is achieved when

$$\log(\text{Sales}) = 12.2990 + 4.3896 * \log(\text{GDPc}) - 48.4656 * (\log(\text{GDPc}))^2$$

If it is attained, our variables are influenced only by changes in stochastic shocks. As it was mentioned previously, the VECM includes only 1 lag. It might suggest that the short-term dynamics of all variables are not significantly influenced by other variables in the system.

¹⁶³ Cointegration implies a long-rung equilibrium among non-stationary variables. "The equilibrium relationship may be causal, behavioral or simply a reduced-form relationship" (Enders, 2009, p. 360).

Stage 1b-1c: Estimation results for the extended model on the log scale, 1990:Q1 – 2007:Q4

We first examine the relationship between sales of polycarbonate and the quantity of articles related to potential risk of BPA by analyzing cross-correlation functions (Figure 52). According to these cross-correlation functions, increases in the quantity of articles related to risk today are correlated with decreases in the sales in the future and increases in the sales seem to correlate with increases in the quantity of articles. We cannot exclude the possibility that changes in sales (which can change exposure level) might increase interest of researchers in the future and therefore the quantity of publications. However, we do not expect that this effect is contemporaneous.

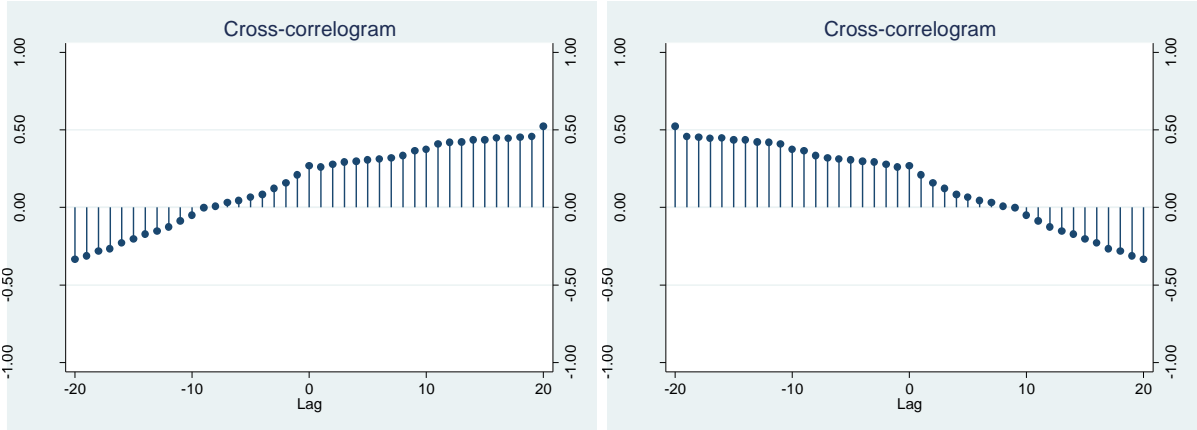


Figure 52. Cross-correlations of log(Sales) and log(BPA), 1990-2013
 Source: Ostapchuk, based on Datastream and PubMed

Therefore, we have extended our model by the quantity of articles related to potential risk of BPA. The Johansen procedure was carried out to test for the possibility of cointegrating relationships among the variables. As in the previous case, first, the lag length and the cointegrating rank are defined.

Table 37. Lag order selection, 1990 – 2007

Selection-order criteria

Sample:	1991q1	-				Number of obs: 64		
	2007q4							
Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	440.213				1.4e-11	-13.6317	-13.5785	-13.4967
1	772.86	665.29	16	0.000	7.1e-16	-23.5269	-23.2611*	-22.8522*
2	791.697	37.675	16	0.002	6.6e-16*	-23.6155*	-23.1371	-22.4012
3	802.917	22.439	16	0.130	7.7e-16	-23.4661	-22.7751	-21.7121
4	819.548	33.263	16	0.007	7.8e-16	-23.4859	-22.5822	-21.1921
5	835.6	32.103	16	0.010	8.2e-16	-23.4875	-22.3712	-20.654
6	843.983	16.766	16	0.401	1.1e-15	-23.2495	-21.9206	-19.8762
7	854.57	21.175	16	0.172	1.5e-15	-23.0803	-21.5388	-19.1674

Sample: 1991q1 - 2007q4						Number of obs: 64		
Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
8	872.172	35.203*	16	0.004	1.6e-15	-23.1304	-21.3762	-18.6777

Endogenous: log(Sales), log(GDPc), (log(GDPc))², log(BPA)

Exogenous: _cons

Source: Ostapchuk, based on Datastream and PubMed

Schwarz's Bayesian information criterion (SBIC) and the Hannan and Quinn information criterion (HQIC) indicate the same lag length (Table 37). However, Akaike's information criterion (AIC) indicates a longer lag length than SBIC and HQIC (2 instead of 1). We proceed including 2 lags and then we conduct a post-estimation procedure. The Johansen test for determining the presence of cointegration (Table 38) suggests that there is 1 cointegrating equation, that is there is a linear combination of integrated of order 1 or I(1) processes which is stationary or I(0). Thus, we estimate VECM with 2 lags and 1 cointegrating vector.

Table 38. Johansen tests for cointegration

Trend: constant, Number of obs=70					
Sample: 1990q3 - 2007q4 , Lags=2					
maximum rank	parms	LL	eigenvalue	trace statistic	critical value 5%
0	20	824.24537	.	51.1032	47.21
1	27	837.43619	0.31400	24.7215*	29.68
2	32	845.42883	0.20416	8.7362	15.41
3	35	849.16973	0.10137	1.2544	3.76
4	36	849.79695	0.01776		
maximum rank	parms	LL	eigenvalue	max statistic	critical value 5%
0	20	824.24537	.	26.3816	27.07
1	27	837.43619	0.31400	15.9853	20.97
2	32	845.42883	0.20416	7.4818	14.07
3	35	849.16973	0.10137	1.2544	3.76
4	36	849.79695	0.01776		

Source: Ostapchuk, based on Datastream and PubMed

Having estimated this VECM, we test the hypothesis that quadratic trends in the equations are jointly insignificant performing the Wald test. We fail to reject this hypothesis at 1% level of significance. Then, we test the hypothesis that a trend term in the cointegrating relationship equals 0 using a likelihood-ratio test. We fail to reject this hypothesis at 1% level of significance, therefore, we eliminate the linear trend in the cointegrating equation. Eventually, we estimate a model with 2 lags and an unrestricted constant.

Table 39. Post-estimation tests, extended form, VECM with 2 lags and 1 cointegrating vector, 1990 – 2007

Jarque-Bera test

Equation	chi2	df	Prob > chi2
log(Sales)	2.808	2	0.24567
log(GDPc)	0.663	2	0.71791
(log(GDPc)) ²	0.652	2	0.72193
log(BPA)	1.843	2	0.39787
All	5.965	8	0.65112

Lagrange-multiplier test

Lag	chi2	df	Prob > chi2
1	36.9582	16	0.00213
2	26.8157	16	0.04358

H0: no autocorrelation at lag order

Eigenvalue	Modulus
1	1
1	1
1	1
.803135	
-.5948301	
.3204697	
.1551475 + .1951791	.24933
.1551475 - .1951791	.24933

Source: Ostapchuk, based on Datastream and PubMed

The post-estimation results of this model can be found in Table 39. The Lagrange-multiplier test detects autocorrelation in the residuals, the hypotheses of no autocorrelation at lag of first and second orders are rejected at 5% level of significance. It might suggest that lag length is inappropriate. Given that the SBIC and HQIC indicate 1 lag, we proceed with estimation of the extended model with 1 lag and an unrestricted constant. The results of post-estimation tests are presented in Table 40.

Table 40. Post-estimation tests, extended form model, VECM with 1 lag and 1 cointegrating vector, 1990 – 2007

Jarque-Bera test

Equation	chi2	df	Prob > chi2
log(Sales)	0.859	2	0.65097
log(GDPc)	1.412	2	0.49352
(log(GDPc)) ²	8.814	2	0.01219
log(BPA)	0.912	2	0.63369
All	11.997	8	0.15132

Lagrange-multiplier test

Lag	chi2	df	Prob > chi2
1	22.9246	16	0.11577
2	22.2977	16	0.13384

H0: no autocorrelation at lag order

Eigenvalue stability condition

Eigenvalue	Modulus
1	1
1	1
1	1
.78963	.78963

Source: Ostapchuk, based on Datastream and PubMed

The Jarque-Bera test shows that the hypothesis of normally distributed residuals in all equations cannot be rejected at 1% level of significance (except for $(\log(\text{GDPc}))^2$). The hypothesis of no serial correlation cannot be rejected at 1% level of significance. Additionally, our model satisfies the stability conditions with 3-unit eigenvalues. The results of this model are presented below (Table 41).

Table 41. VECM results, extended form, 1 lag, 1 cointegrating equation

Equation	Adjustment coefficient vector	Constant
log(Sales)	0.0274 (0.0221)	0.000654 (0.00760)
log(GDPc)	0.0112*** (0.00319)	0.000234 (0.00110)
$(\log(\text{GDPc}))^2$	-0.00448*** (0.000365)	0.00106*** (0.000126)
log(BPA)	-0.000450 (0.270)	0.0351 (0.0930)

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Ostapchuk, based on Datastream and PubMed

The equilibrium relationship is

$$\log(\text{Sales}) = 12.2851 + 3.5251 * \log(\text{GDPc}) - 44.2690 * (\log(\text{GDPc}))^2 + 0.0348 * \log(\text{BPA})$$

$$(0.5419) *** \quad (4.0563) *** \quad (0.0277)$$

The results of the extended model confirm the existence of long-run relationship between consumption of polycarbonate and economic growth in Japan. The results are consistent with our expectations and the reduced model. The coefficients on the log of GDP and its quadratic terms are statistically significant at 1% level of significance. The coefficient on log(BPA) is statistically insignificant at 1% level of significance. If the equilibrium is established, on average, a 1% increase in GDP per capita is associated with 3.53 % increase in polycarbonate

sales per capita (per million) until a particular level of GDP. Then, a 1% increase in GDP per capita is associated with 44,27 % decrease in polycarbonate sales per capita (per million). The results support the EKC in long run. The Phillips-Perron test for unit root suggests that we can reject the hypothesis of the existence of a unit root at 1% level of significance for the cointegrating equation ($Z(t)=-6.079$). Figure 76 (Appendix H) shows the relationship between consumption of polycarbonate and economic growth in Japan and predictions from the extended model.

The speed of adjustment coefficients in sales and BPA equations are not statistically significant at 1% level of significance. It suggests that the short run dynamics of these variables do not change in response to a deviation from long run equilibrium. The speed of adjustment coefficients in GDP and its squared term equations are statistically significant. These two variables do all the correction to remove any deviation from the equilibrium as in an error-correction model variable are affected by a deviation from long-run equilibrium in short-run. Besides, it can be concluded that all variables are unresponsive to changes in other variables in short run. The turning point of centered logarithm of per capita GDP is 0,0398 which corresponds to about 504 thousands Japanese Yen. This result is in accordance with our result in the previous chapter where we have estimated the EKC relationship between bisphenol A consumption and economic growth. Japan is one of the countries that crossed the turning point. Rather than an inverted N-type relationship between polycarbonate consumption and economic growth as in the case of bisphenol A per capita, we found an inverted U-type relationship.

While the coefficient on $\log(\text{BPA})$ together with its speed of adjustment is not statistically significant, both leave one out and repeated k fold cross validation suggest the cointegrating relationship in the extended model with $\log(\text{BPA})$ performs better than the cointegrating relationship in the reduced model (pseudo- R^2 is 0,89 and overfitting measure is 2,91). The results are presented in Table 42.

Therefore, we include this variable in the model and the equilibrium relationship is:

$$\log(\text{Sales}) = 12.2851 + 3.5251 * \log(\text{GDPc}) - 44.2690 * (\log(\text{GDPc}))^2 + 0.0348 * \log(\text{BPA})$$

(0.5419) ***
(4.0563) ***
(0.0277)

Table 42. Cross validation

Model	Cross-validation type	Results	
Reduced model	Leave-One-Out	Root Mean Squared Errors	.09
		Mean Absolute Errors	.07
		Pseudo-R ²	.80
Extended model	Leave-One-Out	Root Mean Squared Errors	.07
		Mean Absolute Errors	.05
		Pseudo-R ²	.89
Reduced model	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	5.25(1.85)
		In sample	-0.03(0.93)
		Overfitting	5.26(2.08)
		Standard errors are in parentheses	
Extended model	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	-2.86(1.00)
		In sample	-0.06(0.53)
		Overfitting	2.91(1.15)
		Standard errors are in parentheses	

Source: Ostapchuk, based on Datastream and PubMed

Stage 2: Impulse response functions and variance decomposition (innovation accounting)

Given that the aim of VAR/VECM analysis, in general, and this one, in particular, is to define the connection among the variables (Sims, 1980) and the relatively small sample size, there is no need to discuss the precise size of the estimated coefficients, we focus on the pattern of the relationship. Some further insights into the linkages between economic growth, the quantity of articles and sales of polycarbonate are given by innovation accounting (impulse response functions and variance decompositions) which are presented below.

Figure 53a-b below illustrate the selected orthogonal impulse response functions from our VECM. They show impulse responses of polycarbonate sales. The impulse response function examines the response of “current and future value” of one variable to one standard deviation shock of another variable (Stock & Watson, 2001, p. 106).

Figure 53(a) presents the response of sales to one standard deviation shock in the squared term of GDP. Figure 53(b) presents the response of sales of polycarbonate to one standard deviation shock in GDP over a 10 quarters horizon. Figure 53(c) illustrates the response of sales of polycarbonate to the quantity of scientific articles related to potential risk of BPA. Figure 53(d) shows the response of sales to its own standard deviation shock. The responses of sales as a result of impulses in these variables are permanent as they do not die out over this horizon. The impulses in GDP and its squared term do not have an immediate effect on sales. Later, sales decrease slowly as a result of one standard deviation shock to GDP and sales

creep up as a result of one standard deviation shock to its squared term. There is no contemporaneous effect due to the assumption related to the identification issue. The impulse in BPA does not affect sales immediately. Later, one standard deviation shock in the volume of scientific articles about potential risks induces sales to decline. After one standard deviation shock in sales, the sales increase immediately.

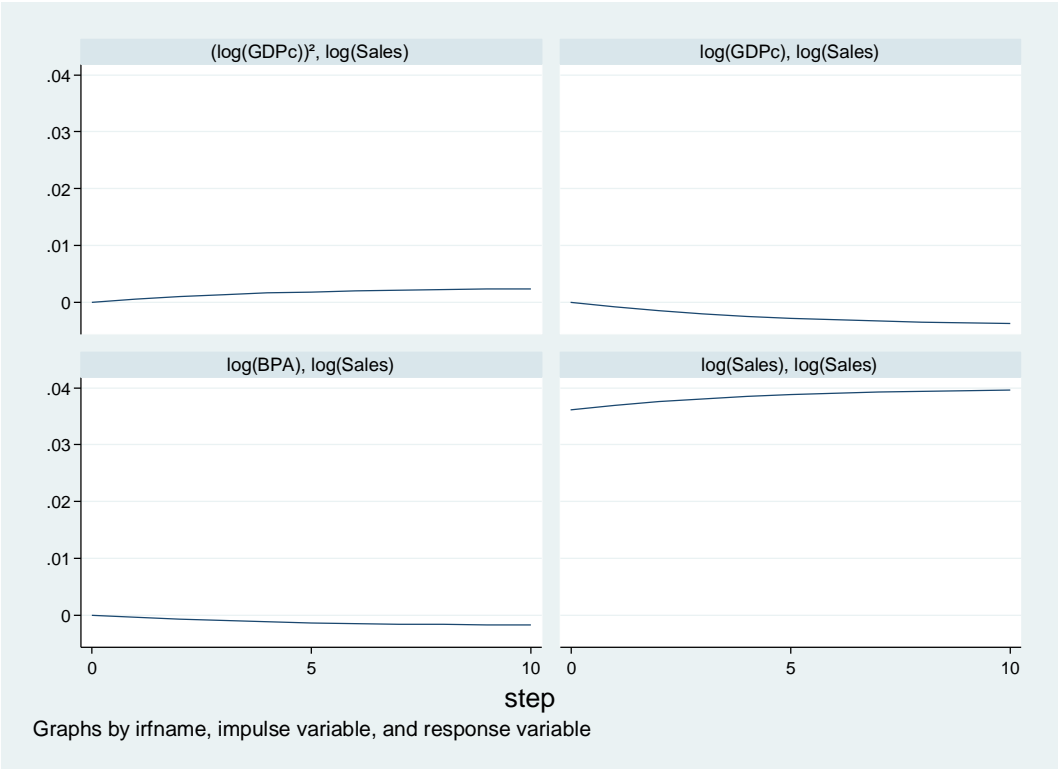


Figure 53. Responses to one standard deviation shock in selected variables in a structural VAR
 (a) Upper-left: Impulse variable: $(\log(\text{GDPc}))^2$, response variable: $\log(\text{Sales})$
 (b) Upper-right: Impulse variable: $\log(\text{GDPc})$, response variable: $\log(\text{Sales})$
 (c) Down-left: Impulse variable: $\log(\text{BPA})$, response variable: $\log(\text{Sales})$
 (d) Down-right: Impulse variable: $\log(\text{Sales})$, response variable: $\log(\text{Sales})$
 Order: $\log(\text{Sales})$, $\log(\text{GDPc})$, $(\log(\text{GDPc}))^2$, $\log(\text{BPA})$
 Source: Ostapchuk, based on Datastream and PubMed

Next, we analyze the importance of shock in each variable to the variations in sales value. Innovation accounting allows to estimate the variation in each variable due to fluctuations in each of the endogenous variable. “For each equation ... on can compute how much of the variance in the predicted path of the dependent variable [computed from the estimated coefficients] is from its own past and how much is due to the past values of the other variables in each equation” (Brandt & Williams, 2007, p.46). Table 43 presents the proportion of the forecast error variance in sales due to specific shocks in other variables over the analyzed

period (1990:Q1 – 2007:Q4). Forecast error variance decomposition gives us “the proportion of the movements in a sequence due to its own shock versus shocks to the other variable” (Enders, 2004). Our result suggests that sales describe the majority of its previous values. In the third quarter the proportion of the variance of the error made in forecasting the sales response due to a shock in the volume of articles is 0,01 %. GDP and its squared term explain only 0,07 % and 0,03 % of the forecast error variance of sales, respectively. As forecast horizon increases, the variance decomposition for the changes in levels of sales due to its own shocks diverges. The errors in predicting sales become more sensitive to disturbances in the BPA equation with time.

Table 43. Variance decomposition, selected results

	-1	-2	-3	-4
Step	fevd	fevd	fevd	fevd
0	0	0	0	0
1	1	0	0	0
2	.99954	.000283	.000112	.000065
3	.998737	.000778	.000308	.000178
4	.997778	.001368	.000542	.000312
5	.996775	.001985	.000786	.000453
6	.995789	.002592	.001026	.000592
7	.994854	.003168	.001254	.000723
8	.993985	.003703	.001466	.000845
9	.993188	.004194	.001661	.000957
10	.992463	.004641	.001837	.001059

(1) irfname = order1*, impulse = log(Sales), and response = log(Sales)

(2) irfname = order1*, impulse = log(GDPc), and response = log(Sales)

(3) irfname = order1*, impulse = (log(GDPc))², and response = log(Sales)

(4) irfname = order1*, impulse = log(BPA), and response = log(Sales)

Order1: log(Sales), log(GDPc), (log(GDPc))², log(BPA)

Source: Ostapchuk, based on Datastream and PubMed

Stage 3: The test for structural break

Since we suspected a presence of structural break, we have analyzed only a part of the series over the pre-break sample. Given that a potential breakpoint can be identified while carrying out a visual inspection of Figure 47 - Figure 49, we perform a formal test to confirm its presence based on the entire sample (1990 – 2013). We apply 3 types of Chow test to verify if the estimated coefficients before and after the potential breakpoint are different. Returning to the Figure 47 - Figure 49, it is apparent that structural change is very likely to occur in the third quarter of 2008. The selection of break date is required by the Chow test and rolling analysis can help to choose it. We estimate rolling VECM with 1 lag and 1 cointegrating vector

on sample windows of span 45, which means that first periods 1-45 periods of the sample will be used for estimation, then periods 2-46, then 3-47, etc. The estimated coefficients of speed of adjustment at the 95% confidence level from sales and GDP equations are presented in Figure 54 below. The date indicated in the figures corresponds to the end of the window size.

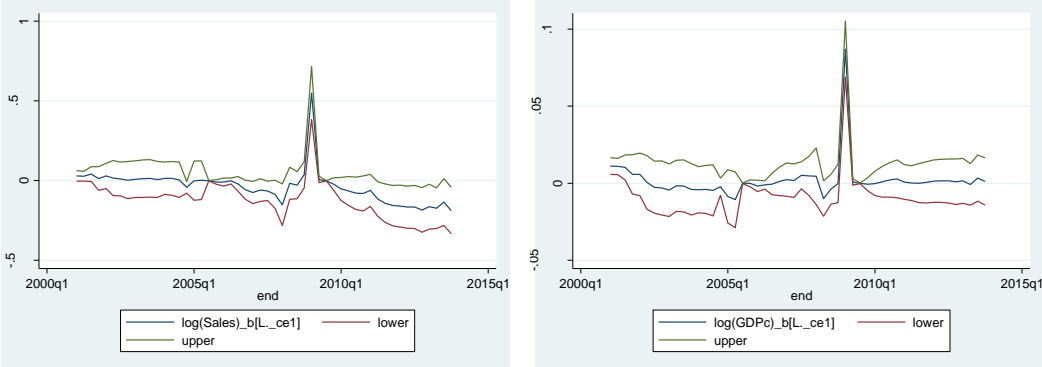


Figure 54. The selected estimation coefficients from rolling VECM with rolling window with 45 consecutive data points, 1990-2013

- a. Left: coefficient of speed of adjustment from sales equation at the 95% confidence level
- b. Right: coefficients of speed of adjustment from GDP equation at the 95% confidence level

Source: Ostapchuk, based on Datastream and PubMed

On both graphs, you may note substantial variation around the third quarter of 2008 which supports our suspicion that our potential break point is around this period. Besides, slight fluctuations are observed around the first quarter of 2005 and they require additional investigation. The overall performance of the model seems to follow a relatively stable pattern given the size of the sample. Thus, the Chow test is conducted for the third quarter of 2008, which means that we compare the estimated coefficients of the potential pre-break sample and after-break sample for the long-run relationship.

The following three models are estimated:

1. $\log(\text{Sales}) = \beta_0 + \beta_1 * \log(\text{GDPc}) - \beta_2 * (\log(\text{GDPc}))^2 + \beta_3 * \log(\text{BPA}) + D + e_t$
2. $\log(\text{Sales}) = \beta_0 + \beta_1 * \log(\text{GDPc}) - \beta_2 * (\log(\text{GDPc}))^2 + \beta_3 * \log(\text{BPA}) + B_1 * D * \log(\text{GDPc}) - B_2 * D * (\log(\text{GDPc}))^2 + B_3 * D * \log(\text{BPA}) + e_t$
3. $\log(\text{Sales}) = \beta_0 + \beta_1 * \log(\text{GDPc}) - \beta_2 * (\log(\text{GDPc}))^2 + \beta_3 * \log(\text{BPA}) + D + B_1 * D * \log(\text{GDPc}) - B_2 * D * (\log(\text{GDPc}))^2 + B_3 * D * \log(\text{BPA}) + e_t$

where D is a time dummy variable that equals 0 in the time period of 1990:Q1 – 2008:Q2 and that equals 1 in the time period of 2008:Q3 – 2013.

Table 44. Chow test

	Model1	Model2	Model3
N1: 1st Period Obs	68	68	68
N2: 2nd Period Obs	28	26	26
Chow Test	108.8720	49.0125	65.8769
Prob > F	0.0000	0.0000	0.0000

Ho: no Structural Change

Source: Ostapchuk, based on Datastream and PubMed

The results of three types of Chow test suggest that the hypothesis that there is no structural break can be rejected at 1% level of significance (see Table 44). Several arbitrary points are tested for the presence of structural break using the first type of Chow test and the result showed that the hypotheses that there are no structural breaks fail to be rejected at 1% of statistical significance. Therefore, the hypothesis of the occurrence of the structural break is confirmed. Given the after-break sample is relatively short (it includes only 26 periods), the estimation of this part separately will lead to misleading results, therefore we will not proceed with estimation of the post-break sample.

7.3. Conclusions

This subsection discusses the main findings (and their possible implications) of our study, some limitations of the paper, and potential further steps.

The growing concerns over endocrine-disrupting properties of BPA resulted in a large number of scientific publications about BPA risks and in bans on its use in several products in several countries afterwards. As a first attempt to assess linkages between new scientific publications related to potential risk of BPA and polycarbonate consumption, the scientific knowledge variable was used to measure availability of information on potential risk of BPA.

This chapter empirically examines the effect of economic growth and new scientific knowledge on the polycarbonate sales in Japan which might have implications on production, marketing decisions making and planning. Besides, it might highlight the importance of taking account of scientific literature in strategic planning in plastics industry. This study allows to address the issue of potential lack of stationarity in the data that is often identified as a limitation in the EKC literature (Stern, 2004). While our study on BPA based on panel data for group of regions give a better understanding of the relationship between BPA consumption and economic growth, it does not necessarily imply that PC consumption in one of the

countries will change in the same way as in a longitudinal data analysis of bisphenol A. One of the reasons is that bisphenol A analysis is conducted at international level and polycarbonate analysis is carried out for Japan. Besides, polycarbonate is a secondary intermediate good which does not necessarily follow the consumption path of bisphenol A which is also used in production of epoxy resin.

We estimated a VECM model and we performed an innovation accounting in order to investigate the impact of economic growth and the quantity of articles related to potential risks of BPA on the sales of polycarbonate in Japan over 1990 – 2007 years. The reduced form model confirms the existence an inverted U type relationship between economic growth and polycarbonate consumption in the long run. Given the size of our sample, we mainly focus on the pattern of the relationship disregarding the degree of precision of the coefficients. In the short run, none of the variables affect polycarbonate consumption. Therefore, the EKC hypothesis does not hold in the short run.

In addition to investigating the EKC relationship between polycarbonate consumption and economic growth, this research studies the relationship between these factors and the global volume of articles related to potential risks of BPA. Preliminary analysis (cross-correlation functions) suggests that increases in the quantity of articles related to risk today are correlated with decreases in the sales in the future and increases in the sales seem to correlate with increases in the quantity of articles. However, a bivariate cross-correlogram does not take into account other variables and none of the measures of statistical significance are provided. Besides, the relationship can change over time (Beckett, 2013).

Further investigation has revealed that the coefficient on $\log(\text{BPA})$ is statistically insignificant at 1% level of significance in the equilibrium equation. However, both leave one out and repeated k fold cross validation tests suggest the cointegrating relationship in the extended model with $\log(\text{BPA})$ performs better than this relationship in the reduced model. Therefore, we include the global quantity of articles in the model. Moreover, our findings suggest that one standard deviation shock in the volume of scientific articles about potential risks equation induces sales to decline, although the impact is not immediate and relatively weak. The extended model confirms the EKC hypothesis in the long run while there is no regulation on BPA use in Japan, although it does not confirm its existence in the short run. The result of the long-run relationship is consistent with the EKC hypothesis, given that it is a long run phenomenon (Saboori, Sulaiman, & Mohd, 2012a).

The underlying mechanism behind the inverted U relationship between polycarbonate consumption and GDP in a situation of uncertainty about environmental and health risk of bisphenol A can be explained by direct (voluntary) limitation on polycarbonate consumption, technological enhancement that allows to use less polycarbonate, changes in input mix that is a substitution of potentially dangerous inputs by less dangerous inputs. These decisions can be provoked by new scientific knowledge about potential risk. Unfortunately, wide usage of polycarbonate and unavailability of detailed data do not allow to test how potential changes in technological improvement and input-mix impact polycarbonate consumption. Besides, the limited existence of substitutes in the past eliminates the need to include it in the analysis over the studied period. However, the model can be extended by other factors which influence polycarbonate consumption to avoid omitted variable bias if the size of data set and availability of data on other explanatory variables permit. For example, an environmental awareness and/or awareness about potential risks of BPA might play an important role in the relationship between polycarbonate consumption and economic growth.

The majority of the empirical literature on the EKC has studied the link between economic growth and pollution. The literature on input/resource as an indicator of environmental degradation has dealt in a similar way to pollution. However, differences between them might exist. They might concern capacity constraint or pricing (D. Katz, 2015). As we have mentioned earlier (chapter 4), there is almost no capacity constraint of bisphenol A over the studied period which is used in production of polycarbonate. Thus, we expect that there is no capacity constraint of polycarbonate. Price of polycarbonate can be considered as relatively inelastic. Polycarbonate and epoxy resin are relatively inexpensive material (for example, compare to glass). A relative increase in price may lead to decrease of input attractiveness (Chandrasekaran et al., 2013). However, the cost of these intermediate inputs produced using BPA is negligible in the production cost of the final good. Material substitution can be very costly (if it is possible). Therefore, undramatic price changes should not change BPA consumption significantly. Moreover, it can be easily put in storage and changes in price can be postponed until the crude oil market stabilizes (Jiang et al., 2015). Therefore, we expect that these determinants are not crucial in our analysis.

An interesting question arises from the analysis of BPA industry facts that suggests further relevant research step:

Many countries have begun to reconsider their policies regarding BPA and they have implemented the bans on bisphenol A use for several applications. Given that these bans were introduced after the voluntary replacement in several regions had already taken place, the following question can be asked: was there a gap between risk revealed by scientists, its perception by society and its recognition by governments?

To our knowledge, this research is the first attempt to examine the effect of the volume of publications concerning BPA-related health and environment risks on the level of consumption of polycarbonate. We, therefore, believe that despite the current limitations, this research contributes to the existing literature by providing new interesting insights into the issue of BPA and comparable intermediate goods.

Chapter 8. Results and discussion

The aim of this research was to explore determinants of uptake of innovation in a situation of uncertainty about environmental and health risks. Due to the lack of data on nanosilver, we were able to study the case of bisphenol A in order to answer two out of three research questions. The data on bisphenol A was available for the following regions North America, South America, Western Europe, CIS and Baltic States, Middle East and Africa, Indian Subcontinent, Northeast Asia (including China, Japan and the Republic of Korea and Taiwan separately) and Southeast Asia for the 1990, 1995 and 2000-2013 years.

Chapter 8 is organized as follows: the first subsection (8.1) states the major findings of the studies on bisphenol A and polycarbonate by answering the research questions posed in the introduction and relate them to those of similar studies and the second subsection (8.2) discusses similarities between BPA and nanosilver. The third subsection (8.3) discusses possible explanations of the results of bisphenol A and a comparison of sequences of events in the history of BPA and the beginning of history of nanosilver. In Chapter 9, conclusions, limitations of this research, contributions to theory and implications for nanosilver are presented and suggestions for further research are made. Then, we link this study to other streams of literature that we have not been discussed in the review (8.4).

8.1. Main results

8.1.1. Question 1. What are the key determinants of international uptake of innovation in a situation of uncertainty about environmental and health risks?

8.1.1.2. Economic growth and consumption of BPA

The primary objective of studies on the Environmental Kuznets Curve (EKC) is to estimate if economic growth can potentially improve the quality of the environment (D. Katz, 2015). Our study has used the EKC framework in order to assess the link between consumption of BPA, economic growth, new scientific knowledge and other variables. As we have already mentioned, the EKC hypothesis has been originated from the debate about economic growth and environmental quality. An increase in economic growth often leads to an increase in the use of natural resources which might rise pollution levels. However, the EKC hypothesis states

that economic growth can be associated with a decrease in environmental degradation. As we have already mentioned, the EKC is an inverted-U type relationship between economic growth and environmental degradation (Figure 55). First, an environmental degradation increases with an increase in economic growth up to the point where it starts decreasing with an increase in economic growth. As we have discussed in Chapter 6, among other things, it can be explained by the greater ability of richer nations to abate the effect of environmental degradation. Increasing evidence of side-effects might raise public concerns. As a result, nations with higher economic growth might increase environmental expenditure and/or production of byproducts can be decreased by the choice to use a product.



Figure 55. *Inverted U-shaped (left)/inverted N-shaped (right) curves*
 Source: Adapted from Dinda (2004)

Variety of limitations of the EKC studies are highlighted by several authors as we have stated earlier in Chapter 6. One of the limitations is that the evidence of the EKC is not supported by the analysis of all kinds of pollutants. Regarding the methodology part, the literature on the EKC reveals the presence of heteroscedasticity which requires the application of corrective procedures that we have discussed previously. We have addressed this critique in our study. Different pollution indicators are often used as measures of environmental quality. We use material consumption, namely BPA, instead of pollution indicators to test the EKC. A decrease in BPA consumption can be associated with the choice of users to decrease undesirable side-effects by limiting its usage or replacement by other products as soon as income rises. This might lead to changes in the state of the environment.

To answer the questions about factors that influence the uptake of innovation in the context of uncertainty about environmental and health risks, we have estimated whether macroeconomic changes (measured by GDP per capita) are correlated with consumption of BPA. The results indicate that rather than an inverted U-shaped relationship between consumption of bisphenol A per capita and economic growth, we found an inverted N-shaped

relationship (Figure 55). We observe that only the consumption of BPA in the CIS region substantially decreased in 1995 (at the beginning of the analyzed period)¹⁶⁴.

Broadly speaking, with the exception of this region at the beginning of the analyzed period, the results suggest that consumption of BPA per capita increases as income per capita increases up to the point where the consumption decreases with an increase in income. Only three entities, namely Japan, the US and Western Europe have crossed the turning point.

We observe that worldwide consumption still increases despite the decrease in consumption in several countries. This result is in line with Stern, Common, & Barbier (1996). It can be explained by relocation of industry from developed region to less developed region with less strict environmental legislation. This might result that less developed regions use more potentially harmful materials to produce final goods. However, trade can enhance the environment through increase in income which might result in the growing need for the cleaner environment (Dinda, 2004).

Besides, a decrease in consumption can be a result of technological progress which might lead to more efficient use of materials given that BPA is an intermediate good. A technological progress is one of the factors which defines the EKC pattern. A technological progress might occur as a result of income growth as developed nations can invest more in R&D and enhance environmental quality with using clean(er) technologies (de Bruyn, van den Bergh, & Opschoor, 1998; Dinda, 2004). To estimate an effect of technological improvement, data on use of BPA in different sectors is needed (it is not available)¹⁶⁵.

While our study on BPA based on panel data for group of regions gives a better understanding of the relationship between BPA consumption and economic growth, it does not necessarily imply that consumption of BPA in one of the countries will change in the same way as a longitudinal data analysis of bisphenol A suggests. One of the reasons is that bisphenol A analysis is conducted at international level and several regions are included in the sample¹⁶⁶. In order to verify this hypothesis, we have used a slightly different dataset on polycarbonate

¹⁶⁴ which results in a tiny U-type curve initially, but beyond a certain level the relationship between consumption of BPA and GDP exhibits an inverted U-type curve

¹⁶⁵ The data is not available

¹⁶⁶ The difference in results of analysis between time-series and panel data might also suggest that there is no the de-linking phenomenon in less developed countries (de Bruyn et al., 1998). Simonis (1989) argues that “de-linking of environmental pressure from economic growth” characterizes the last stage of the EKC (as cited in de Bruyn, van den Bergh, & Opschoor, 1998, p. 162). However, we are not able to verify this hypothesis given the absence of time-series data in less developed countries.

use in Japan. It is one of the countries which has crossed the turning point, that is the point where increase in GDP per capita is associated with decrease in consumption. Polycarbonate is a secondary intermediate good which does not necessarily follow the consumption path of bisphenol A which is also used in production of epoxy resin.

The results confirm the existence an inverted U-type relationship between economic growth and polycarbonate consumption in Japan in the long run. Given the size of our sample, we mainly focus on the pattern of the relationship disregarding the degree of precision of the coefficients. In the short run, none of the variables affect polycarbonate consumption. Therefore, the EKC hypothesis does not hold in the short run.

The results validate that an individual country might follow an inverted-U type relationship between consumption of polycarbonate¹⁶⁷ and economic growth (measured by GDP per capita).

A reduced form model (that includes GDP per capita, its squared and cubed terms) captures the effect of economic growth on technology, economic policy and other factors indirectly which in turn impact the environmental quality and/or consumption of potentially harmful materials. We cannot identify the effect of each variable individually due to a small sample size. This model can be considered as descriptive and it does not allow to identify the cause. Moreover, it does not imply that high level of economic growth is associated directly with lower consumption of BPA or polycarbonate and better environmental quality.

Prior literature on the diffusion of innovation and the product's life cycle suggests that particular factors have different impacts at different stages of product's life cycle. Additionally, one of our results suggests that certain factors might have different influence at the same stage in the absence of uncertainty and in its presence. For example, Golder & Tellis (2004) have found that a decrease in income can be associated with an increase in probability of slowdown. Contrary to these findings, **we have found that higher income might be associated with a decrease in consumption of product in a situation of uncertainty about environmental and health risks. At higher level of income, people become more concerned about the environment and health and as a result production/generation of byproducts can be reduced by the choice of consumption of the main product (or input).**

¹⁶⁷ Secondary intermediate good

8.1.1.2. Other factors that influence consumption of BPA in a situation of uncertainty about environmental and health risks

In addition to economic growth, we have developed a set of hypotheses regarding market-level, cultural and industry factors, information access and introduced policies.

We have used a principal component analysis, the Wald test and cross validation procedures to select a subset of the predictor variables for a cross-regional analysis of BPA. We have demonstrated the usefulness of CD player possession as proxy for final goods demand together with cable TVs possession in explaining BPA consumption. From 1990 to 2013 CDs were still used. As we have mentioned in Chapter 5, the share of optical media sector is decreasing.

We have found that, on average, 1% increase in possession of cable TV among the households is associated with 3,1 % increase in annual consumption of bisphenol A per capita holding other factors fixed.

There are two reasons why BPA consumption is responsive to the possession of cable TV. First, BPA is used in the production of polycarbonate which is used in the production of TVs. Second, a level of information access has a positive effect on BPA consumption as it spreads information about a large number of products made from bisphenol A (not only baby bottles and food packaging). Our results are consistent with previous findings in the literature, which identify **media intensity as a significant driver of the diffusion of innovation** (Putsis Jr., Balasubramanian, Kaplan, & Sen, 1997; Tellefsen & Takada, 1999; Tellis et al., 2003). This effect can be slightly reduced due to the media that spreads the information about potential risk of BPA related to several applications of BPA. The coefficient of the possession of CD players is statistically insignificant¹⁶⁸. However, the sign is positive as it is expected, and it is shown by PCA analysis.

We have used polycarbonate prices in the European Union as a proxy for BPA prices given the unavailability of data.

We have concluded that the prices are not much correlated with BPA consumption per capita.

It can be attributed to the sample construction and unavailability of prices for each entity separately or by the low price volatility. De Bruyn et al. (1998) mention that prices of materials

¹⁶⁸ at 10% level of significance

are relatively low which might suggest that changes in prices do not impact considerably its consumption. This is another possible explanation for low correlation between price and consumption of BPA.

Additionally, we have estimated the effect of the bans on BPA use in baby bottles production on aggregate consumption of BPA.

A weak relationship between the ban introduced in the US and consumption of bisphenol A per capita has been found.

This could be attributed to voluntary replacement of bisphenol A component in baby bottles that preceded the ban on BPA use in the bottles.

We have found no statistically significant relationship between the average aggregate consumption of bisphenol A per capita and the ban introduction on the BPA use in the baby bottles production in the EU, China, Brazil and Malaysia in 2011.

However, the sign is positive. The positive sign (increase in the consumption of aggregate level of bisphenol A per capita) could be explained by the shift from production of baby bottles to other products with BPA as an input using the same equipment. Another reason could be the effect of green light to other applications which are not banned. Besides, the displacement hypothesis could be another explanation for increased consumption of BPA. A relocation of production units to less developed regions where regulations concerning BPA might be weaker. The displacement hypothesis is related to trade factor which is one of the drivers that explains the EKC. This factor is not included in the analysis, and it can be considered as one of the limitations of this study.

8.1.2. Question 2. Does the number of risk-related scientific publications impact consumption?

In order to estimate the impact of new scientific knowledge about consumption of bisphenol A, we have used the volume of scientific papers about risk of BPA as a measure of new scientific knowledge.

Using various methods, we cannot see a clear pattern of impact of new scientific knowledge about risk on consumption of BPA. We have found that the effect of new scientific articles might change depending on cultural factors (uncertainty avoidance). We observe that consumption of BPA per capita is the lowest in one of the countries with high level of uncertainty avoidance index. The level of consumption per capita is the lowest in countries

with high and average levels of uncertainty avoidance over the analyzed years. In the countries/regions with a low rate of uncertainty avoidance, there is no correlation between new scientific knowledge and consumption.

We observe a slight reduction in consumption as the quantity of articles increases if the uncertainty avoidance is high. Thus, the uncertainty avoidance modifies the intensity of the relationship. It can be suggested that the uncertainty avoidance moderates the impact of new scientific knowledge on consumption of bisphenol A. Given the small sample size, caution must be taken, parametric estimation technique would be needed in order to confirm this relationship as soon as a larger and more detailed dataset become available.

Additionally, we have analyzed the relationship between polycarbonate consumption and the global volume of articles related to potential risks of BPA in Japan. Preliminary analysis has suggested that increases in the quantity of articles are correlated with decreases in the sales in the future (several periods of time ahead). However, a cross-correlogram does not take into account other variables. The cross-correlation does not provide the measures of statistical significance. And the relationship among variables can change over time (Beckett, 2013). But we have observed some patterns in the data. Further investigation has revealed that the relationship between new scientific knowledge and polycarbonate consumption is not significant. However, both cross validation tests suggest the model with new scientific knowledge variable performs better than the reduced model. The variable is relevant to our model. Due to a small sample size, there are only a limited number of variables included in the model. An omission of a relevant variable might lead to “misleading conclusions about the statistical significance of the estimated parameters” (Gujarati, 2004, p. 210). The signs of coefficients on GDP, its squared and cubic terms are significant and in accordance with a reduced model, this model can be considered as adequate. One of the possible solutions is to add a relevant variable to the model if a larger dataset becomes available.

Among other things, these findings add to earlier empirical studies on food consumption and associated health and safety concerns, demand for cigarettes and health information shocks. The results of these studies are controversial. Some of them have found a link between consumption and information shocks. In contrast to these findings, several studies indicate no effect or only a slight reduction in consumption.

Taken together, our findings would seem to suggest that, on average, there is a weak relationship between consumption of BPA and new scientific knowledge about potential risks of BPA.

These results can be considered different from what the model of impact for unfortunate events suggests. We expected that a perceived lack of control and a hazard perceived to be new would intensify the event signals (breadth and seriousness of the impact). Drawing on this model, we have hypothesized that new scientific knowledge about risk can be an additional factor which is not discussed in the literature and which is of considerable importance if a product is in a situation of uncertainty about environmental and health risks. Quantitative data was used to examine the consumption of BPA. Additionally, our findings can be illustrated through the analysis of the shape of the PLC. Over the studied period, sales of bisphenol A can be considered in the period of transition from the growth to decline stage across multiple countries. This corresponds to slowdown point. Figure 56 compares BPA consumption in four groups (3 entities in each group) based on the uncertainty avoidance index. The slope of the curve shows that the growth rate was higher early, from 1990 to 2000, except for the group with the lowest uncertainty avoidance index. We observe a decrease in the sales BPA growth in several regions. Regarding the consumption of BPA in the US, Taiwan and/or Western Europe, we observe that sales declined sharply from 2008 to 2010. We can note that BPA consumption in Central Europe, South Korea and/or Japan decreased slightly in 2009. This decline in sales corresponds to the recession of 2008-2009.

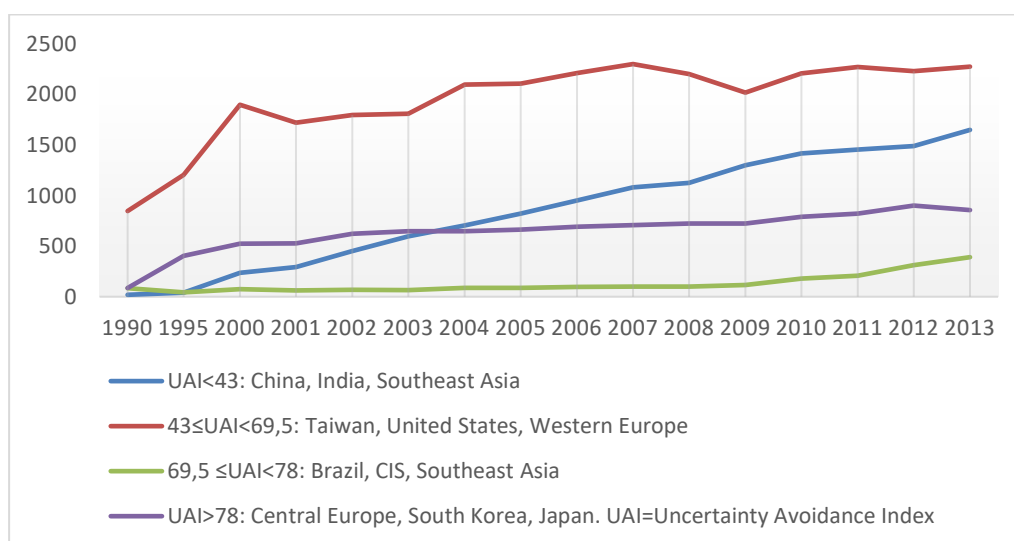


Figure 56. BPA consumption (thousands of metric tons) and uncertainty avoidance index
Source: Ostapchuk, based on Hofstede (2001) and IHS Chemical

We suspect that sales decline from 2000 to 2004 could be partly due to the early 2000s recession. However, based on Figure 56, we cannot rule out the possibility that the decline from 2000 to 2004 was partly due to information shocks. Besides, no clear evidence of substitution¹⁶⁹ or extension¹⁷⁰ strategies which can be implemented to take control of sales decline, has been found except for baby bottles over the studied period (Figure 57). We cannot rule out the possibility that these strategies have been implemented. Besides, we cannot exclude that after the year 2013, BPA consumption has decreased as a result of new scientific knowledge.

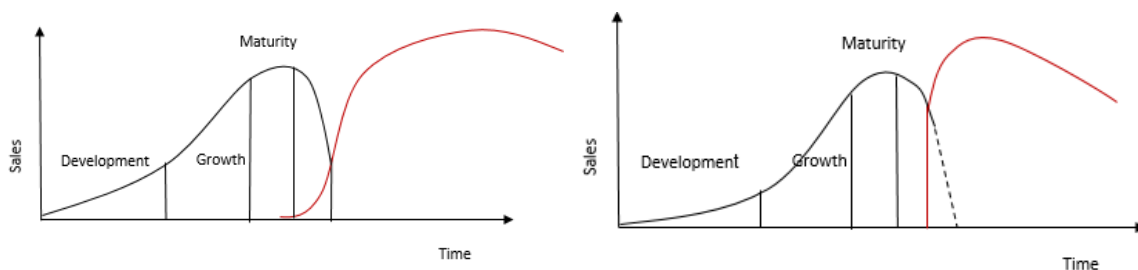


Figure 57. *Substitution (left) and extension (right) strategies*
 Source: adapted from Levitt (1965)

Our findings would seem to show that there are no continual changes which could be expected due to information shocks. There is indeed a decline in the growth rate of sales in several regions, on average. However, we observe the worldwide consumption of bisphenol A increases, despite the information shock. In our view, this emphasizes the need to discuss other possible strategies which might have been employed to take control of sales in response to new scientific knowledge.

Returning to our hypothesis posed at the beginning of this study, we restate the ideas behind the precautionary principle. The PP underpins most EU regulations. As we have mentioned, the basic idea the absence of proof should not be a justification for no action. The basic idea of PP together with the interpretation suggested by Godard (2003) which takes as a starting point the principle of proportionality implicate a role for new scientific knowledge about risk. Several precautionary measures can be taken by authorities responsible for risk management (research finding, provisional suspension, ban, etc). It can be legitimate to ban as a precaution one application that has a substitute and maintain the usage of other applications which do

¹⁶⁹ Innovation is launched when a recently introduced product is in the phase of growth. The old product is phased out as soon as a new product reaches a certain level (Scheuing, 1989).

¹⁷⁰ Sales are pushed upward instead of continuing their pattern (stability or decline). It can be achieved through more frequent and diverse usage among current users, conquering new markets and discovering new uses for the product (Levitt, 1965; Scheuing, 1989).

not have substitutes (cost-benefit reasoning) (Godard, 2003). However, the following questions arise: does the moment of introduction of this measure (ban) correspond to the particular stage of knowledge maturity (known risk)? Are the measures applied proportional to scientific knowledge about risk? Is the precautionary principle properly applied?

The importance of our work lies in the following paradox: **PP applies to BPA, decision making under uncertainty calls for scientific knowledge, our findings suggest that more research does not result in a proportional use of tools and a proper application of the precautionary principle with respect to available scientific knowledge.**

The reason for this unexpected result is still not entirely clear. One of the possible explanations is a substantial time lag which is not captured by our model. Besides, the following questions arise: **what is the underlying mechanism that makes scientific knowledge ineffective with respect to risk management? What does it mean for nanomaterials like nanosilver?**

In order to answer these questions and refine the interpretation of the main result, first, we will describe the link of our work with the literature on the Industry Life Cycle (ILC) and we will discuss the relevance of BPA study to nanotechnology.

8.1.3. Link to the industry life cycle

The period of the BPA history that we have analyzed is closely linked to the transition from the growth to maturity stage of the product life cycle. We have observed that not much systematic research on the product life cycle has studied the maturity stage (they focus on the introduction and growth stages). Thus, our analysis contributes to the literature on the maturity stage of the PLC. A product life cycle depicts evolution of many industries (S. Klepper, 1997). Many industries also have their life cycle which includes: introduction, growth, maturity, decline, and eventually, death stages (Krafft, 2006).

Several authors discuss the PLC: Dean (1950); Levitt (1965); Vernon (1966). Klepper (1997) discusses if there are regularities of entry, exit, firm survival and firm structure among industries which are not captured by the regular PLC. Mainly, Williamson (1975), Clark (1985) and Drew (1987) (as cited in Klepper, 1997) define 3 stages of the industry life cycle (ILC): exploratory (embryonic/introduction/development), intermediate (growth) and maturity stage. The first stage is characterized by high uncertainty about buyer's preferences, product characteristics and technological capacity/advances. There are no barriers to entry, the quantity of firms increases. R&D can be characterized as "trial and error". Output is relatively

low. Then, output increases, design of products improve, product innovation decreases and specialized equipment is introduced. The quantity of firms which enter market decreases. Industry experiences a shakeout as the regular ILC states. A shakeout can be caused by a technological event and exogenous development outside the industry. The quantity of firms decreases during the shakeout and the quantity of product innovation decreases. Uncertainty declines. At maturity stage, output growth is lower, there are less innovations and entrants, management and manufacturing approaches are improved, market shares are stabilized. As soon as a main design is chosen, innovations related to product decrease, producers invest in innovations related to process. The literature on evolution of vertical structure is limited. However, the authors suggest that as industries evolve, firms become specialized.

Klepper (1997) concludes that over a specific period the following industries conform with the PLC: tires, televisions, penicillin and aircraft. However, their further development is not consistent with the PLC due to new industrial dynamics. The author has concluded that alternative patterns are possible. Some of the examples of industries with alternative patterns are petrochemicals, disposable diapers and zippers (“non shakeout” products). Klepper (1997) states that as market stabilizes in terms of number of firms and their market shares, the PLC does not always capture an evolution of industry. Grebel, Krafft, & Saviotti (2006) recognize the need to update the industry life cycle models as a result of evolution of industries which can be knowledge-intensive (for example, biotechnology) to take account of survival of incumbent firms, emergence of new technology firms and innovation network. What can we say about the BPA and nanosilver industries?

This rises many questions for future research:

Does the product life cycle pattern capture the BPA industry evolution? Are there barriers to entry for knowledge-based industry as nanotechnology at introduction stage? Can the introduction stage be characterized as the one with the high number of fundamental innovations? Are these innovations related to product or process? Has the quantity of product innovations started declining?

Unfortunately, it was not possible to obtain detailed data on market structure, survival rates and technological change in order to investigate these issues. However, we have obtained data on entry, exit and number of BPA plants which serves as an additional characteristic of the industry evolution. In addition to the analysis of consumption of bisphenol A through the estimation of the Environmental Kuznets Curve (over the transition from the growth to

maturity stage of the PLC), we make an attempt to discuss changes in BPA industry in terms of entry/exit of BPA plants.

In general, whether an industry depicts a regular life cycle pattern can be compared defining survival rates of entrants, horizontal/vertical market structure of firms, technological change and growth of the market (Table 45). Klepper's (1996) work on industry's life cycle draws on marketing studies on innovation diffusion and Abernathy & Utterback's (1978) study on a transition from radical to evolutionary innovation (Le Masson & Weil, 2016). Abernathy & Utterback (1978) explain that a radical innovation and an evolutionary innovation are not independent types of innovation. The latter involves incremental innovations which aim for cost reduction and a product standardization. Organizations which initially deal with a radical innovation can focus on evolutionary innovation with time. Several studies suggest that within one industry the rate of important innovation reduces and the type of innovation changes with time. Using the example of the semiconductor industry, among other things, the authors describe changes in a "classical" innovation pattern. In the early period of the new industry, they distinguish between established enterprises and new entrants. In the face of competition from new entrants, established enterprises encourage process innovations. In the meantime, entrants seek product innovation. When the rate of product innovation reduces, process innovations help to maintain a competitive edge. Evolutionary innovations begin with several important innovations and at the end "a highly-standardized commodity-like product" prevails (Abernathy & Utterback, 1978). Klepper (1996) considers the shift from product to process innovations as one of the characteristics of the industry life cycle.

Table 45. Evolution of industry structure

Dimension	Growth of the market (the product life cycle curve)	Horizontal market structure	Survival rates ("first mover advantage")	Technological change	Vertical market structure (within industry)
Characteristics	Sales, profit	Entry, exit, number of producers and the number of firms undergoing a sharp shakeout, market shares of leading producers	Survival rates of entrants from different periods, including survival rates of incumbent	Number of product and process innovations, labor productivity	Vertical integration/non-integration/disintegration

Source: Based on Grebel, Krafft, & Saviotti (2006); Helfat (2015); Klepper (1997); Levitt (1965); Mazzucato & Tancioni (2005); Meenaghan & O'Sullivan (1986)

Evolution of the BPA industry: horizontal market structure

Figure 58 and Figure 59 present the horizontal market structure of BPA industry.

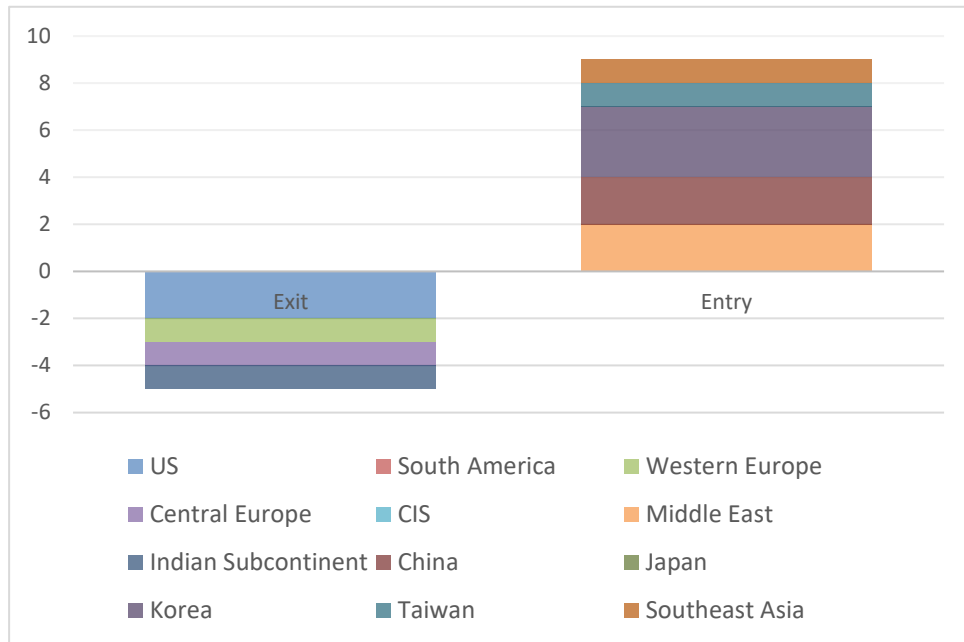


Figure 58. Entry and exit of BPA plants by entity, 2010 and 2013

Source: Ostapchuk, based on Sriram et al. (2014)

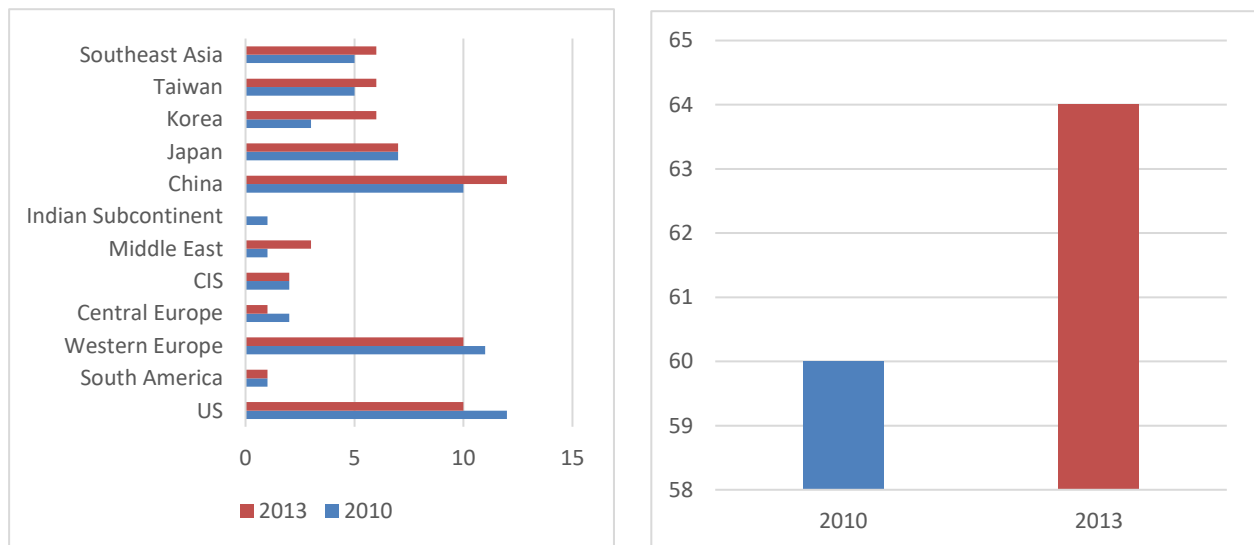


Figure 59. Number of BPA plants by entity (left) and total (right), 2010 and 2013

Source: Ostapchuk, based on Sriram et al. (2014)

We observe that the quantity of BPA plants has grown from 2010 to 2013. These years correspond to the maturity stage of the product life cycles. While we cannot say if entry has slowed over the last 30 years due to the absence of data. We can see that entry is higher than exit. There are possible explanations of this observation. This might demonstrate that the BPA industry does not follow a regular pattern. On the other hand, these observations might

support the previous findings in the literature. Klepper (1997) states that shakeouts are rare in petrochemicals which can be explained by the fact that entrants are provided with process innovation by the engineering firms. Besides, the number of companies increased by 2 from 2010 to 2013, entry was higher than exit. This might suggest that a relocation of capacity from incumbents to entrants occurred. Another possible reason for this is that certain actions were undertaken over these years that we were not able to observe. These actions might have extended the industry life cycle. While these propositions are based on limited data, this discussion should be treated with caution. We believe that this research provides results which can be further used as a base for studies on the evolution of BPA and nanosilver industries. In addition to questions mentioned above, the following question may arise: does the increasing quantity of articles on potential environmental and health risks impact a horizontal market structure or technological change in a situation of uncertainty about environmental and health risks?

In order to explain our results and make a comparison between nanotechnology and BPA, first we discuss the similarities between nanosilver and bisphenol A. We try to understand if these similarities allow us to draw an analogy between them with regard to determinants of adoption of innovation in a situation of uncertainty about environmental and health risks. Then, we make an attempt to understand the underlying mechanism of weak relationship between consumption of BPA and new scientific knowledge about potential risk of BPA through the discussion of the link between new scientific knowledge and stakeholders. These discussions add to the understanding of the role of new scientific knowledge in the diffusion of innovation in a situation of uncertainty about environmental and health risks.

8.2. Similarities between bisphenol A and nanosilver

We seek to understand if similarities between nanosilver and bisphenol A allow us to draw an analogy between them with regard to the path of intermediate good life cycle and determinants of diffusion in a situation of uncertainty about environmental and health risks. We attempt to define potential determinants of diffusion of nanosilver based on the analysis of bisphenol A consumption together with existing literature on the diffusion of innovation. These determinants can be tested as soon as data on nanosilver consumption become available.

We have chosen bisphenol A as a starting point for the study of nanosilver because of some similarities among them:

- time sequences of diffusion of scientific knowledge related to environmental and health risks (8.2.1)
- similar positions in their value chains (8.2.2)
- similarities in their perceived psychological distance (8.2.3)

Subsections 8.2.1 – 8.2.3 discuss these similarities. This subsection concludes on what is specific about nanosilver and BPA as candidates to explore different stages in the diffusion of new products in a situation of uncertainty about environmental and health risks.

8.2.1. Time sequences of diffusion of scientific knowledge related to environmental and health risks and sources of uncertainty about environmental and health risk of nanosilver and bisphenol A

As we have stated, bisphenol A (BPA) is a synthetic substance used in production of polycarbonate plastic and epoxy resin. Polycarbonate plastic is a clear, tough and durable material which is employed, among other things, in packaging and automotive industry¹⁷¹. Epoxy resin has been in commercial use as protective coatings in metal equipment, beverage and food cans since the early 1950s. It was synthesized in 1891 and its estrogenic properties were discovered in the 1930s, but the negative implications for public health were not understood neither by scientists nor by the public at that time.

Given that earlier studies show that the toxicity of BPA is low, its use in production of polycarbonate and epoxy resin was officially accepted without investigation of its carcinogenicity. The first study on its carcinogenicity was conducted in 1977 concluding potential evidence of carcinogenic effect at high doses. In spite of some doubt about the quality of this study, it served as a basis for the first safety standard in the USA. In 1993, the BPA release from polycarbonate was discovered and its estrogenicity was reported. This and subsequent studies on the low-dose effects of BPA have initiated a debate on the safety of BPA-based plastic (and other applications of BPA) and have provoked controversy surrounding its potential adverse effects (Krishnan et al., 1993; Møller et al., 2012; Vogel, 2009). Since then it has become an extensively researched topic as presented in Figure 60. Number of published articles on bisphenol A and toxicology, 1950-2015 which shows the quantity of

¹⁷¹ Other applications of bisphenol A and associated concerns about environmental and health risks are discussed in Chapter 5

published articles on bisphenol A and toxicology between 1950 and 2015. Data on the quantity of articles is collected from the PubMed website¹⁷² using the keyword “bisphenol A” together with “toxicity”.

As was stated earlier, to evaluate risks, both hazard and exposure should be considered (Berube et al., 2010; Mark R. Wiesner et al., 2006). According to the EFSA (2015), existing levels of exposure to bisphenol A is considered low¹⁷³. Therefore, EFSA’s conclusion states that there are no health risk to humans in contrast to other organizations (Bakker et al., 2014). It can be another source of controversy in addition to contradictory conclusions of studies on the effects of BPA (Vogel, 2009).

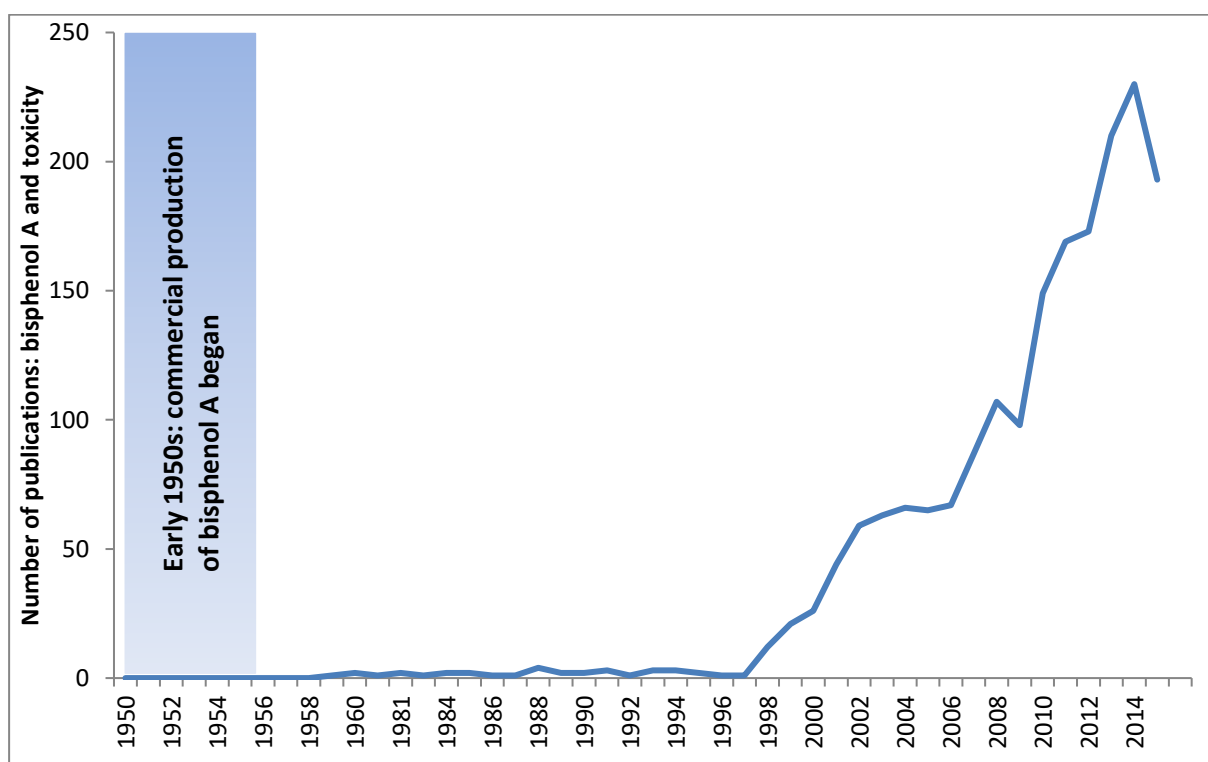


Figure 60. Number of published articles on bisphenol A and toxicology, 1950-2015

Source: Ostapchuk based on PubMed¹⁷⁴

As we have discussed, nanosilver has found many applications in medicine, textile, cosmetics, water purification, packaging and electronic industries because of its antibacterial properties and/or anti odor effect (Cantuarias-Villessuzanne et al., 2016; Köhler & Som, 2014; Scientific Committee on Emerging and Newly Identified Health Risks, 2014; Tran et al., 2013). Besides,

¹⁷² <http://www.ncbi.nlm.nih.gov/pubmed>, accessed in August 2016

¹⁷³ Although that period is beyond the scope of this research

¹⁷⁴ <http://www.ncbi.nlm.nih.gov/pubmed>, accessed in August 2016

potential adverse effects associated with nanosilver and the nature of uncertainty are presented in the Introduction.

Figure 2 from the Introduction illustrates again that the quantity of scientific articles examining nanosilver and toxicity is constantly growing. Data on the quantity of articles is collected from the PubMed website using the keyword “nanosilver/silver nanoparticles” together with “toxicity”¹⁷⁵. According to SCENIHR (2014), the early studies express concerns for potential health effects of long term exposure to nanosilver. More studies on environmental and health toxicity are needed to assess risk of nanosilver which is not fully evaluated partly due to lack of information on long-term hazards.

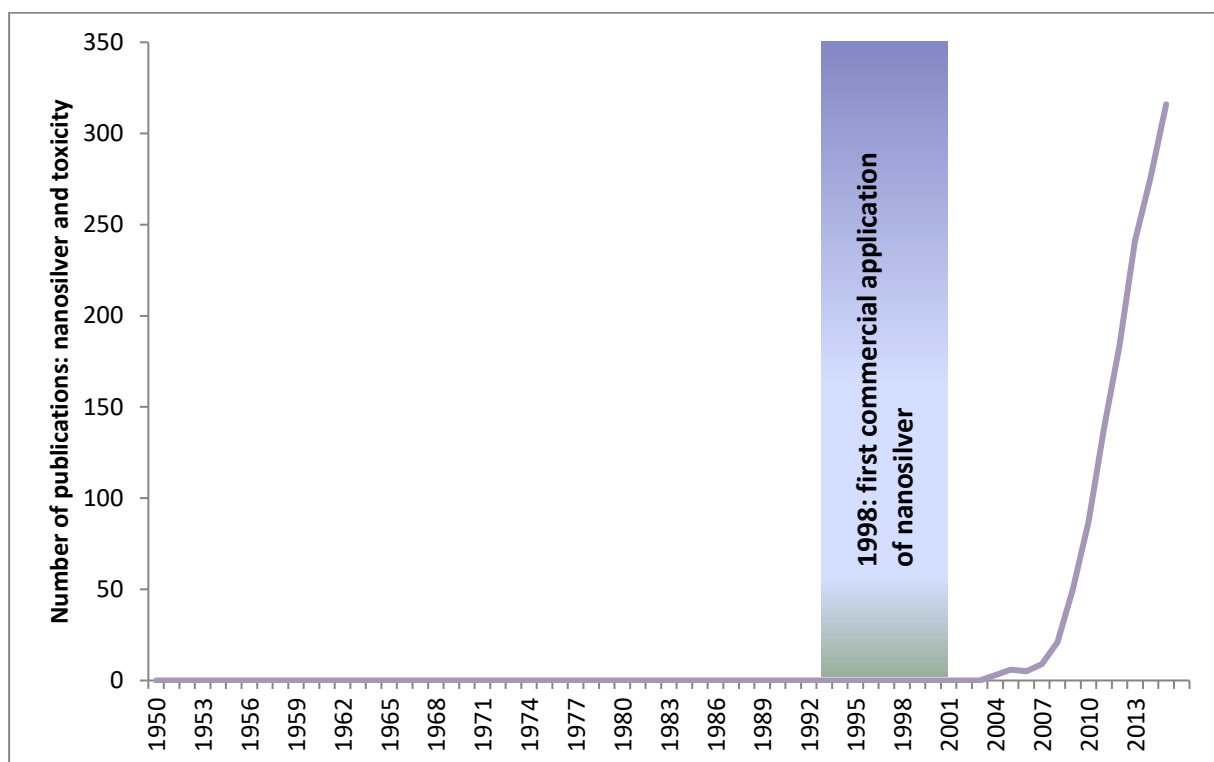


Figure 2. *Number of publications: nanosilver and toxicity*
(Figure 2 from Chapter 1) Source: Ostapchuk based on Pubmed

Information on potential hazards of bisphenol A related to its current applications and nanosilver came out after they had been put on the market. However, it should be noted that nanosilver has a remarkably shorter period of time between a new product launch (Acticoat can be considered to be the first commercial application of nanosilver) and its first risk assessment than bisphenol A (Figure 60, Figure 2). The knowledge on nanosilver currently is in the process of accumulation.

¹⁷⁵ Articles which appear twice after appending the data sets are deleted, the website was accessed in August 2016

Furthermore, uncertainty about environmental and health risks of nanosilver is associated with insufficient knowledge on exposure and hazards levels. Regarding bisphenol A, uncertainty about environmental and health risks is mainly related to its hazard and it arises partly from unclearness of what scientific studies should be used to define its potential risk (Vogel, 2009) taking the EFSA's conclusions about exposure level into account. However, the Scientific Committee on Emerging and Newly Identified Health Risks (2015) recognizes that there is a great deal of uncertainty about the exposure assessment. It is reported that there is a potential risk of adverse effects as a result of chronic exposure to bisphenol A via medical devices. Incomplete scientific understanding results in epistemic uncertainty¹⁷⁶ (Köhler & Som, 2014).

Thus, both nanosilver and bisphenol A face an epistemic uncertainty about environmental and health risks.

One of the ways to deal with epistemic uncertainty is to acquire additional knowledge and improved representation of process which could reduce the uncertainty¹⁷⁷ (Beven et al., 2015). However, scientific opinions alone are not always sufficient for risk assessment (Falkner & Jaspers, 2012).

8.2.2. Bisphenol A and nanosilver in the value chains

We have demonstrated the position of BPA in the value chain in Chapter 5. Nanosilver is “an aggregate or agglomerate and where for 50% or more of the particles in the number size distribution, one or more external dimensions are in the size range 1-100 nm. Those silver materials with a particles size larger than 100 nm are indicated as bulk silver” (Scientific Committee on Emerging and Newly Identified Health Risks, 2014, p. 16).

According to Fauss (2008), nanosilver can appear in different forms: liquid (colloid), solid (masterbatch) or powder. Nanosilver-contained coating can be in liquid or powder form, it is embedded in a product by its manufacturer. In most cases, coatings are nanointermediates. Nanointermediates are intermediate goods which are not raw materials or finished goods, they contain nanomaterials or “have been constructed de novo with nanoscale features” (Knutson, Riswadkar, Epprecht, & Weymann, 2010, p. 6). Nano-enabled products are goods

¹⁷⁶ The majority of decision making methods applied in risk assessment involves the determination of probability of occurrence of an event. If uncertainty is due to a lack of knowledge (that is epistemic uncertainty), then it will be complicated to measure it and depict it in the form of a probability distribution over possible outcomes (Beven et al., 2015).

¹⁷⁷ A full discussion of practices of dealing with epistemic uncertainties is beyond the scope of this research

which are located at the end of a value chain and they include nanomaterials or nanointermediates (Knutson et al., 2010).

One of examples of coating application for nanosilver is a manufacturing of antimicrobial packaging film (Sadeghnejad, Aroujalian, Raisi, & Fazel, 2014). Besides, packaging can be improved by incorporation of nanomaterial in polymer matrix¹⁷⁸. Types of nanotextiles include nanofinished textiles and nanocomposite textiles. The former is characterized as being treated in the post-manufacture phase by applying nanomaterials to fibre media, for example, powder¹⁷⁹. The former contains composite fibre materials which incorporate components with nanomaterials. Silver powder is employed in electronics as thick film conductors due to “high electrical and thermal conductivity, and high resistance to oxidation” (El-Aassar, Said, Abdel-Gawad, & Shawky, 2013, p. 423). Nanotextile can be used in production of clothing, therefore nanotextile can be considered as nanointermediate. The Silver Nanotechnology Commercial Inventory indicates that a nanosilver can be included in a soap in a colloidal form. These are some of examples of nano-enabled products which are the results of nanosilver applications (Figure 61).

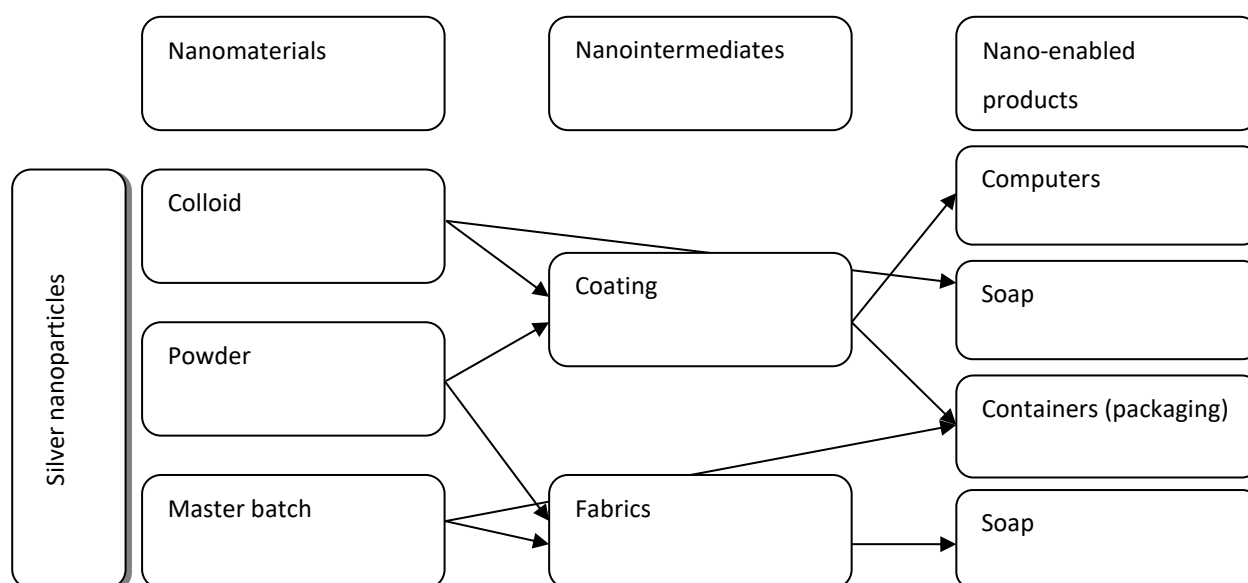


Figure 61. Nanosilver value chain: from silver nanoparticles to nano-enabled products (selected products)

Source: Adapted from Frederick (2011)

An overview of bisphenol A and nanosilver value chain structures helps to define positions of bisphenol A and nanosilver in the value chains. It can be seen that both bisphenol A and

¹⁷⁸ <http://www.safenano.org/news/intheknow/in-the-knowon-food-packaging/>, accessed in August 2016

¹⁷⁹ <https://www.ic.gc.ca/eic/site/textiles-textiles.nsf/eng/tx03232.html>, accessed in August 2016

nanosilver are intermediate goods which, in turn, are used in the production of secondary intermediate goods or finished goods. Therefore, their positions in the value chains can be defined as relatively similar. This might help to define a set of common factors that affects their diffusion.

8.2.3. Similarities in the perceived psychological distance

One of the primary sources of human exposure to BPA is food/beverage packaging. Bisphenol A applications related to food include a thin coating used in food/beverage cans, BPA is also the basic component of polycarbonate that is used in food/beverage containers including baby bottles (Bakker et al., 2014). Besides, a BPA-based coating is used in kitchen utensils and metal tanks and vats in the agri-food industry¹⁸⁰. These applications of bisphenol A can be classified under processing and conservation phases in the food production chain¹⁸¹. Similarly to bisphenol A, nanosilver is used in processing and conservation phases. According to SCENIHR (2014), examples of nanosilver application in food processing and conservation are food preparation equipment with anti-bacterial coating, packaging and refrigerators. Moreover, nanosilver is used as a dietary supplement which is classified under food consumption phase in the food production chain.

While there are various existing and potential applications of nanosilver, applications related to food might be the most questionable in terms of societal acceptance according to expert opinions (Gupta et al., 2013; Gupta, Fischer, van der Lans, & Frewer, 2012). One of the possible explanations is a frequent comparison with genetically modified organisms which have met a negative response from consumers (Gupta et al., 2013). Consumer attitudes precede a decision to adopt or reject innovation as soon as consumers have gained knowledge about its existence. Perceived attributes of a new product help to explain its adoption (Rogers, 2003). A few studies suggest that consumer attitudes towards nanotechnology applications in food among other things depend on the psychological distance of an attribute related to nanotechnology to an end user (Gupta et al., 2013; Steenis & Fischer, 2016). Psychological distance is a subjective experience of how close an object is to a consumer in terms of “time, space, social distance and hypothetically” (Trope & Liberman, 2010, p. 1).

¹⁸⁰ <http://www.ineris.fr/substitution-bpa/en/fag/what-kinds-food-contact-materials-are-epoxy-resins-used>, accessed in August 2016

¹⁸¹ Food production chain can be subdivided in 3 phases: food processing, food conservation and food consumption. Each application of bisphenol A or nanosilver can be classified under one of these phases (Scientific Committee on Emerging and Newly Identified Health Risks, 2014).

Steenis and Fischer (2016) classify nano-food applications according to psychological distance depending on whether consumers have a direct experience with nanotechnology. The authors define a psychological distance as small if nanotechnology is employed as a part of diet, for example, like supplements, which can be considered as a direct experience. In other words, a distance can be defined as small if nanosilver is applied in the food consumption phase (food production chain). Packaging materials with nanoparticles can interact with food, but they are not involved in the processing of food and its direct consumption. As the physical and chronological¹⁸² distances are considerable, they can be considered as more distant objects. Food processing is the most distant object among nano-food applications and consumers do not have a direct experience with food preparation equipment. Nevertheless, it impacts a finished good. Steenis and Fischer (2016) use the construal level theory to explain how a physical distance influences consumer attitudes towards nanotechnology. The construal level theory suggests that a consumer responds to a distant object based more on mental construal and less on direct experience (Trope & Liberman, 2010). Steenis and Fischer (2016) have found that applications of nanotechnology with low distance are considered as less positive. Moreover, they have found that psychological distance to nano-enabled goods influences risk perception towards these goods. Applications with low psychological distance are associated with higher and immediate risk.

Bisphenol A and nanosilver applications are diverse. However, some applications can be compared in terms of psychological distance. A negative or positive attitude towards one or several applications by society does not imply a complete rejection of bisphenol A or nanosilver, but it might trigger more attention of the public to applications with lower psychological distance. Regarding applications of bisphenol A to food industry, there is a difference between nanosilver and bisphenol A, the latter is not applied as an explicit ingredient to prepare food. This might suggest that some final results of our analysis of bisphenol A consumption do not necessarily hold for low distance applications of nanosilver. To sum up, the similarities between bisphenol A and nanosilver include time sequences of diffusion of scientific knowledge related to environmental and health risks, positions in their value chains and perceived psychological distances of several applications. These similarities

¹⁸² Physical and chronological distances can be considered as distant for the following reasons: 1. packaging materials are not consumed as food and they are not used as ingredients, 2. these materials are not in contact with food at the moment of food consumption, although they could have been in contact with food to preserve it at some time in the past.

together with the difference in the stages of product's life cycle make BPA appropriate for an investigation of determinants of the diffusion of new products with nanosilver in a situation of uncertainty about environmental and health risks. Sales of nanosilver can be currently considered in the transition between the introduction and growth stage which corresponds to takeoff point. Bisphenol A is in the period of transition from the growth to decline stage across multiple countries over the studied period which corresponds to slowdown point (Table 5). BPA is an example of an innovation that has been on the market for a long time and it has reached the key turning points (takeoff and slowdown) in the majority of regions. The study on BPA consumption contributes to the analysis of the trajectory of nanosilver.

8.3. Comparison of sequences of events in the history of BPA and the beginning of history of nanotechnology (interpretation of results)

8.3.1. Question 3. What is the link between new scientific knowledge and different stakeholders in a situation of uncertainty about environmental and health risks?

A product as an object of transaction is exchanged for another value for those who want it or need it. The question about the link between a product and consumers points to certain aspects of the interaction between different actors involved in this exchange. Besides, actions of stakeholders help us to interpret our main result and make a comparison between nanotechnology and BPA.

Building on Fligstein & McAdam (2012), we have classified stakeholders as producers, users, governance units and agencies responsible for food, environmental and occupational health and safety, para-public institutions (internal and external) and NGOs. In our case, it seems that this classification does not allow to demonstrate the existing differences among stakeholders which could help us to discuss the link between a product and consumers. We make an attempt to extend this classification integrating the notion of new scientific knowledge as an additional characteristic. This, in turn, required to discuss the relationship between new scientific knowledge and different stakeholders (passive consultation or active engagement). An active engagement involves a stakeholder's which results in a two-way influence between this stakeholder and new scientific knowledge. The contribution to knowledge includes research funding and the provision of new knowledge on potential risks of BPA.

8.3.1.1. Phases of BPA and nanosilver histories

Figure 15 - Figure 23 (Chapter 4) show the number of events¹⁸³ which have occurred for each type of stakeholders. These figures describe how things change over time. The BPA data suggests that **the analyzed period can be subdivided in 3 phases in relation to new scientific knowledge about risk and the earliness of responses of different stakeholders:**

- **before the discovery of the low-dose effects of BPA**
- **period of relative silence** (before the reaction of internal governance units and agencies responsible for food, environmental and occupational health & safety, users and NGOs to new scientific knowledge). The alerts by NGOs were not noticed
- **after the first reactions of internal agencies to new scientific knowledge** (in the middle of 2000s)

Governance units, para-public institutions and agencies responsible for food, environmental and occupational health and safety have reacted to new scientific knowledge about risk earlier than other stakeholders. While some experts suggested that NGOs had reacted earlier, the period of silence was comparatively long. The governance units in the USA and Japan have reacted earlier than other countries (which are classified as the second lowest and the highest region with respect to uncertainty avoidance index, respectively). This could be explained by the dioxin panic that had spread earlier, and the first scientific alerts that had occurred first in the USA. As we are interested in actions related to new scientific knowledge, we will propose a new classification related to the third period.

The stages are roughly the same for nanosilver, but the time taken by each stage is relatively shorter. The period of silence ends if internal governance units and agencies start reacting to new scientific knowledge. There are differences that should be pointed out. First, NGOs have reacted earlier than internal governance units and agencies or the signs of alerts in the case of nanosilver could have been relatively stronger than in the case of bisphenol A. Second, a new category of events “responsible innovation and research” has emerged. This category includes activities which can be associated with the responsible innovation framework (for example, workshops, debates, public engagement related to potential risks of

¹⁸³ “Longitudinal analyses are often chosen because a researcher is particularly concerned with certain events that may affect the life of an organization... Any relatively sudden qualitative change that happens to an individual or to an organization can be classes as an event. Examples of events that may occur include an individual, or an organization experiencing a strike or a takeover bid” (Thietart, 2001, p. 339).

nanotechnology, code of conduct for responsible research. Responsible research and innovation can be defined as *“a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)”* (von Schomberg (2012) as cited in Stilgoe, Owen, & Macnaghten (2013)). Responsible innovation activities involve the following actors: internal and external governance units and agencies (including research bodies), representative bodies, consumers, intergovernmental organizations and other NGOs (including challengers).

Besides, it should be reminded that BPA reached the maturity stage and 7 entities out of 12 reached the decline stage of the PLC. Nanosilver is in the transition from the introduction stage to the growth stage of the PLC.

8.3.1.2. The relationship between new scientific knowledge and stakeholders

As we have already mentioned, the BPA release from polycarbonate was discovered in 1993. Since then, a growing number of studies on potential risks of BPA has been published. However, research bodies and institutes are not the only ones who contribute to the existing body of knowledge which in turn becomes available to other stakeholders. In the context of uncertainty about environmental and health risks, it can be suggested that the scientific studies initiated a debate on safety of BPA-based products and have provoked controversy surrounding its potential adverse effects. Several stakeholders contribute to the existing knowledge in different ways. Internal and external agencies and para-public institutions provide scientific opinions on BPA. There is evidence that an intergovernmental organization develops guidelines for the testing of potential endocrine disrupting chemicals (OECD, 2015). The recent drafts of guidelines are open for public comments. However, if we compare with nanotechnology, a level of public engagement related to BPA is relatively low. Regarding external representative bodies, a piece of evidence that the American Chemistry Council (ACC) supports the research on BPA through the Polycarbonate/BPA Global Group: *“Steve Hentges, Ph.D. ... leads the Polycarbonate/BPA Global Group, which consists of the leading global manufacturers of BPA and polycarbonate plastic. This group of the American Chemistry Council sponsors health and environmental research and supports a wide range of communications and advocacy activities... In his current position, he [Steve Hentges] has been deeply involved*

with the science on BPA for more than 14 years. The author periodically writes about the science of BPA in a Science 2.0 column at http://www.science20.com/steve_hentges¹⁸⁴. Besides, since 2010 the ACC has provided news, fact sheets and comments related to BPA. According to the ACC website, the mission is “to deliver value to our members through advocacy, using best-in-class member engagement, political advocacy, communications and scientific research”¹⁸⁵, which implies that there is a knowledge exchange between representative bodies and producers. Besides, we have already mentioned that the research is funded by industry. Since 2010, Women’s Voices for the Earth¹⁸⁶ (which are characterized as “challengers”) has published several reports and articles related to BPA on the website including the report “No Silver Lining” (National Workgroup for Safe Markets, 2010). This report quantifies the exposure to BPA canned food.

Based on this discussion and the information provided in Chapter 4, a two-way influence between new scientific knowledge and the following stakeholders related to BPA exist: producers and users, representative bodies, governance units and agencies, intergovernmental organizations and challengers. Both internal and external actors interact with new scientific knowledge in a passive or active manner.

We have proposed a new classification of stakeholders over the third period based on their interaction with new scientific knowledge. Now, we will make an attempt to compare the interaction between stakeholders involved in the nanosilver industry and new scientific knowledge.

As in the previous case, we observe that a two-way influence between new scientific knowledge and the following stakeholders related to nanosilver exists: producers and users, representative bodies, governance units and agencies, intergovernmental organizations and challengers.

For example, there is some evidence that the European Chemical Industry Council (Cefic, which can be characterized as a representative body) participates in research: “*Cefic’s Long-range Research Initiative has completed three projects on testing and assessment of reproductive toxicity and safety to human health of nanomaterials, and has launched a fourth*

¹⁸⁴ <https://plastics.americanchemistry.com/Why-Replace-BPA.pdf>, accessed in April 2017

¹⁸⁵ <https://www.americanchemistry.com/About/>, accessed in April 2017

The missions of main NGOs are presented in Appendix I

¹⁸⁶ While it is an American organization, several experts have defined it as influential one. This is one of the reasons, we have included this organization in the group

one to develop evaluation process best practice”(Cefic, 2014, p. 21). The Cefic Research and Innovation Programme addresses innovation policy and new technologies. It also addresses research and emerging science issues such as endocrine disruptors, indoor air quality and human biomonitoring. The American Chemical Society (ACS, another external body) contributes to research as well: *“The Society launched two new journals (ACS Nano and The Journal of Physical Chemistry C), made significant enhancements to its end-to-end electronic workflow for ACS journals, introduced a Web version of the SciFinder® research tool, and revamped its Web site”* (American Chemical Society, 2007, p. 32). As we have mentioned, the consumer organization, BEUC¹⁸⁷, contributes to research through an inventory of products claiming to contain nanosilver particles on the EU market. This inventory may help to define a level of exposure by making a list of goods containing nanosilver. The report on the state of the art of nanotechnology commissioned by Greenpeace (Huw Arnall, 2003) also adds to knowledge on nanotechnology. This implies that NGOs also adds to knowledge. Besides, different NGOs provide scientific information for consumers and producers together. The media also provides consumers with information. OECD has published a series of reports and guidance on the safety of nanosilver. Several agencies and para-public institutions have published scientific opinions related to nanosilver.

In addition to these activities, based on the data in Chapter 4, it can be suggested that the events which are characterized as “responsible research and innovation” and which are closely related to new scientific knowledge about potential risks imply additional interactions among stakeholders involving new activities. Moreover, these activities result in greater cooperation between stakeholders.

While some attempts can be considered as unsuccessful (for example, the UK Responsible NanoCode), a number of events are successful. The emergence of new activities related to new scientific knowledge about risk shows the evolution of interaction among stakeholders. Besides, end users have become involved in a two-way relationship with new scientific knowledge through these activities.

¹⁸⁷ Bureau Européen des Unions de Consommateurs

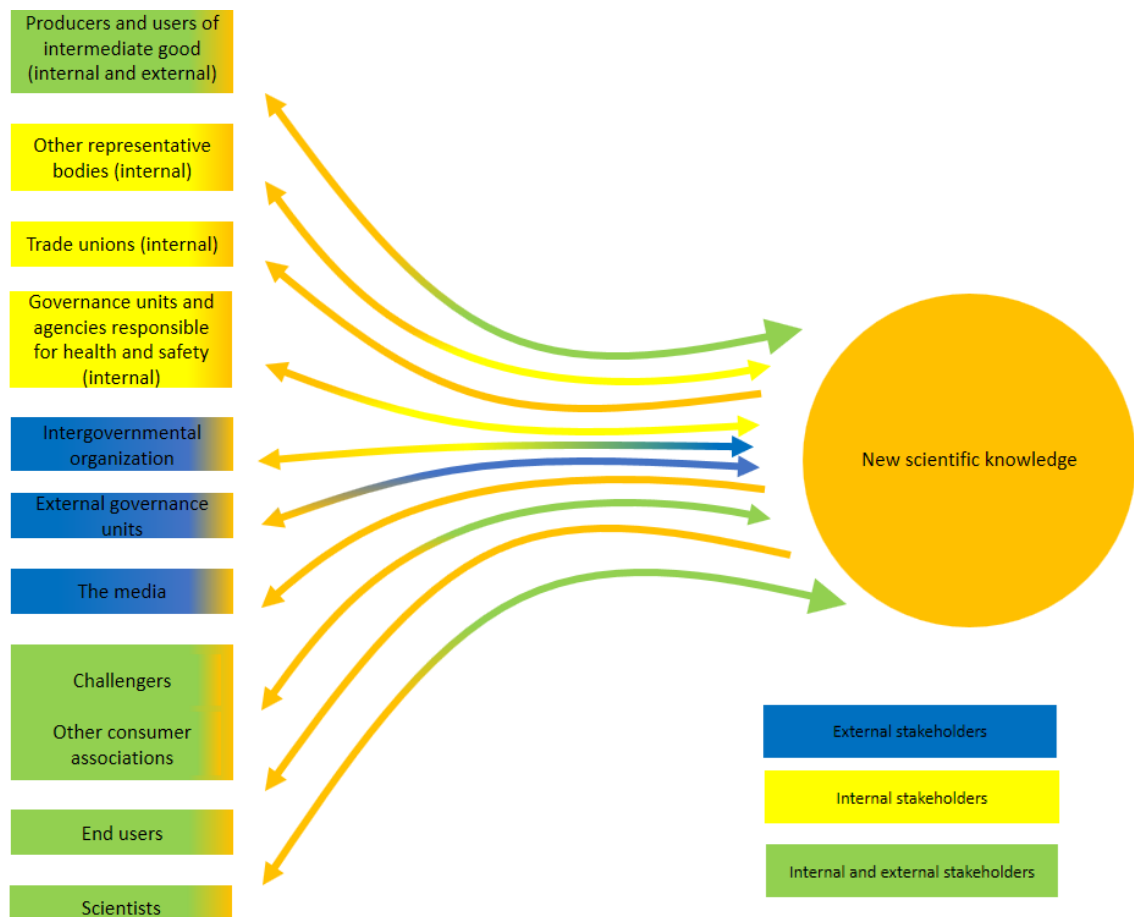


Figure 62. *Model of stakeholder interactions leading to responsible research and innovation (influences are indicated by tipped arrows)*

Source: *Own work*

Figure 62 shows a clear difference in one-way/two-way influence between representative bodies and governance units/agencies/para-public institutions, producer-user and governance units/agencies, producer-user, representative bodies, consumer, etc. A large number of interaction among stakeholders can be observed, which enlarges the existing link between new scientific knowledge and stakeholders which might modify the link between the good and end users. The "responsible innovation and research" events add more weight to scientific knowledge and increase a number of two-way influences among stakeholders despite the consumer and industry associations which act as prescribers. **The following question arises: what is the relationship that exists between stakeholders and what is the range of activities that different stakeholders employ in response to scientific knowledge about potential risks.** We are interested in a model for action¹⁸⁸ which can explain the weak relationship between new scientific knowledge and consumption.

¹⁸⁸ The management research focuses on collective actions, "which form what are then perceived as economic or social phenomenon" (David, Hatchuel, & Laufer, 2013, p. 36). The term action is not used by David et al. (2013) to refer to a naturally

8.3.2. Activities in response to new scientific knowledge

Our research contributes to the identification of a range of activities that different stakeholders might use in response to new scientific knowledge. Moreover, we compare the activities of the BPA and nanosilver industries with the activities of the tobacco and alcohol industries which they have pursued “in response to legitimacy-threatening social issues” (Christiansen & Kroezen, 2016, p. 103).

Research funding is one of the activities that has been employed by different stakeholders as we have already mentioned. Both, the representatives of tobacco and alcohol industries have employed similar activities in response to new scientific evidence. “Other industries are drawing inspiration from tobacco company strategies” (European Environment Agency, 2013, p. 17). Moreover, Savell et al. (2014) state that the tobacco industry has tried to “shape the evidence” through research funding or diffusion of research findings. For example, representative bodies state that there is some evidence about the impact of excessive alcohol consumption which is not necessarily true for moderate consumption. These activities are a part of information strategy which delineates a heavy alcohol use group at risk and encourages research related to moderate drinking. Similarly, the representatives of BPA and nanosilver industries dispel the myths about potential risks, discuss benefits of intermediate goods and explain that these goods have to be consumed in large quantities to cause harmful effects.

We have already discussed the attempt of BPA and nanosilver industries to engage in self-regulation and voluntary reporting schemes. Both activities have been employed by the tobacco and alcohol industries as a result of the increased regulatory pressure in order to avoid formal legislation (Christiansen & Kroezen, 2016; Savell et al., 2014). Besides, the representatives of tobacco industry have used an argument that regulation will cause job losses (manufactures and related industries) (Savell et al., 2014). A similar argument was used during the debate on BPA according to Gilles Garnier, French Senator Annie David’s Assistant. While “shaping the evidence” can be considered as an information strategy, direct and indirect lobbying are also parts of information strategies. There are signs of direct and indirect lobbying by tobacco industry. For example, the tobacco industry persuaded several organizations, namely “the British Brands Group, the Association of Convenience Stores, and the Advertising

observable phenomenon. The authors use this term to refer to “a modification of the world that we need to conceive. The conception of the action can be taken in two non-exclusive ways: either to make it exist, in which case the action is our creation; or to recognize it, in which case the action is not created by us, but exists because we perceive it” (p. 49).

Association”, to lobby on the behalf of the industry against the Tobacco Advertising Bill in the UK in 2000 (Savell et al., 2014, p. 3). Similarly, according to "Seeking safer packaging: ranking packaged food companies on BPA", \$18, 85 mln spent to lobbying in 2009, among other things, against bills that might have limited consumers’ exposure to BPA. These activities explain the diffusion of BPA, which is in line with “the forced-selection perspective” presented in Chapter 2. According to this perspective, innovations are diffused if they are supported by powerful groups (Abrahamson, 1991).

To sum up, the following similar tactics and arguments have been used by BPA and nanosilver industries, tobacco and alcohol industries:

- **research funding and commissioning research**
- **shaping the evidence**
- **delineating a group at risk**
- **self-regulation and voluntary reporting schemes**
- **job loss argument**
- **lobbying**

We can see that the relationship between the product and end users involves among other things exchange of knowledge and expertise. Regarding the exchange of expertise, we observe that both consumer associations and industry associations are involved in the process of exchange. They have become intermediate actors which might influence the process of learning about scientific knowledge about potential risks. One of the seminal studies, Hatchuel (1995) focuses on the impact of prescriber on consumer choices. The author suggests uncertainty or lack of value of prescription might not end up with exchange and the need for a prescriber might arise. We are interested in the moment when a buyer (end user) disqualifies himself from being responsible for his own choice and he has to rely on a prescriber. The term “prescriber” tends to be used in the fields of medicine and marketing. The following questions arises: **Who is this prescriber? Can we define consumer and industry associations as prescribers?**

8.3.3. Prescriber in the relationship between an intermediate good and consumers

Hatchuel (1995) suggests a prescriber recommends a direction to a buyer. He recommends consumer behavior, an analysis to conduct, questions to ask, etc. These elements are involved in the constitution of transaction between sellers and buyers, but they also establish a new

market. A prescriber contributes to value formation and modifies a field of exchange including the existing market. He helps buyers to get oriented. A prescriber can make goods substitutable which have not been perceived as such and enlarge the perception of existing offers (“you can make this good from plastic”, “white wine can be served as aperitif”). He can also create a monopoly or oligopoly by restricting available choices. Finally, he can participate in a market development by recognizing new goods or categories (new technology, new cuisine). When a prescriber contributes to preferences formation, the nature of value of prescription is highlighted: an active mental construction reconstructs cultural s. In Management, Hatchuel’s study (1995) provides a theoretical framework for studying the role of prescriber in the relationship between seller and buyer. The notion of prescription has created a new relationship which consists of 3 parts: seller, prescriber and buyer instead of seller-buyer relationship. A specialized journal, a doctor, a technology expert, a literary critic, a selection board that awards a prize addressing potential buyers are some examples of prescribers. New information and communication technologies encourage to use the services provided by prescriber. Additionally, a variety of exchange crises encourages the establishment of prescribers.

Prescriptions can be categorized based on a “knowledge inflow” criteria:

- factual prescription,
- technical prescription and
- judgment prescription.

Hatchuel (1995) uses the term “factual prescriptions” to refer to prescriptions which provide deeper knowledge about earned benefits or something else. A prescriber narrows uncertainty related to world’s states, states which can be known by a seller, but this seller could not admit these states. It should be noted that a prescriber speaks out about the existence of a particular world’s state. The characteristics of this state are known to buyers and sellers. The author notes that a prescriber deals with uncertainty about facts.

“Technical prescription” is defined by Hatchuel (1995) to refer to a prescriber who has to intervene in the process of buying providing notions which are initially unknown to buyer. He can indicate alternative suppliers and use strategies. He can suggest action plans or causal patterns to buyers. The author underlines that a prescriber deals with uncertainty about notions. Experts suggest technical solutions to a problem defined by a buyer. Doctors, engineers and architects are examples of prescribers who give technical prescriptions. A buyer

does not have a choice, he does not know what to buy. The process of buying becomes the process of delegating and controlling.

The term “judgement prescription” has been applied to deal with uncertainty about values. Before now, a prescriber provides his knowledge about something that can be acquired or its mode of usage. But a buyer has been a master of his appreciation of utility that he will get. But we can easily switch from technical prescription to judgement questioning. The majority of consumer magazines define criteria of judgement which have been unknown to buyers or could not be easily formulated. A literacy critic passes her judgment and a proper way to judge. Hatchuel (1995) mentions that in the language of economic theory, it means that buyers who rely on prescribers are offered a modification of their utility functions.

While this description of prescriber is applied to the study of process of buying new goods, we are interested in description of the role of NGOs as potential prescribers. We will make an attempt to discuss if this theoretical framework is suitable for the purpose. Besides, we will see whether we can define NGOs in a situation of uncertainty about environmental and health risks as prescribers by discussing the nature of the relationship which has formed among the stakeholders.

In a situation of uncertainty about environmental and health risks, a buyer might not be able to make a decision as he does not possess all the necessary knowledge which allows to ease the exchange. A buyer can go to a prescriber for guidance on her choice. In the context of uncertainty and growing number of scientific articles on potential risks, the presence of prescribers who are able to elucidate potential risks related to this good and new scientific knowledge about these risks might be needed.

First, we discuss a buyer-prescriber relationship. Then, we discuss a seller-prescriber relationship. Hatchuel (1995) describes a buyer-prescriber relationship as trusting. The trust is based on a principle that two stakeholders pursue the same interest, that is the interest of the buyer. A prescriber strives to keep his knowledge up to date, he is committed to confidentiality and not to join competitors, he wants to demonstrate his independence from seller’s pressure. **Based on the mission statements of consumer associations related to BPA and nanosilver together with their activities, it can be suggested that consumer associations can be identified as prescribers.**

For example, the UFC-Que Choisir states that it serves consumers to inform, guide and defend them (the mission statements of several associations are presented in Appendix I). Besides,

consumer associations explain environmental and health risks related to BPA and nanosilver. It can be suggested that these consumer associations pursue common interests with buyers, they inform them about notions which have been initially unknown to buyers¹⁸⁹ and define criteria of judgement which could not be easily formulated. These criteria are related to new scientific knowledge which might be less accessible to buyers or buyers might not have special knowledge (or enough time) to understand results of research. At the same time industry associations provide information about BPA and nanosilver by dispelling the myths (which they define as myths) about potential risks associated with these intermediate goods on the website, which can be dedicated to this purpose. Can we define them as prescribers?

Hatchuel (1995) states that a seller is interested in influencing a prescriber as soon as this prescriber is identified. A seller has to persuade a prescriber of the quality of his offer. A prescriber needs information provided by seller to be well informed about product and its evolution. However, a buyer should exercise caution. A seller might decide to hold a contest and maintain a direct relationship with a buyer or offer a new prescriber to buyers. Besides, a seller might make an attempt to pretend to be a prescriber. This might lead to the initial exchange crisis. **It can be suggested that industry associations related to BPA and nanosilver can be perceived as prescribers based on their activities which are reported previously despite the close relationship with the industries. Given their interdependence with producers and users, they cannot be categorized as prescribers.** We can see that this theoretical framework is appropriate in order to discuss the role of prescribers in the relationship between a product and end users in a situation of uncertainty about environmental and health risks. Besides, it helps to describe NGOs as prescribers, explain additional reasons why a seller might return to an exchange crisis, show similarities between BPA and nanosilver and better understand the link between a product and consumers in a situation of uncertainty about environmental and health risks.

The actions taken by prescribers enlarge the range of possible actions of other stakeholders. If these stakeholders face similar exchange crisis, they might use similar criteria of judgement. This might eliminate the need for prescribers and exclude this activity from the range of possible responses to scientific knowledge used by industry associations.

¹⁸⁹ Several studies state that end users are not always aware what nanotechnology is and of its potential effects.

8.3.4. Change levers, new scientific knowledge and consumption

On the one hand, we have just listed actions of stakeholders which can lead to ineffectiveness of scientific information. On the other hand, we would like to discuss how a lack of change levers might influence the relationship between new scientific knowledge about risk and consumption.

Our findings show that there is a weak correlation between scientific articles on risk and consumption of BPA. This result is important. It shows that the link between new scientific knowledge about risk and behavior of users is not direct. Because users do not have freedom of choice what to consume or what not to consume, there is no change lever. The decision not to consume a potentially harmful product is of central importance in the relationship between new scientific knowledge and consumption. The example below illustrates this point.

In recent years, there has been growing interest in valproic-acid which is used in the treatment of epilepsy. It is marketed under the name “Dépakine” in France. In the 1980s it was discovered that the use of valproic-acid during pregnancy was likely to cause different congenital malformations (Jentink et al., 2010). Since 1977¹⁹⁰, more than 1000 scientific articles on toxicity and Depakine (Valproate) have been published. However, Jentink et al. (2010) state “If treatment with valproic acid has been providing good seizure control, it can be difficult to change the drug before or during pregnancy” (Jentink et al., 2010, p. 2186). This is one of the reasons why Valproate has still been used. This situation illustrates that the existence and availability of scientific information does not initiate a change in behavior and does not lead to rejection. After years of inertia, there is no choice but to continue to take medication.

Regarding BPA, there are substitutes for several applications of BPA. For example, glass baby bottles can be considered as substitutes for polycarbonate baby bottles together with bottles made from polypropylene. According to "Les biberons en verre: le retour" (2010), a marked increase in sales of glass baby bottles has been observed since 2008. Regarding other final products made from BPA, their substitutes for packaging and containers are not easily available over the studied period as the discussion about food packaging indicates. As we have already mentioned, the food and beverage companies which use BPA-free packaging have

¹⁹⁰ <https://www.ncbi.nlm.nih.gov/pubmed/?term=depakine+toxicity>

first-mover advantage if the ban on the use of BPA in food packaging is introduced other than in France. **The absence of substitutes for several applications which possess similar characteristics (but pose no potential risk to health and the environment) can be compared to the lack of change lever.** Similarly, medical applications of nanosilver (wound dressing, catheter) are useful because of their strong antibacterial properties. These applications currently do not have close substitutes (or they are not known) as the conversation with one of the experts has revealed. **It can be suggested that the existence of substitutes can serve as a change lever to effect change in behavior.**

The "Safer by design" approach (safety integrated early in the design process) can be used to minimize side-effects of innovations. The implementation of this approach is gradually gaining momentum. The application of substitutes (nano or bulk material) requires a hazard assessment, cost and functionality analysis (Morose, 2010)¹⁹¹. According to Morose (2010), the goal of "Safer by design" approach¹⁹² is "for product designers to design safer products that use nanoparticles by reducing the overall risk to human health and safety of the nanoparticle throughout the product life cycle. This would include consideration for degradation products or metabolites that may be generated during any point in the product life cycle". It can be suggested that this approach may act as a change lever and it can be considered as an additional factor of adoption.

The following question might arise: are there processes which are closely linked to a substitution and a slowdown? We will discuss one process which can be linked to both issues below.

8.3.5. Disruptive innovation

The question of substitution might involve a new product launch which might cause a slowdown of existing products. Besides, the following questions might arise: what might happen if entrants have started introducing new products without potential environmental and health risks delivering suitable functionality in the less profitable segments? In what situations does a slowdown might occur? We think that it is particularly interesting to discuss disruptive innovation in relation to new products and a slowdown as **"the process of disruption is inherently one of substitution"** (Guttentag & Smith, 2017, p. 4).

¹⁹¹ It is worth mentioning that substitute risks can appear, as substitutes can also pose risks.

¹⁹² The term "Design for Safer Nanotechnology" has been used by Morose (2010)

“Disruption describes a process whereby a smaller company with fewer resources is able to successfully challenge established incumbent business” (Christensen, Raynor, & McDonald, 2015). Meanwhile, incumbents concentrate on improvement of products for customers which require to have things as they want (the most profitable segment), they satisfy the desires of this segment and they disregard the needs of others. Disruptive entrants start by targeting the segment which is ignored by providing better functionality of products. And if the incumbents do not reply, entrants may reach mainstream customers providing the required performance using improvements which they have introduced earlier. Incumbents start providing high quality products while leaving a space for entrants to satisfy mainstream and low end markets and establishing the dominance of the incumbents. “Disruptive innovations ... are initially considered inferior by most of an incumbent’s customers” (Christensen et al., 2015). Then, the quality improves and the disruptive innovations are adopted (Christensen et al., 2015). Disruptive innovations arise if new technologies with initially inferior performance exist and they have striking features which are undervalued by incumbents. New market disruptive innovation might occur if features of a product introduced by incumbents “force consumption to take place in inconvenient, centralized settings” (Kohlbacher & Hang, 2011, p. 85). Besides, the price of this innovation is often lower. The model of disruptive innovation is presented in Figure 63.

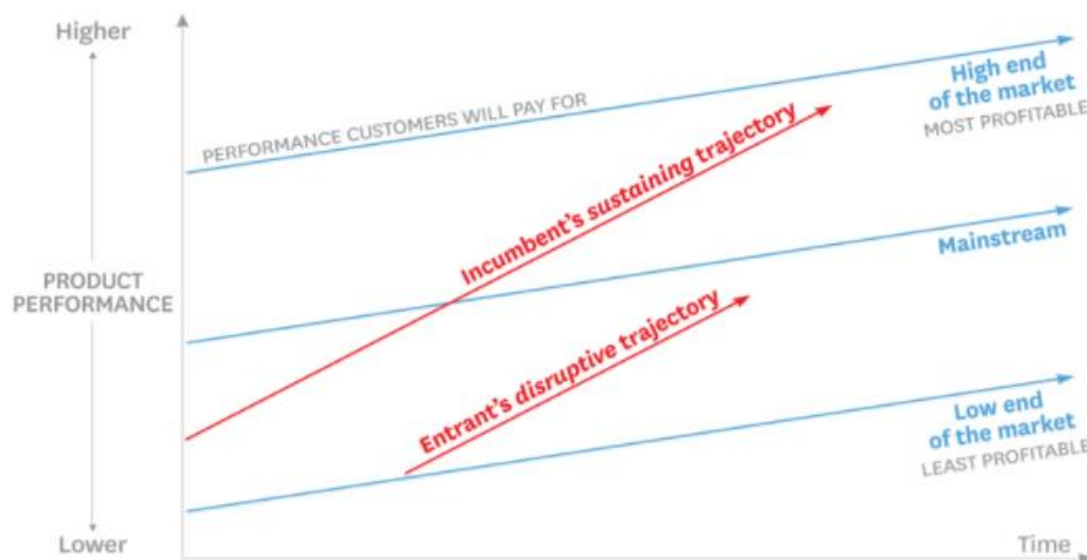


Figure 63. *Disruptive innovation model*
 Source: Reproduced from Christensen et al. (2015)

Slowdown (and/or decline) on the low-end and mainstream markets can be a result of disruptive innovation which can be a substitute for the existing product. Further analysis on existing substitutes can be done to establish whether the process of disruption is currently occurring and whether it can cause slowdown. A recovery can be observed if incumbents reply to disruption by investing in developing new goods (or technologies) with less potential risks to maintain market growth targeting well-known users. As a result, incumbents can provide better goods at lower or comparable prices (Christensen et al., 2015).

If there is a new intermediate good (as a substitute for BPA or nanosilver) which has an attractive feature, then this innovation can be disruptive relative to BPA (or nanosilver). This new good may help users to get needed characteristics of the products. One of the characteristics can be a safer performance compared to the existing products. Besides, affordability remains important given its initial focus on low end users and a relatively low price of BPA. We have discussed the price of BPA earlier.

Chapter 9. Conclusions, directions for future investigations and contributions

9.1. Conclusions

In this thesis, we investigated the determinants of market uptake of innovation in a situation of uncertainty about environmental and health risks. We analyzed the consumption of BPA across 8 world regions. Additionally, the sales value of polycarbonate was explored.

We chose BPA as a starting point for the study of nanosilver because BPA was an example of an innovation that has been on a market for a long time in a situation of uncertainty about environmental risks and the detailed data on nanosilver was not available. The other reasons for the selection were: time sequences of diffusion of scientific knowledge related to environmental and health risks, similar positions in their value chains, similarities in the perceived psychological distance.

The key results of this thesis were as follows:

- Widely speaking, except for the beginning of the studied period, the consumption of BPA per capita rose as income per capita increased up to the point where the consumption declined with an increase in income over the studied period. Three entities crossed the turning point: Japan, the US and Western Europe. While BPA consumption was in the transition from the maturity to decline stage in the majority of regions over the studied period, the global consumption was still increasing over the studied period. One of the possible explanations could be relocation of industry from developed region to less developed region with different environmental legislation.
- An inverted U-type relationship between economic growth per capita and a secondary intermediate good made from BPA was found in Japan over the studied period. The consumption of polycarbonate follows the EKC pattern. Our results suggest that an increase in income can be associated with an increase in probability of slowdown of an intermediate good or (and) a secondary intermediate good in a situation of uncertainty about environmental and health risks.

- The consumption of BPA increased with a higher level of information access.
- An increase in the consumption of BPA was associated with a rise of final good sales.
- The prices of polycarbonate were not much correlated with BPA consumption per capita.
- The effect of the bans on BPA use in baby bottles production in the EU, China, Brazil and Malaysia in 2011 on aggregate consumption of BPA was positive, but statistically insignificant.

Returning to the main hypothesis posed at the beginning of this study, it is now possible to state that there was a weak relationship between new scientific knowledge about risk and consumption of BPA in a situation of uncertainty about environmental and health risks. In other words, we could not relate a decrease in BPA consumption to new scientific knowledge about risk in a conclusive way. A cultural factor partly explained the relationship. A slight reduction in consumption was observed in regions with high uncertainty avoidance as the quantity of articles about risk increases. Further analysis is needed as soon as more detailed data (sector level data) on BPA and nanosilver becomes available. Besides, our findings would seem to demonstrate that there were no continual changes in the shape of product life cycle which could be explained by information shocks.

Drawing on the interpretation of the precautionary principle and the model for unfortunate events, we hypothesized that the higher the number of scientific articles related to potential risks of BPA, the lower the consumption of BPA. We restate the paradox that our research would seem to suggest: **the PP applies to BPA, decision making under uncertainty calls for scientific knowledge, our findings suggest that more research does not result in a proportional use of tools and a proper application of the precautionary principle with respect to available scientific knowledge.**

Besides, the weak correlation between new scientific information and consumption of BPA in a situation of uncertainty about environmental and health risks shows the importance of this research. This work demonstrates that the influence of new scientific knowledge on the behavior of consumers is not direct.

In order to explain this result, open the “black box” of this link, and compare BPA with nanosilver, we studied the link between a product and users, which involved interactions between different stakeholders. We extended the existing classification of stakeholders by

discussing their link with new scientific knowledge (passive consultation, active engagement). We observed that the “responsible innovation and research” events gave more weight to scientific knowledge and enabled a number of two-way influences among stakeholders to increase. These events were of particular relevance to nanosilver. Things may change. But this does not necessarily mean that the adoption of innovation slows down as a result of introduction of new scientific knowledge about risk in a situation of uncertainty about environmental and health risks. This might lead to wider application of a “Safer by design approach” using new scientific knowledge about risk. The “Safer by design approach” can be defined as a mitigation of potential risks of nanosilver or other nanomaterials during the design phase (Morose, 2010).

We identified a range of activities that different stakeholders might have used in response to new scientific knowledge about risk (similar to the tobacco and alcohol industries). These activities included: research funding and commissioning research, shaping the evidence, delineating a group at risk, self-regulation and voluntary reporting schemes, job loss argument and lobbying.

Besides, we discussed the role of prescriber in the relationship between a product and consumers. We postulated that the consumer organizations related to BPA and nanosilver could be defined as prescriber. The industry associations related to BPA and nanosilver could be perceived as prescribers based on their activities. It can be also conceivably hypothesized that an unavailability of substitutes for several applications can be compared to the lack of change lever. This help to explain why a product could be still used despite the existence of scientific knowledge about risk.

The debate over BPA and nanotechnology is important as it brings forward the debate between science and innovation. Our findings suggest that the scientific evidence of risks becomes ineffective with respect to risk management in a situation of uncertainty about environmental and health risks. Several types of action can be undertaken by regulators and/or users of an intermediate good or a final good containing this intermediate good.

The information has been transmitted (spread), but actions are not undertaken which leads to ineffectiveness of information. There is a weak relationship between consumption and information shock in a situation of uncertainty about environmental and health risks. **The weak relationship is worth noting because it shows that the link between new scientific**

information about risks and consumption of a potentially harmful product is not direct.

Several possible mechanisms might explain the ineffectiveness of information:

- the absence of substitutes, which can be compared to **the lack of change lever**, makes several actions impossible. **Consumers do not have choice but to consume a potentially harmful product.** It might explain the widespread use and the relationship between scientific information about risk and behavior of consumers. Meanwhile, an intensive use of a good does not always suggest that the good is accepted.

- **activities undertaken by stakeholders** in response to new scientific knowledge

- **the presence of intermediate actors in the relationship between sellers and buyers**

9.2. Limitations and further research

9.2.1. Limitations

This research has several additional limitations. First, our study focused on aggregate level data of bisphenol A consumption, not on sector level data. Therefore, we assessed overall consumption of BPA while it was used in the production of many different products which can be less or more sensitive (or not sensitive at all) to the impact of new scientific knowledge. An assessment of sector-level data of BPA consumption at international level can provide additional insights into the relationship between new scientific knowledge and consumption of bisphenol A. This analysis was not possible in the framework of the current study due to unavailability of data.

One issue that requires more examination is the price of bisphenol A and its consumption. Given the unavailability of BPA prices, we have used polycarbonate prices as a proxy for BPA prices (BPA is used in the production of polycarbonate). We have found no correlation between BPA consumption per capita and polycarbonate prices. This result can be attributed to the sample construction and unavailability of prices for each entity separately and/or by the low-price variability and volatility. As soon as data becomes available, further studies should address this.

We have constructed the measures of under- and over-consumption of BPA building on the study of Ghimire & Woodward (2013). But we are not able to apply parametric techniques in order to assess the relationship between under- and over-consumption of BPA due to a small sample size. Further works need to be done if larger and more detailed dataset exists.

The BPA analysis can be extended by other factors which influence BPA consumption to avoid omitted variable bias if the size of the data set and availability of data on other explanatory variables permit. For example, an environmental awareness and/or awareness about potential risks of BPA might play an important role in the relationship between BPA consumption and economic growth.

Our main limitation is the lack of sales data on nanosilver. We have used an original method to deal with this problem by using the quantitative data on BPA together with the qualitative data on BPA and nanosilver. Future studies on the current topic are required in order to clarify the relationship between nanosilver and new scientific knowledge in addition to other determinants of the diffusion of innovation. Future work is recommended to answer the following questions: How does the relationship between new scientific knowledge and stakeholders change over time? What type of scientific knowledge is used by regulators to take decisions? What is the link between new scientific knowledge about risk, regulations and consumption? Which stakeholder is most important based on their contribution to research and regulatory decisions? Although there are limitations, we believe that this research provides a framework for future studies on nanotechnology and our results are an initial step towards understanding of determinants of adoption of nanotechnology and other innovations in a situation of uncertainty about environmental and health risks.

In addition, we would like to discuss the link to a sociological ballistics. In the second subsection and threshold models of collective behavior is presented.

9.2.2. Sociological ballistics

According to Godard et al. (as cited in Merad, 2009) and Merad (2009), if there is a potential risk, scientific knowledge becomes a topic of controversy as the knowledge is hypothetical. In this case, a collective decision seeks to decrease uncertainty. The diffusion of scientific information leads to an overlap between scientific and public controversies associated with challenges of knowledge and challenges of actions. The analysis of dynamics of social controversy is related to the study on sociological ballistics which helps to formally describe the trajectory of an object of controversy (Chateauraynaud, 2011). The dynamics of controversy outlines the evolution of study on risk and collective decisions which allows to distinguish a steady universe from controversial universe.

The model of sociological ballistics of collective process is based on the manner in which actors and arguments are involved in a dispute (identification of an object of controversy, discussions, scientific controversy, experts' reports, "public debate, political mobilization") and how they impact the trajectory (how stakeholders "think, judge and act") (Chateauraynaud, 2009, p. 40). The use of temporal diagram based on the presence of the object of controversy at the political and media scenes is a simple way to present a trajectory using the national press, parliamentary debates or discussions of experts' reports.

Chateauraynaud (2009) distinguishes 5 phases of trajectory over time:

- Emergence ("making new signs and problems visible")
- Controversy ("agree or disagree on facts and matters of facts")
- Claims, denunciation and polemics ("defining victims, responsibilities and guilt people")
- Political mobilization ("in the aim to modify or to defend law and conventions")
- Normalization and regulation ("put in practice texts and rules, by involving many actors in the process of governance")

The description of this model seems to suggest that this model could be relevant to risk controversies related to BPA and nanosilver. We propose that further research should be undertaken in this area. We have conducted a qualitative analysis based on interviews with experts and reports focusing on the relationship between a product and consumers. Additional work can be done to establish the differences between the phases of trajectories of controversies using additional sources of data (for example, the national press). This analysis can show changes of trajectory of controversy over time and how they have happened including elements which contribute to these changes. It helps to define the degrees of reversibility and bifurcation. The term "reversibility" has come to be used to refer to the impossibility of returning to an initial position on the trajectory by simple actions inversion. The term "bifurcation" tends to be used to refer to a deviation from an expected trajectory due to unintentional events or stakeholders interventions (Chateauraynaud, 2011). Moreover, possible activities of different stakeholders can be also defined.

Building on this study, we are able to define clearly two phases related to the trajectories of BPA and nanosilver using our data: the phase of emergence and the phase of normalization and regulation. Based on our data, it can be suggested that the phase of emergence of BPA

issue started when the first article about potential danger of polycarbonate was published. And the phase of normalization started when the ban on the use of BPA in production of baby bottles. Regarding nanosilver, the emergence of dossier of nanosilver could be attributed to the year 2004 when one of the first scientific articles related to nanosilver and toxicity was published. And the normalization phase started with the cosmetics regulation concerning nanotechnology in 2009, followed by a few more regulations. However, these regulations do not concern all available applications of nanosilver. Similarly, bans on BPA are related to some of its applications.

Regarding other phases, further analysis needs to be conducted. It can be suggested that the phases of controversy related to both dossiers have started when the quantity of articles about toxicity with different conclusions has begun increasing (BPA – 1997 and nanosilver – 2005). Meanwhile, we observe that the phase of polemics started with attempts at voluntary and safe-regulations and research funding (which can be defined as a defense). These activities were undertaken simultaneously with the increase in articles related to risk. This might mean that the objects of controversy have passed directly to the phases of polemics. The phase of mobilization could have started when governance units, agencies and para-public institutions have started publishing the reports concerning BPA and nanosilver, consumer associations have started reacting to new scientific knowledge, inventories of products claiming to contain nanosilver have been published and the evidence of false or misleading claims has become available¹⁹³. In order to confirm the timing of these phases and define the degrees of reversibility and bifurcation, further analysis is needed.

9.2.3. Threshold models of collective behavior

While we have used aggregate data in order to study the consumption of BPA, the analysis could be extended by examining how individual preferences interrelate and aggregate in a situation of uncertainty about environmental and health risks. Citizens of each entity (region or country) may be wary of adopting (or rejecting) products containing BPA or nanosilver and wait until some proportion of their fellow citizens adopt these products. Various citizens might have various thresholds¹⁹⁴ based on their levels of education, age, family background, beliefs,

¹⁹³ As we have mentioned, according to Vogel (2009), out of 115 studies, 11 studies on the impact of BPA funded by industry found no effects compared to other studies funded by government found numerous effects.

¹⁹⁴ Granovetter (1978) has developed one of the classical threshold models. The author defines threshold as “the number of proportion of others who must make one decision before a given actor does so; this is the point where net benefits begin to exceed net costs for that particular actor” (Granovetter, 1978, p. 1420).

tastes, etc. Can we hypothesize that if most citizens make similar decisions, they hold similar beliefs and norms? Granovetter (1978) has developed a model which deals with an aggregation of individual preferences that can vary within a country or region. The author states that “groups with similar average preferences may generate very different results; hence it is hazardous to infer individual dispositions from aggregate outcomes or to assume that behavior was directed by ultimately agreed-upon norms” (Granovetter, 1978, p. 1420). The author states that an application of threshold model is valuable in a situation where average preferences are in favor of some action, but this action is not undertaken. However, it might be difficult to measure thresholds before the actions happen. Given that the introduction of new scientific knowledge about potential risk might lead to dissatisfaction of citizens and no actions are taken, an application of this model may provide additional insight into collective behavior by relating micro to macro level.

9.3. Theoretical and methodological contributions, implications for nanosilver and limitations

9.3.1. Theoretical contribution

With respect to contributions to theory, this thesis sheds lights on a set of factors which influences or not the diffusion of innovation and how these factors are related to innovation in a situation of uncertainty about environmental and health risks. The results have important implications for understanding the diffusion of nanosilver.

We advance the diffusion of innovation theory under conditions of uncertainty about environmental and health risks. We find that an increase in income can be related to a decrease in consumption. This is opposite to findings of Golder & Tellis (2004). We theorize that affordability does not always explain innovation adoption if an innovation is under conditions of uncertainty. To the best of our knowledge, this finding is new to the innovation diffusion theory. Based on the EKC hypothesis and results of our study, it can be suggested that the prior assumptions about the impact of wealth are invalid under conditions of uncertainty (epistemological and empirical evidences).

Based on our results regarding the EKC and affordability, we propose that under conditions of uncertainty, it is likely that a rise in income increases the time to slowdown. If the gap in knowledge about exposure and hazard widens, the uptake of nanosilver might fall as income increases. However, it is unlikely that this effect goes beyond one product line or industry (Berube et al., 2010).

Additionally, we have analyzed the case of polycarbonate in Japan. We have found that sales increase with growing income up to a turning point beyond which its sales decrease with higher income per capita. Under conditions of uncertainty (implication for nanosilver), it might be suggested that nanointermediates and nano-enabled goods can be negatively affected by the quantity of articles related to potential risk of nanosilver given the similarities between BPA and nanosilver.

Besides, we have identified an additional factor that has to our knowledge never been reported before in the literature of diffusion of innovation and how this factor can be related to the diffusion of innovation including nanosilver. This factor is new scientific knowledge.

We theorize that new scientific knowledge might impact the adoption of an innovation in the presence of a change lever under conditions of uncertainty. The uncertainty avoidance moderates the impact of new scientific knowledge. The empirical evidence suggests that new scientific knowledge is likely to have a negative effect on adoption in countries with high uncertainty avoidance. We hypothesize that the presence of substitutes can be a change lever that allows actions. In the absence of a change lever, the effect of new scientific knowledge might be weak. Regarding nanosilver, it can be suggested that “responsible innovation and research” events can bring about significant changes in the relationship between different stakeholders by increasing the number of two-influences. As a result, the role of knowledge might change.

A technology emergence cannot be a result of one actor. A large number of different actors are involved in the development of new technology. Actors become embedded in a path of technology, which in turn might influence these actors and their activities: enable new activities and/or constrain the existing ones (Garud & Karnoe, 2003). Their involvement may differ over time. The actors involved in technology emergence are not limited to those who discover new ideas. Garud & Karnoe (2003) define 4 major categories: designers and producers, users, evaluators and regulators. Based on the experience and beliefs, producers learn “by doing and by experimenting”. This might give additional capability to producers. Users provide feedback on goods that are manufactured using this new technology. This might result in “learning by using” knowledge which might help to improve the technology. Regulators formulate policies which might guide companies towards successful development of technology based on the beliefs in different efficient policy tools. Evaluators or test centers

contribute to technology development through “learning by testing”. Inputs generated by these actors make an emerging technology keep getting better (Garud & Karnoe, 2003).

Our discussion about new scientific knowledge related to potential risks of nanosilver seems to suggest that a collaboration between different stakeholders which results in “responsible innovation and research” events can lead to successful diffusion of nanosilver. Garud & Karnoe (2003) provide additional support for the importance of collaboration between different stakeholders.

The authors conduct a comparative study on the emergence of wind turbines in the USA and Denmark. They explain why one group of actors can prevail another one based on different levels of stakeholder involvement. The authors reach the conclusion that a lack of collaboration between different stakeholders is one of the reasons why Danish wind turbine path has prevailed over the US turbine path. The authors state that “Designers and producers steadily scaled up designs all the while incorporating the inputs of the many actors involved. Users offered continual feedback while those in test centers developed evaluation routines that co-evaluated with experiences in the field of the many actors involved. Users offered continual feedback while those in test centers developed evaluation routines that co-evaluated with experiences in the field. All the while, policy makers modulated the emergence of the market to keep the technological path alive.” (Garud & Karnoe, 2003, p. 284). Co-shaping of technological path has occurred through different interactions between various stakeholders.

Besides, we have enriched the literature by listing the collective activities that different stakeholders may undertake in response to new scientific knowledge. We focused mainly on French stakeholders and their activities. Based on the case of BPA, we have shown that collective activities, namely research funding, shaping the evidence, delineating a group at risk, self-regulation and voluntary reporting scheme and lobbying are important factors that explain ineffectiveness of new scientific knowledge. While the industry’s efforts to defend long-term interests of BPA industry can be observed, these efforts do not explain the phenomenon completely. And the presence of a change lever might be an important factor. Using the example of “Dépakine”, we have additionally demonstrated the importance of our results. The link between new scientific knowledge about risks and behavior of consumers is not direct. The ability to choose whatever you want to consume or not to consume is a change

lever. The absence of this ability may explain a weak correlation between new scientific knowledge about risk and consumption.

Moreover, we have enriched the management theory by forwarding the role of prescriber in the relationship between a product and consumers in a situation of uncertainty about environmental and health risks. We describe how industry associations can imitate the behavior of prescribers despite close link with producers or intermediate users. Several industry associations have created a separate website dedicated to the issue of BPA where they pretend to dispel the myths about BPA (which they define as myths). However, they are transparent about their members. Industry associations combine characteristics of prescribers and organizations that coordinate collective responses of the industry (several companies) as the empirical evidence suggests. In this case, industry associations can be perceived as prescribers.

We have defined several periods in the history of BPA industry and have described them:

- before the discovery of the low-dose effects of BPA
- period of silence
- after the first reactions of internal agencies to new scientific knowledge

Our results show similar trend related to nanosilver (collective activities and the periods in the history).

9.3.2. Methodological contributions

We have employed an original approach to study the drivers of the diffusion of innovation that is in the introduction stage by comparing it with a similar product in the maturity stage. The maturity stage of the PLC is an indication that the input as BPA become routine. And BPA can be considered as adopted.

We have used the following characteristics:

- time sequences of diffusion of scientific knowledge related to environmental and health risks
- similar positions in their value chains
- similarities in their perceived psychological distance
- their positions in the PLC

Then, we analyzed activities of different stakeholders related to both products to see if the drivers would have similar effect (in terms of direction). We consider this approach as suitable

one given the absence of historical sales data on nanosilver. Besides, we have extended the classification of stakeholders suggested by Fligstein & McAdam (2012) by including the relation with new scientific knowledge (passive consultation or active engagement).

Moreover, we contribute to the literature on the EKC by exploring the case in a situation of uncertainty about environmental and health risks. As we have stated earlier, relatively little literature examines the validity of the EKC hypothesis under these conditions. Based on our analysis, it can be suggested that the inverted U-type relationship may hold under these conditions.

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Appendix A. Bass model and its extensions

Bass model

The solution to the non-linear differential equation is

$$F(t) = (q - pe^{-(t+c)(p+q)})/q(1 + e^{-(t+c)(p+q)})$$

Given $F(0) = 0$, we receive $F(t) = (1 - e^{-(p+q)t})/(1 + \frac{q}{p}e^{-(p+q)t})$

with a sales peak at

$$t^* = -\frac{1}{p+q} \ln \frac{q}{p}$$

If new products are successful q is greater than p , the solution is presented in Figure 64 (the plot of cumulative sales against time is presented earlier in Chapter 1). It depicts S-curve. Talukdar et al. (2002) have compared the coefficient of innovation and imitation across several new products and several countries. The authors have estimated that the mean of the coefficients of innovation for developed and developing countries are about 0.001 and 0.0003, respectively. The mean of the coefficients of imitation in developed and developing countries are about 0.509 and .556, respectively. The average time to sales peak in developed and developing countries are 16 and 19 years, respectively.

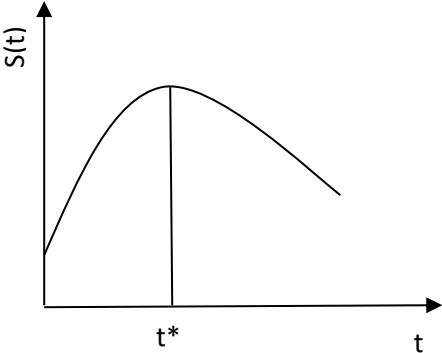


Figure 64. Growth rate
Source: Bass (1969)

A discrete version of the Bass model can be estimated by ordinary least squares (OLS). Even if several authors (Putsis Jr., 1996; Putsis Jr. & Srinivasan, 2000) state that the coefficients can have a wrong sign if the number of observations is insufficient. Additionally, the standard errors are not estimated directly due to the fact that p , q and m are expressed as nonlinear functions of estimated parameters. Besides, Putsis (1996) states that the OLS estimators will overestimate sales before the peak and underestimate afterwards. Instead, maximum likelihood estimation (MLE) and nonlinear least squares

(NLLS) estimation procedures are suggested by Jain & Rao (1990), Schmittlein & Mahajan (1982), Srinivasan & Mason (1986). Even though they exhibit some limitations, the literature claims that they are preferable to OLS approach. One of the shortcomings of NLLS and MLE procedures is the existence of closed form solutions that is required in order to use these methods.

Extensions of the Bass model

The importance of price incorporation into aggregate diffusion models have been recognized by several authors (Bass, Krishnan, & Jain, 1994; Jain & Rao, 1990; Robinson & Lakhani, 1975, Song & Chintagunta, 2003). First attempt to include dynamic price effect in the Bass model was implemented by Robinson & Lakhani (1975). According to this extension, a decrease in price will result in a rise in the number of adoptions in the current and following periods. Their findings suggest that price impacts adoption decision for durables.

Song & Chintagunta (2003) incorporate forward-looking behavior of adopters in the empirical model of diffusion of innovation applied to durables. The authors assume that price declines exponentially over time and all potential adopters aware about that. That is why they might postpone the purchase decision. The adopters are involved in the tradeoff between purchasing at the moment or later. Therefore, price in the current period impacts future adoptions.

The impact of marketing mix variables is of particular interest to marketing scholars. Other diffusion models include advertising to estimate its effect on adoptions (Bass et al., 1994; Horsky & Simon, 1983). For instance, Horsky & Simon (1983) assume that advertising is used to raise awareness about innovation and then it is communicated to imitators through WOM. The authors apply their model to telephonic banking and they conclude that advertising stimulates the diffusion process.

Bass et al. (1994) incorporate advertising and price in the Bass model. This model is one of the few that includes both price and advertising. Their results confirm the existence of "*carry-through*" property which means that the effects of price and advertising will be carried out through the entire diffusion process (but not necessarily having the same magnitude every period).

Whereas the studies that include marketing-mix variables are widespread, limited empirical literature is available regarding repeated purchases. One of the reasons is a lack of data that differentiate first purchases from replacement or multiple purchases. Besides, the employment of mixed data to first-adoption model may lead to biased estimates. Ratchford, Balasubramanian, & Kamakura (2000) admit that assumption that all uses of innovation correspond to first-adoptions might hold if the innovation has just been put on the market. The reasoning behind replacement is different due to the presence of user experience and word of mouth is less likely to drive diffusion in this case. Hence, three different processes might exist simultaneously on the market, namely first use of innovation, replacement and multiple units purchase. In the case of introduction of new generation of technology, replacement can be driven by introduction of improved version of a product rather than its destruction. Broadly

speaking, the replacement of technology suggests that the newer technology is better one in terms of better price, improved process or product, or redefined segmentation, targeting, or positioning. However, it is not necessarily the case. Several generations of product can exist together at the same time, for instance, digital album downloads and CD album sales coexist and compete with each other. The sales of one product can be determined by a success or a fail of another product. Interdependence among several products concerns not only substitutes, but also complements. The success of two complementary products not necessarily provided by the same manufacturer is interrelated as well (Bayus, Kim, & Shocker, 2000; Chandrasekaran & Tellis, 2007).

Appendix B. Questionnaire

Ce questionnaire est réalisé dans le cadre de la thèse en gestion qui s'intitule « Determinants of market uptake of innovation in a situation of uncertainty about environmental and health risks: from BPA to nanotechnology » de Mariia Ostapchuk. Cette thèse est réalisée au sein du LABEX SERENADE, dans l'équipe M-Lab du laboratoire DRM de l'université Paris-Dauphine et l'INERIS. Le but de ce questionnaire est de cartographier les acteurs impliqués dans les nanotechnologies (et nano-argent, spécifiquement) et d'écrire le début de l'histoire des nanotechnologies (les événements principaux qui peuvent impacter la consommation de nano-argent et les réactions des différents acteurs par rapport aux informations sur les risques potentielles liés au nano-argent). Je vous serais reconnaissante si vous pouviez renseigner le questionnaire ci-dessous. Merci de me le retourner par e-mail : mariia.ostapchuk@dauphine.eu, mariia.ostapchuk@ineris.fr. Je vous remercie de votre coopération.

Je vous serais reconnaissante pour tout envoi de documentation/rapport pouvant m'aider dans la cartographie et la rédaction de l'historique des nanotechnologies.

1. Comment êtes-vous arrivés à vous intéresser et à vous impliquer dans le domaine des nanotechnologies ? Cliquez ou appuyez ici pour entrer du texte.

2. Comment définiriez-vous votre rôle dans ce domaine ? Cliquez ou appuyez ici pour entrer du texte.

ACTEURS PRINCIPAUX

3. Pourriez-vous identifier 3 principaux producteurs de nano-argent en France (a) / dans le monde (b) ?

(a) Cliquez ou appuyez ici pour entrer du texte.

(b) Cliquez ou appuyez ici pour entrer du texte.

3. Pourriez-vous mentionner les utilisateurs principaux de nano-argent (nom des entreprises et leur secteur d'activité) en France (a) / dans le monde (b) ?

(a) Cliquez ou appuyez ici pour entrer du texte.

(b) Cliquez ou appuyez ici pour entrer du texte.

4. Etant donné que le nano-argent est un bien intermédiaire, qui sont les principaux fabricants (nom des entreprises et leur secteur d'activité) de produits finaux en France (a) / dans le monde (b) ?

(a) Cliquez ou appuyez ici pour entrer du texte.

(b) Cliquez ou appuyez ici pour entrer du texte.

5. Est-ce qu'il existe des instances représentatives (e.g. syndicat professionnel, associations professionnelles) liés aux nanotechnologies / nano-argent, en France et/ou dans le monde ? Si oui, lesquelles ?

Cliquez ou appuyez ici pour entrer du texte.

« **CHALLENGERS** » : Ils reconnaissent la nature du champ d'activité et les logiques des acteurs principaux, ils tentent d'articuler une vision alternative de champ

6. Qui sont les lanceurs d'alerte¹⁹⁵ ? Cliquez ou appuyez ici pour entrer du texte.

7. Qui sont les autres « challengers » ? Cliquez ou appuyez ici pour entrer du texte.

UNITES DE GOUVERNANCE (au niveau français, européen)

8. Pourriez-vous définir les unités de gouvernance liées aux nanotechnologies / nano-argent ? Cliquez ou appuyez ici pour entrer du texte.

9. Pourriez-vous lister les textes réglementaires liés aux nanotechnologies / nano-argent ? Cliquez ou appuyez ici pour entrer du texte.

ACTEURS EXTERNES (associations de consommateurs, autres ONGs et media nationaux et internationaux)

10. Qui sont les acteurs externes ? Cliquez ou appuyez ici pour entrer du texte.

UNITES DE GOUVERNANCE EXTERNES (institutions d'autres pays européens et internationaux, organisations internationales, chercheurs internationaux, producteurs internationaux)

¹⁹⁵« Le terme est plus fréquemment utilisé pour désigner des individus – simples citoyens, travailleurs indépendants ou subordonnés – qui, par inadvertance ou par choix volontaire, signalent l'existence d'un risque encouru par la société » (Dupissson-Guihéneuf, 2014, p. 81). Ce terme peut être également utilisé pour désigner des personnes, groupes ou institutions.

11. Pourriez-vous définir les unités de gouvernance externes liées aux nanotechnologies / nano-argent ? Cliquez ou appuyez ici pour entrer du texte.

EVENEMENTS

12. Connaissez-vous les réactions des différents acteurs par rapport aux informations sur les risques potentiels liés aux nanotechnologies/nano-argent en France et/ou dans le monde ? Si oui, pourriez-vous indiquer quelles étaient les:

Réactions des producteur(s) ? A quel moment ont-ils commencé à répondre ? Cliquez ou appuyez ici pour entrer du texte.

Réactions des utilisateur(s) ? A quel moment ont-ils commencé à répondre ? Cliquez ou appuyez ici pour entrer du texte.

Réactions des fabricants de produit finaux ? A quel moment ont-ils commencé à répondre ? Cliquez ou appuyez ici pour entrer du texte.

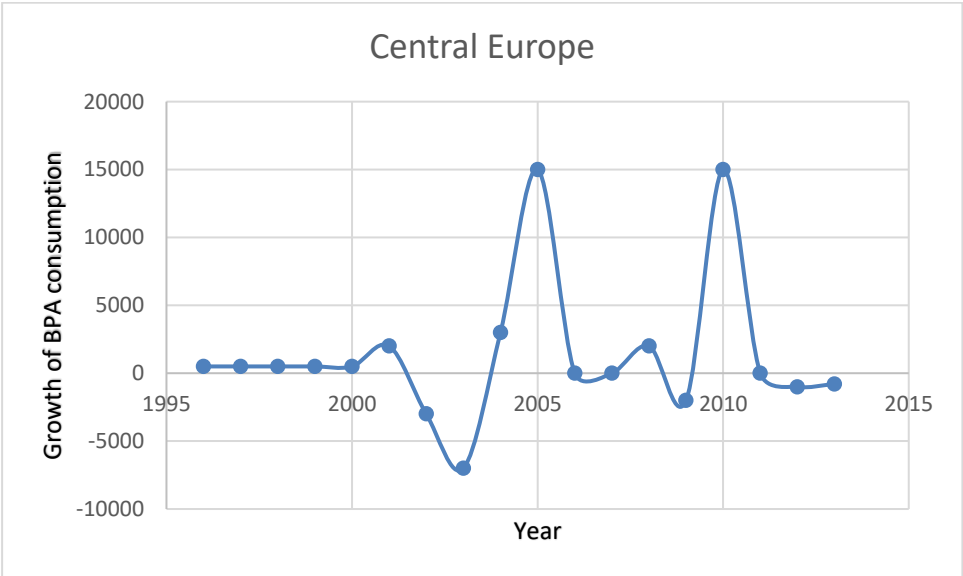
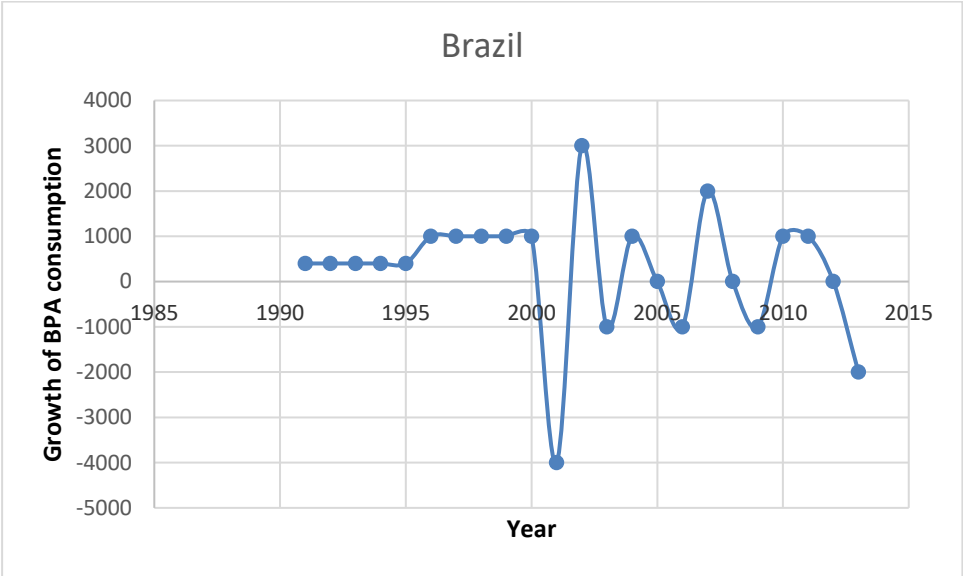
Réactions des instances représentatives ? A quel moment ont-ils commencé à répondre ?? Cliquez ou appuyez ici pour entrer du texte.

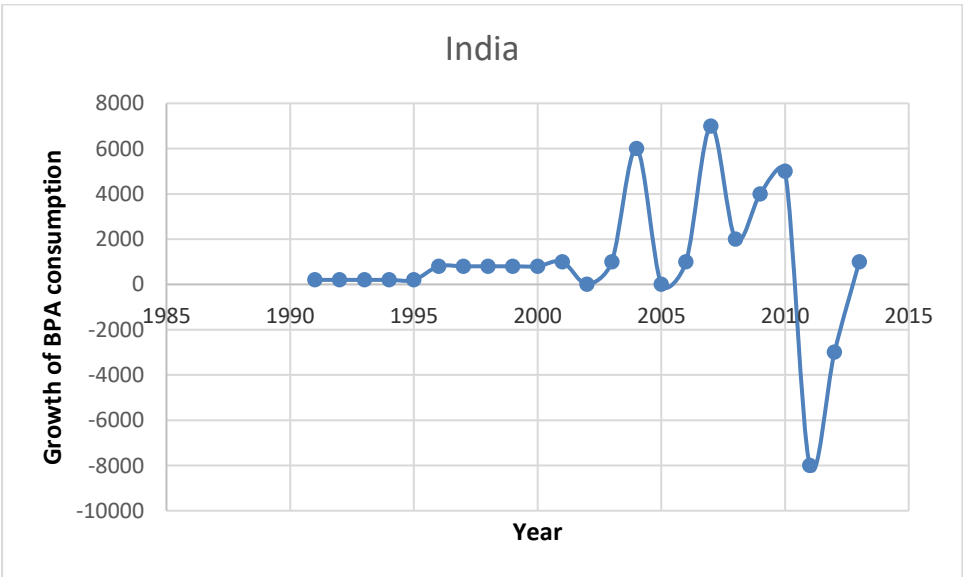
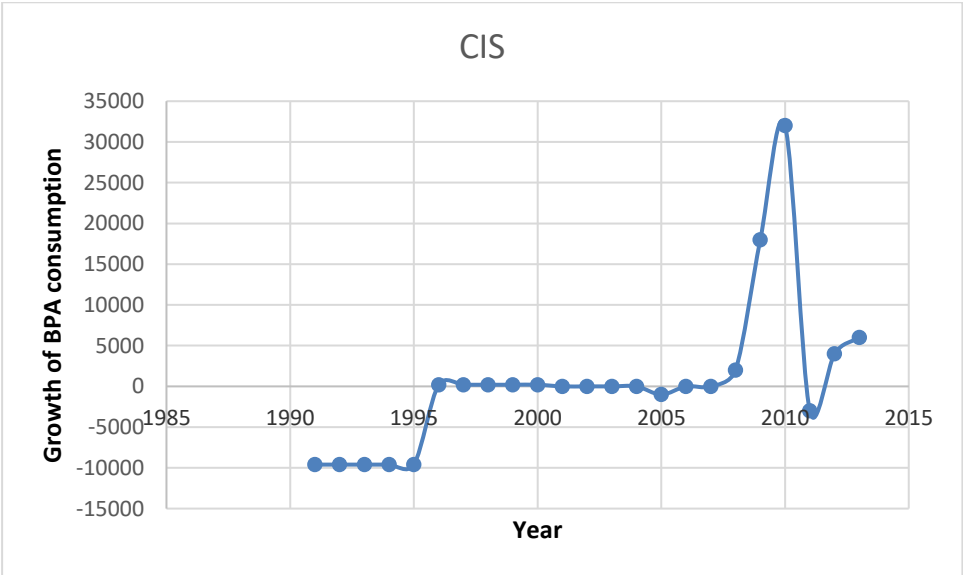
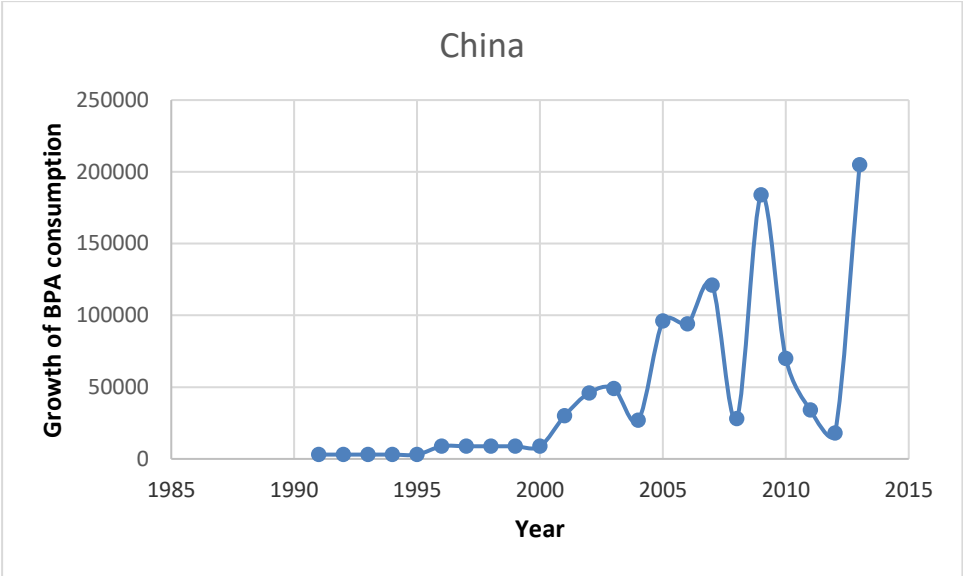
Réactions des lanceurs d'alerte ? A quel moment ont-ils commencé à répondre ? Cliquez ou appuyez ici pour entrer du texte.

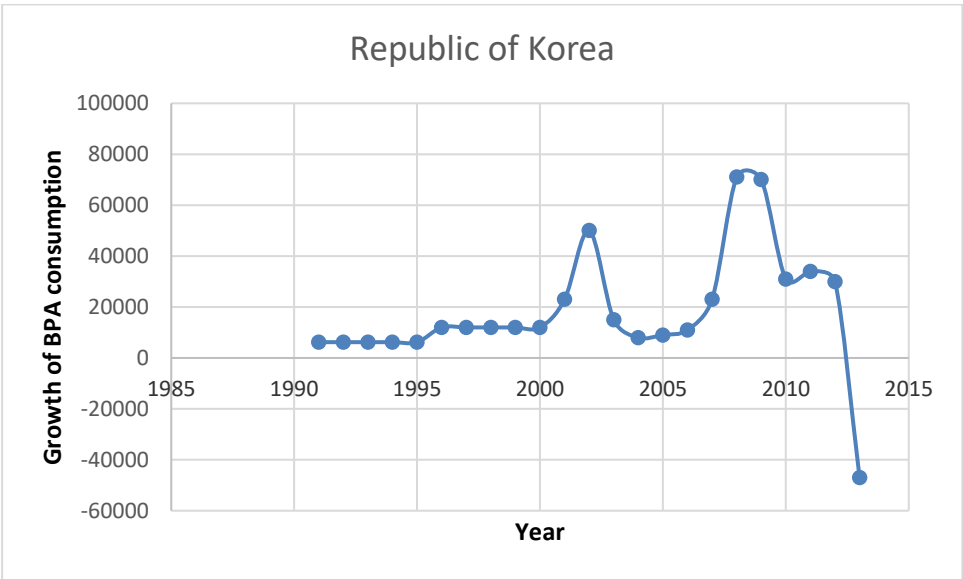
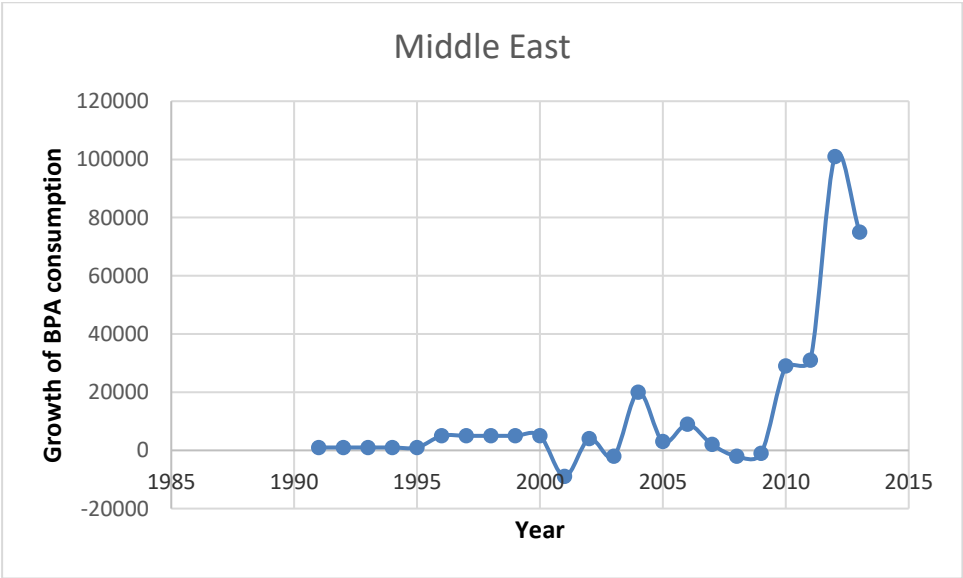
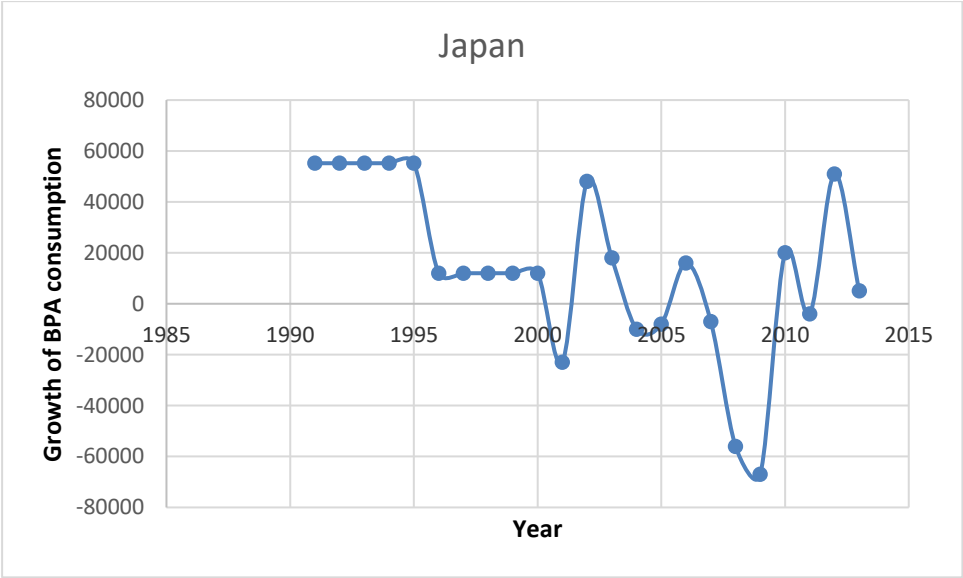
Réactions des associations de consommateurs ? A quel moment ont-ils commencé à répondre ? Cliquez ou appuyez ici pour entrer du texte.

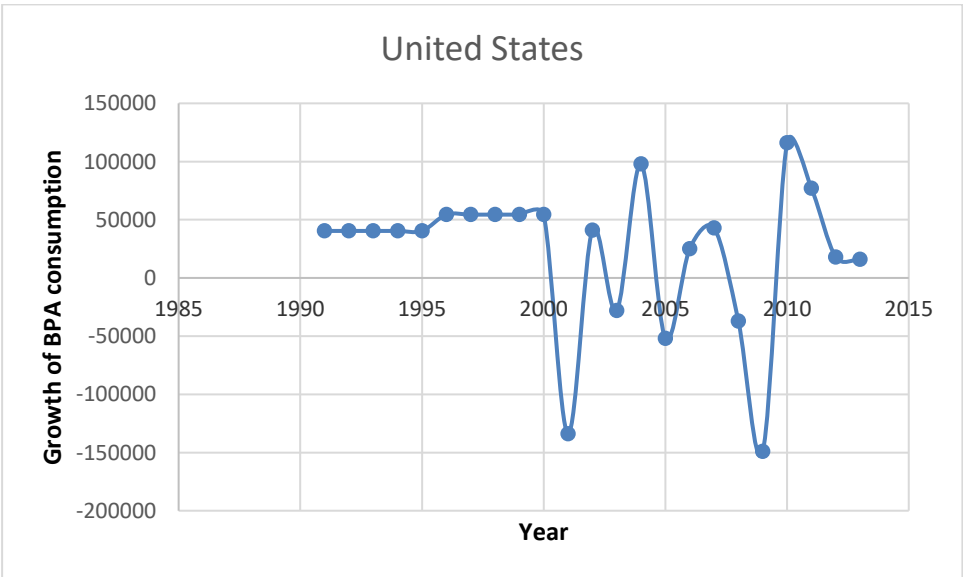
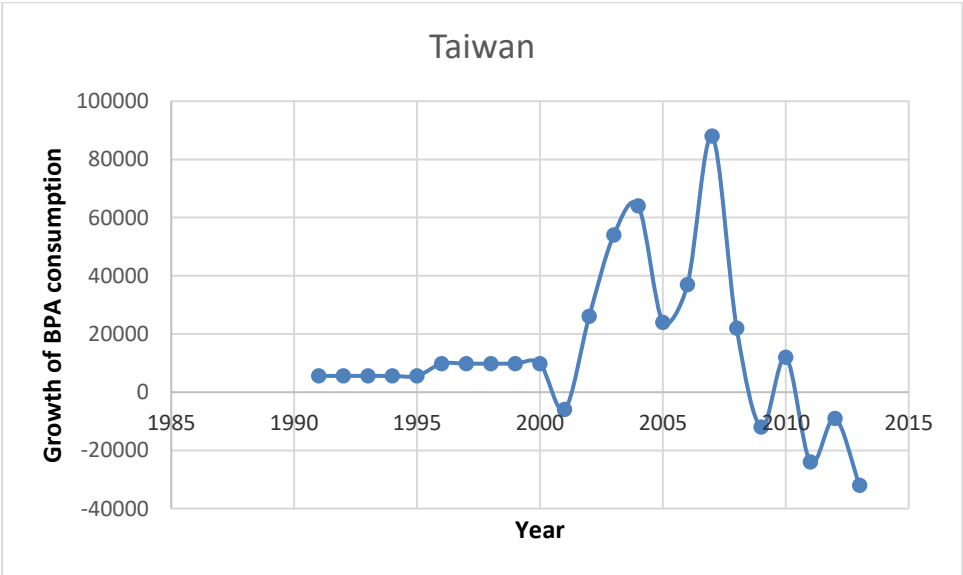
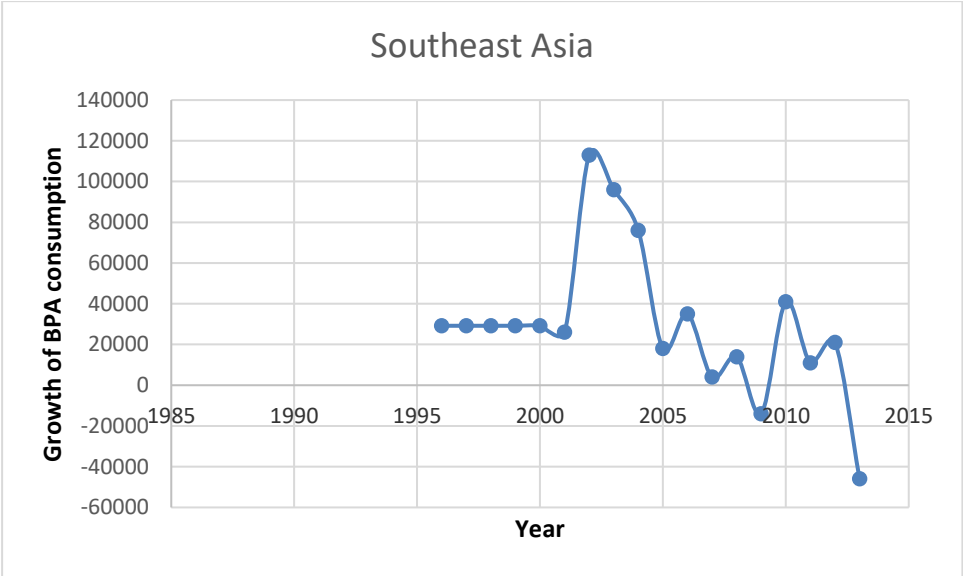
11. Pourriez-vous identifier les autres évènements importants dans l'histoire des nanotechnologies qui pourraient avoir une influence sur la consommation des nanotechnologies/nano-argent en France et/ou dans le monde ? Cliquez ou appuyez ici pour entrer du texte.

Appendix C. Turning points: slowdown and the beginning of decline, by entity









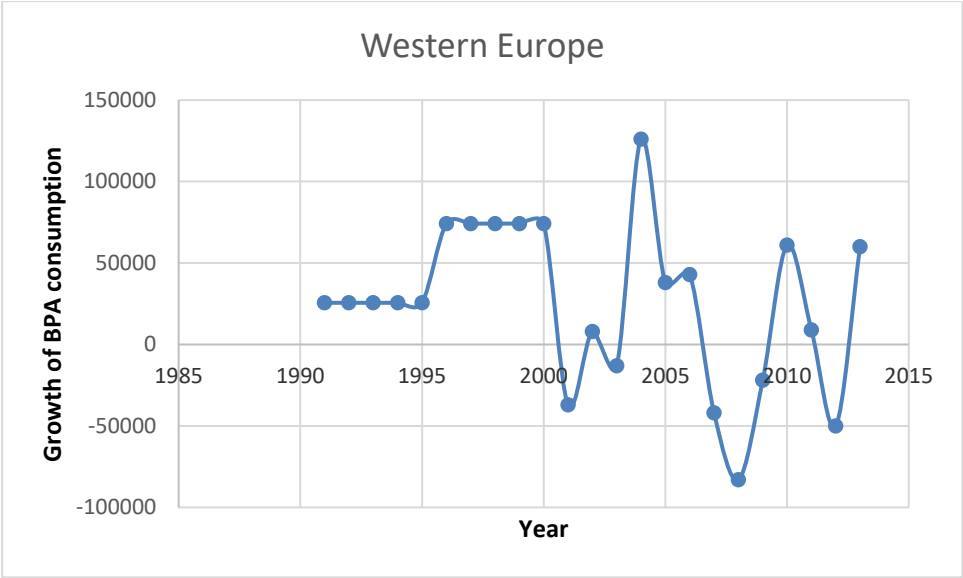


Figure 65. Growth of BPA consumption by entities, 1990-2013
 Source: Ostapchuk, based on Sriram et al. (2014)

Appendix D. List of contacts

ADELPHE

Anses

Baby friends

British glass

Bureau Européen des Unions de Consommateurs, BEUC

Centre Européen des Consommateurs France

Chicco

CI: consumer international

Commission consommation du MEDEF

Commission européenne DGs Santé et Consommateurs

CONSOMMATION, LOGEMENT ET CADRE DE VIE

CREDOC, centre de recherche pour l'étude et l'observation des conditions de vie

CSEMP (Chambre syndicale des emballages en matière plastique)

Datastream

Direction de la Consommation, de la Concurrence et de la Répression des Fraudes (DGCCRF)

Dodie

Eco-Emballages

ECOFUT

EFSA

Euro Coop, the EU community of consumer cooperatives

Euromonitor International/Passport

FECD

Fédération des Chambres Syndicales de l'Industrie du Verre

FJP

GFK, RETAIL SALES TRACKING

ICIS

ICIS pricing

ICRT, GLOBAL RESEARCH AND TESTING IN THE CONSUMER INTEREST

IHS Chemical

INSEE

Institut national de la consommation (INC)

International commission on glass

International glass Institute

L'Union des Industries Chimiques

La Fédération de la Plasturgie et des Composites

Philips

Philips Avent

PIE

PlasticsEurope

Platts

SGD

Syndicat Professionnel Producteurs Matières Plastiques

UFC-Que Choisir Paris

UFC-Que Choisir SENLIS

UNAF, Union Nationale des Associations Familiales

Which?

Appendix E. Questionnaire about new scientific knowledge and responses

Part 1

Q1: Please rate your level of English. You have a set of 3 choices to describe different aspects of your ability. Choose the statement that best sums up your level of English for this skill.

Table 46. Responses to Question 1

	basic user	fairly confident user	very fluent and skilled user	Total
Reading and comprehension skills	0.00% 0	75.00% 9	25.00% 3	12
General information	0.00% 0	75.00% 9	25.00% 3	12
Technical information	16.67% 2	75.00% 9	8.33% 1	12

Source: Ostapchuk

Q2: Please read the following abstract: Bisphenol-A induces cellular transformation, aneuploidy and DNA adduct formation in cultured Syrian hamster embryo cells (Tsutsui T, Tamura Y, Yagi E, Hasegawa K, Takahashi M, Maizumi N, Yamaguchi F, Barrett JC) Abstract Bisphenol-A (BP-A) is a major component of epoxy, polycarbonate and other resins. For an assessment of in vitro carcinogenicity and related activity of BP-A, the abilities of this compound to induce cellular transformation and genetic effects were examined simultaneously using the Syrian hamster embryo (SHE) cell model. Cellular growth was reduced by continuous treatment with BP-A at doses > or = 100 microM. However, colony-forming efficiencies were not decreased significantly following treatment with up to 200 microM BP-A for 48 hr. Morphological transformation of SHE cells was induced by treatment of cells with BP-A at 50 to 200 microM for 48 hr. BP-A exhibited transforming activity at doses > or = 50 microM but was less active than the benzo[alpha]pyrene used as a positive control. Over the dose range that resulted in cellular transformation, treatment of SHE cells with BP-A failed to induce gene mutations at the Na⁺/K⁺ ATPase locus or the hprt locus. No statistically significant numbers of chromosomal aberrations were detected in SHE cells treated with BP-A. However, treatment of cells with BP-A induced numerical chromosomal changes in the near diploid range at doses that induced cellular transformation. ³²P-Postlabeling analysis revealed that exposure of cells to BP-A also elicited DNA adduct formation in a dose-dependent fashion. Our results indicate that BP-A has cell-transforming and genotoxic activities in cultured mammalian cells and potential carcinogenic activity. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 12 Skipped: 0

Table 47. Responses to Question 2

Answer Choices	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	100.00% 12
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPA	0.00% 0
C. I can't choose A or B (you can explain why if you wish below)	0.00% 0
Total	12

Source: Ostapchuk

Comments (1)

i did not understand most of the abstract, but the last 3 words were clear enough !
10/30/2015 5:21 PM

My reply: A

("Our results indicate that BP-A has cell-transforming and genotoxic activities in cultured mammalian cells and potential carcinogenic activity")

Q3: Please read the following abstract: Exposure to bisphenol A during embryonic/fetal life and infancy increases oxidative injury and causes underdevelopment of the brain and testis in mice (Kabuto H, Amakawa M, Shishibori T) Abstract We investigated the modifications in endogenous antioxidant capacity and oxidative damage in the brain, liver, kidney and testis in mice exposed to bisphenol A (BPA), an environmental endocrine disrupter. Mice were exposed to BPA throughout embryonic/fetal life and during lactation by feeding their pregnant/lactating mothers BPA at 5 or 10 microg per milliliter of drinking water. At the age of four weeks, male mice were sacrificed. Exposure to BPA increased the activity of catalase and glutathione peroxidase in the liver and kidney, respectively. It also increased thiobarbituric acid-reactive substances in the brain, kidney and testis, and decreased the wet weight of the brain, kidney and testis. Our results suggest that exposure to BPA throughout embryonic/fetal life and during infancy induces tissue oxidative stress and peroxidation, ultimately leading to underdevelopment of the brain, kidney and testis. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 12 Skipped: 0**Table 48. Responses to Question 3**

Answer Choices	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	100.00% 12
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPA	0.00% 0
C. I can't choose A or B (you can explain why if you wish below)	0.00% 0
Total	12

Source: Ostapchuk

Comments (1)

this one is easier to understand than the previous one

My reply: A

("Exposure to BPA throughout embryonic/fetal life and during infancy induces tissue oxidative stress and peroxidation, ultimately leading to underdevelopment of the brain, kidney and testis")

Q4: Please read the following abstract: Normal reproductive organ development in CF-1 mice following prenatal exposure to bisphenol A (Cagen SZ1, Waechter JM Jr, Dimond SS, Breslin WJ, Butala JH, Jekat FW, Joiner RL, Shiotsuka RN, Veenstra GE, Harris LR) Abstract Bisphenol A (BPA) is a monomer used in the manufacture of a multitude of chemical products, including epoxy resins and polycarbonate. The objective of this study was to evaluate the effects of BPA on male sexual development. This study, performed in CF-1 mice, was limited to the measurement of sex-organ weights, daily sperm production (DSP), epididymal sperm count, and testis histopathology in the offspring of female mice exposed to low doses of BPA (0, 0.2, 2, 20, or 200 microg/kg/day), by deposition in the mouth on gestation days 11-17. Male sexual development determinations were made in offspring at 90 days-of-age. Since this study was conducted to investigate and clarify low-dose effects reported by S. C. Nagel et al., 1997, Environ. Health Perspect. 105, 70-76, and F. S. vom Saal et al., 1998, Toxicol. Indust. Health 14, 239-260, our study protocol purposely duplicated the referenced studies for all factors indicated as critical by those investigators. An additional group was dosed orally with 0.2 microg/kg/day of diethylstilbestrol (DES), which was selected based on the maternal dose reported to have maximum effect on the prostate of developing offspring, by F. S. vom Saal (1996, personal communication), vom Saal et al. (1997, Proc. Natl. Acad. Sci. U S A 94, 2056-2061). Tocopherol-stripped corn oil was used as the vehicle for BPA and DES, and was administered alone to control animals. No treatment-related effects on clinical observations, body weight, or food consumption were observed in adult females administered any dose of BPA or DES. Similarly, no treatment-related effects on growth or survival of offspring from dams treated with BPA or DES were observed. The total number of pups born per litter was slightly lower in the 200-microg/kg/day BPA group when compared to controls, but this change was not considered treatment-related since the litter size was within the normal range of historical controls. There were no treatment-related effects of BPA or DES on testes histopathology, daily sperm production, or sperm count, or on prostate, preputial gland, seminal vesicle, or epididymis weights at doses previously reported to affect these organs or at doses an order of magnitude higher or lower. In conclusion, under the conditions of this study, the effects of low doses of BPA reported by S. C. Nagel et al., 1997 (see above) and F. S. vom Saal et al., 1998 (see above), or of DES reported by F. S. vom Saal et al., 1997 (see above) were not observed. The absence of adverse findings in the offspring of dams treated orally with DES challenges the "low-dose hypothesis" of a special susceptibility of mammals exposed perinatally to ultra-low doses of even potent estrogenic chemicals. Based on the data in the present study and the considerable body of literature on effects of BPA at similar and much higher doses, BPA should not be considered as a selective reproductive or developmental toxicant. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 12 Skipped: 0

Table 49. Responses to Question 4

Answer Choices	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	0.00% 0
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPA	58.33% 7
C. I can't choose A or B (you can explain why if you wish below)	41.67% 5
Total	12

Source: Ostapchuk

Comments (6)

This study deals with male sexual development. No effect is observed but it does not mean that other risks do not exist.

11/22/2015 9:35 PM

in this abstract BPA is not identified as a threat *for the specific endpoint considered* not sure I would generalise to any health risk

10/30/2015 5:26 PM

The conclusion of this study is related to specific experimental conditions, so it should not be generalized or cannot fully exclude potential risk/danger to health/environment associated with BPA.

9/30/2015 1:50 PM

Several studies, same method = opposite conclusion ==> uncertainty for me

9/23/2015 4:50 PM

I think for the use of your study I'd say B, but otherwise I'd say C, as only specific health impacts, not all (e.g. not cancer) were studied. Feel

9/23/2015 3:27 PM

They are searching for potential risks but with no real findings

9/18/2015 8:55 AM

My reply: B

("Based on the data in the present study and the considerable body of literature on effects of BPA at similar and much higher doses, BPA should not be considered as a selective reproductive or developmental toxicant")

Q5: Please read the following abstract: Normal reproductive organ development in Wistar rats exposed to bisphenol A in the drinking water (Cagen SZ1, Waechter JM Jr, Dimond SS, Breslin WJ, Butala JH, Jekat FW, Joiner RL, Shiotsuka RN, Veenstra GE, Harris LR.) Abstract Bisphenol A (BPA) is a chemical used primarily as a monomer in the manufacture of numerous chemical products, such as epoxy resins and polycarbonate. The objective of this study was to evaluate potential effects of BPA on sexual development of male rats and was designed to clarify low-dose observations reported as preliminary results by Sharpe et al. (1996). The protocol for the present study followed the same treatment schedule as reported by Sharpe et al. (1995, 1996), but included more treatment groups, a greater number of animals per group, and a more comprehensive number of reproductive endpoints. Groups of 28 female Han-Wistar albino rats were exposed to drinking water that contained 0, 0.01, 0.1, 1.0, or 10 ppm BPA or 0.1 ppm diethylstilbestrol (DES), 7 days per week, for a total of 10 weeks. Treatment of the females began at 10 weeks of age and continued throughout a 2-week pre-mating period, 2 weeks of mating (to untreated males), 21-22 days of gestation, and 22 days of lactation. Offspring weanling males were given untreated drinking water and maintained until 90 days of age when evaluations were made of various reproductive organs. Consistent with Sharpe et al. (1996) the female offspring were not evaluated. No treatment-related effects on growth or reproductive endpoints were observed in adult females exposed to any concentration of BPA. Similarly, no treatment-related effects were observed on the growth, survival, or reproductive parameters (including testes, prostate and preputial gland weights, sperm count, daily sperm production, or testes histopathology) of male offspring from dams exposed to BPA during gestation and lactation. DES administered in the drinking water at 0.1 ppm resulted in decreased body weight, body weight change, and food consumption in adult females. In addition, an increase in the duration of gestation and a decrease in the number of pups delivered and number of live pups were also observed in animals exposed to DES. In conclusion, these results do not confirm the previous findings of Sharpe et al. (1996) and show that low doses of BPA had no effects on male sexual development in the rat. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 12 Skipped: 0

Table 50. Responses to Question 5

Answer Choices	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	0.00% 0
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPA	66.67% 8
C. I can't choose A or B (you can explain why if you wish below)	33.33% 4
Total	12

Source: Ostapchuk

Comments (6)

Same remark as previously. In addition, given that different results had been observed by Sharpe et al., it is difficult to conclude B.

11/22/2015 9:39 PM

mixed feeling, this paper is only looking at small doses really

10/30/2015 5:27 PM

This study shows that low doses of BPA had no effects on male sexual development in the rat, so cannot be generalized to all cases and cannot exclude that BPA hasn't any risk on health.

9/30/2015 2:02 PM

ibid. even if the experiment seems more precise (more groups...) ! Need more study, I guess

9/23/2015 4:55 PM

As in the previous, I'd conclude no risk for sexual development, but cannot say whether no other health/environment risks. If the question is meant very general I'd have to choose C.

9/23/2015 3:30 PM

Not so clear, maybe they find that there is no real danger with bisphenol A/BPA

9/18/2015 8:58 AM

My reply: B

("Low doses of BPA had no effects on male sexual development in the rat")

Q6: Please read the following abstract: Knockdown of the gene encoding Drosophila tribbles homologue 3 (Trib3) improves insulin sensitivity through peroxisome proliferator-activated receptor- γ (PPAR- γ) activation in a rat model of insulin resistance(Weismann D, Erion DM, Ignatova-Todorava I, Nagai Y, Stark R, Hsiao JJ, Flannery C, Birkenfeld AL, May T, Kahn M, Zhang D, Yu XX, Murray SF, Bhanot S, Monia BP, Cline GW, Shulman GI, Samuel VT.) Abstract AIMS/HYPOTHESIS:Insulin action is purportedly modulated by Drosophila tribbles homologue 3 (TRIB3), which in vitro prevents thymoma viral proto-oncogene (AKT) and peroxisome proliferator-activated receptor- γ (PPAR- γ) activation. However, the physiological impact of TRIB3 action in vivo remains controversial.METHODS:We investigated the role of TRIB3 in rats treated with either a control or Trib3 antisense oligonucleotide (ASO). Tissue-specific insulin sensitivity was assessed in vivo using a euglycaemic-hyperinsulinaemic clamp. A separate group was treated with the PPAR- γ antagonist bisphenol-A-diglycidyl ether (BADGE) to assess the role of PPAR- γ in mediating the response to Trib3 ASO.RESULTS:Trib3 ASO treatment specifically reduced Trib3 expression by 70% to 80% in liver and white adipose tissue. Fasting plasma glucose, insulin concentrations and basal rate of endogenous glucose production were unchanged. However, Trib3 ASO increased insulin-stimulated whole-body glucose uptake by ~50% during the euglycaemic-hyperinsulinaemic clamp. This was attributable to improved skeletal muscle glucose uptake. Despite the reduction of Trib3 expression, AKT2 activity was not increased. Trib3 ASO increased white adipose tissue mass by 70% and expression of Ppar- γ and its key target genes, raising the possibility that Trib3 ASO improves insulin sensitivity primarily in a PPAR- γ -dependent manner. Co-treatment with BADGE blunted the expansion of white adipose tissue and abrogated the insulin-sensitizing effects of Trib3 ASO. Finally, Trib3 ASO also increased plasma HDL-cholesterol, a change that persisted with BADGE co-treatment. CONCLUSIONS/INTERPRETATION: These data suggest that TRIB3 inhibition improves insulin sensitivity in vivo primarily in a PPAR- γ -dependent manner and

without any change in AKT2 activity. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 11 Skipped: 1

Table 51. Responses to Question 6

Answer Choices	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	0.00% 0
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPB	0.00% 0
C. I can't choose A or B (you can explain why if you wish below)	100.00% 11
Total	11

Source: Ostapchuk

Comments (9)

the abstract is not about bisphenol

12/8/2015 9:58 AM

The abstract is not about BPA.

11/22/2015 9:40 PM

not understood at all

10/30/2015 5:28 PM

Not about bisphenol

10/30/2015 11:06 AM

I read nothing about BPA in this abstract

10/20/2015 3:21 PM

The abstract is not about bisphenol A/BPA

9/30/2015 2:04 PM

not sure if i've well understood the abstract

9/23/2015 5:01 PM

The abstract is not about BPA.

9/23/2015 3:32 PM

not so clear about bisphenol A/BPA

9/18/2015 9:00 AM

My reply: C

(Reasoning behind: not directly related, BADGE is produced from BPA epoxy resins)

Part 2

Q7: Please read the following abstract: Freshwater mudsnail (*Potamopyrgus antipodarum*) estrogen receptor: identification and expression analysis under exposure to (xeno-)hormones (Stange D, Sieratowicz A, Horres R, Oehlmann J.) Abstract Molluscs are raising attention as ecotoxicological test organisms due to their high diversity and ecological importance. The ovoviviparous prosobranch gastropod *Potamopyrgus antipodarum* (freshwater mudsnail) responds very sensitively to xenobiotics and has therefore been proposed as OECD standard test organism. Endocrine disrupting chemicals influence the reproduction of *P. antipodarum*, which can be assessed by embryo numbers in the brood pouch. However, the knowledge about the endocrine system of *P. antipodarum* is rather limited. The aim of this study was to identify an estrogen receptor in the endocrine system of *P. antipodarum* and to investigate if this receptor is differentially expressed under exposure to (xeno-)hormones (17α -ethinylestradiol, bisphenol A and 17α -methyltestosterone). The DNA-binding domain of the identified ER-like transcript has an amino acid identity of 92 percent compared to the ER of the gastropod *Nucella lapillus* (84 percent to human ER α) and 83 percent in the ligand binding domain (38 percent to human ER α). Furthermore,

the *P. antipodarum* ER is transcriptionally regulated as shown by quantitative real-time PCRs of (xeno-)hormone exposed snails. 17 α -ethinylestradiol and bisphenol A exposure resulted in a transitory ER-mRNA increase while 17 α -methyltestosterone caused a transitory reduction of ER-mRNA. In addition the solvent dimethyl sulfoxide had also a modulating effect on the receptor. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 11 Skipped: 1

Table 52. Responses to Question 7

Answer Choices	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	18.18% 2
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPA	0.00% 0
C. I can't choose A or B (you can explain why if you wish below)	81.82% 9
Total	11

Source: Ostapchuk

Comments (7)

The text is written for expert on that subject and no understandable conclusions are given.

12/8/2015 10:06 AM

I don't know what an increase of ER-mRNA means.

11/22/2015 9:44 PM

not understood at all

10/30/2015 5:29 PM

the abstract is not directly to the issue of risk

10/30/2015 11:11 AM

I read nothing about BPA

10/20/2015 3:24 PM

I can't choose A or B because the abstract is not related to the issue of risk directly

9/30/2015 2:11 PM

Not clear about the results

9/18/2015 9:05 AM

My reply: C

("17 α -ethinylestradiol and bisphenol A exposure resulted in a transitory ER-mRNA increase while 17 α -methyltestosterone caused a transitory reduction of ER-mRNA". Reasoning behind: no findings in the abstract/or it is not clear if the issue of risk was discussed/or the meaning of findings is not clear]

Q8: Please read the following abstract: Endocrine disruptors in utero cause ovarian damages linked to endometriosis (Signorile PG, Spugnini EP, Citro G, Viceconte R, Vincenzi B, Baldi F, Baldi A.) Abstract Timed pregnant Balb-C mice were treated from day 1 of gestation to 7 days after delivery with the endocrine disruptor bisphenol a (BPA) (100, or 1,000 microg/kg/day). After delivery, pups were held for three months; then, ovaries were analyzed in their entirety. We found that in the ovaries of BPA-treated animals the number of primordial follicles and of developing follicles was significantly lower than in the untreated animals. Moreover, the number of atretic follicles was significantly higher in the treated animals. Finally, we found that the animals displaying endometriosis-like phenotype had a more severe impairment of the ovaries in term of number of primordial and developing follicles in comparison with the other mice exposed to BPA. In conclusion, we describe for the first time a complex phenotype in mice, elicited by pre-natal exposition to BPA, that includes ovarian lesions and endometriosis. Considering the high incidence of endometriosis and of the premature ovarian failure associated to infertility in these patients, the data showed prompt a thoroughly reconsideration of the pathological framing

of these lesions. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 12 Skipped: 0

Table 53. Responses to Question 8

Answer Choices	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	100.00% 12
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPA	0.00% 0
C. I can't choose A or B (you can explain why if you wish below)	0.00% 0
Total	12

Source: Ostapchuk

My reply: A (In conclusion, we describe for the first time a complex phenotype in mice, elicited by pre-natal exposition to BPA, that includes ovarian lesions and endometriosis. Considering the high incidence of endometriosis and of the premature ovarian failure associated to infertility in these patients, the data showed prompt a thoroughly reconsideration of the pathological framing of these lesions.)

Comments (0)

Q9: Please read the following abstract: Detecting the cytotoxicities of five bisphenol A analogues to the MCF-7 human breast carcinoma cell line through different endpoints (Zhang SS, Liu Y, Liu SS, Zhu XW) Abstract As the main synthetic raw materials of polycarbonate, bisphenol A (BPA) and its analogues have been important issues in environmental pollution. The current studies focus mainly on BPA's estrogen effects and little on their cytotoxic effects. To assess the cytotoxicities of the five BPA analogues, we employed the MTS assay to determine the inhibition toxicity to MCF-7 (ER-), 2,4-dinitrophenylhydrazine assay to determine the release rate of lactate dehydrogenase (LDH) escaping into cell culture medium, and single cell gel electrophoresis assay (SCGE) to detect DNA damage. The dose-response curves (DRC) between the observed inhibition toxicities and concentrations of the BPA compounds in MTS assay were fitted by using the nonlinear least squares (NLS) and the results showed that all the dose-response relationships were effectively described by the Weibull or Logit function. The toxicities expressed by $-lgpEC50$ were $BPB > BPC > TDP > BPE > BPA$. LDH assay and SCGE assay showed that when the concentrations of BPA analogues were $EC20$, the MCF-7 cell proliferation was slightly inhibited due to its little damaged DNA, and at $EC40$ the cell proliferations were significantly inhibited due to the seriously damaged DNA, leading to the damage of cell membrane and release of LDH. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 12 Skipped: 0

Table 54. Responses to Question 9

Answer Choices–	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	66.67% 8
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPA	0.00% 0
C. I can't choose A or B (you can explain why if you wish below)	33.33% 4
Total	12

Source: Ostapchuk

Comments (3)

According to the inequalities, the toxicity of BPA is lower than the toxicity of other compounds but this does not mean there is not potential risk.

11/22/2015 9:49 PM

The abstract is not about bisphenol A/BPA but about its analogues.

9/30/2015 2:27 PM

The results are not clear

9/18/2015 9:08 AM

My reply: C

("Detecting the cytotoxicities of five bisphenol A analogues to the MCF-7 human breast carcinoma cell", Reasoning behind: comparative study)

Q10: Please read the following abstract: Effects of bisphenol A on growth and nitrogen nutrition of roots of soybean seedlings (Sun H1, Wang L, Zhou Q) Abstract Bisphenol A (BPA) is an environmental endocrine disruptor that seriously threatens ecological systems. Plants are the primary producers in ecological systems, but little information is available concerning the toxic effect of BPA on plants. In the present study, the effects of BPA on the growth and nitrogen nutrition of roots of soybean seedlings were investigated by using a root automatic scan apparatus and biochemical methods. It was found that when soybean seedlings were treated with 1.5 mg/L BPA, the growth of roots was improved, the content of nitrate in roots was increased, the content of ammonium in roots was decreased, and the activities of nitrate reductase and nitrite reductase in roots were not changed. The opposite effects were observed in roots treated with 17.2 mg/L and 50.0 mg/L BPA, except for an increase in the content of nitrate in roots treated with 17.2 mg/L BPA and a decrease in the activities of nitrate reductase and nitrite reductase in roots of soybeans seedlings. Statistical analysis indicated that the change in the nitrogen nutrition of roots of soybean seedlings treated with BPA was one reason why the growth of roots was changed. The authors suggest that the potential environmental and ecological risk of BPA to plants should receive more consideration. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 12 Skipped: 0

Table 55. Responses to Question 10

Answer Choices	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	83.33% 10
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPA	0.00% 0
C. I can't choose A or B (you can explain why if you wish below)	16.67% 2
Total	12

Source: Ostapchuk

Comments (3)

The issue of potential risk is discussed but the conclusion is that more work is needed on the subject
12/8/2015 10:14 AM

again, most of the abstract is cryptic, I have to trust the authors in their formulation of the last sentence
10/30/2015 5:32 PM

There are opposite results
9/18/2015 9:09 AM

My reply: C

(Reasoning behind: review, some studies can be omitted intentionally or the review can represent the opinion of the author)

Q11: Please read the following abstract: Short-term treatment with bisphenol-A leads to metabolic abnormalities in adult male mice (Batista TM, Alonso-Magdalena P, Vieira E, Amaral ME, Cederroth CR, Nef S, Quesada I, Carneiro EM, Nadal A.) Abstract Bisphenol-A (BPA) is one of the most widespread endocrine disrupting chemicals (EDC) used as the base compound in the manufacture of polycarbonate plastics. Although evidence points to consider exposure to BPA as a risk factor for insulin resistance, its actions on whole body metabolism and on insulin-sensitive tissues are still unclear. The aim of the present work was to study the effects of low doses of BPA in insulin-sensitive peripheral tissues and whole body metabolism in adult mice. Adult mice were treated with subcutaneous injection of 100 µg/kg BPA or vehicle for 8 days. Whole body energy homeostasis was assessed with in vivo indirect calorimetry. Insulin signaling assays were conducted by western blot analysis. Mice treated with BPA were insulin resistant and had increased glucose-stimulated insulin release. BPA-treated mice had decreased food intake, lower body temperature and locomotor activity compared to control. In skeletal muscle, insulin-stimulated tyrosine phosphorylation of the insulin receptor β subunit was impaired in BPA-treated mice. This impairment was associated with a reduced insulin-stimulated Akt phosphorylation in the Thr(308) residue. Both skeletal muscle and liver displayed an upregulation of IRS-1 protein by BPA. The mitogen-activated protein kinase (MAPK) signaling pathway was also impaired in the skeletal muscle from BPA-treated mice. In the liver, BPA effects were of lesser intensity with decreased insulin-stimulated tyrosine phosphorylation of the insulin receptor β subunit. In conclusion, short-term treatment with low doses of BPA slows down whole body energy metabolism and disrupts insulin signaling in peripheral tissues. Thus, our findings support the notion that BPA can be considered a risk factor for the development of type 2 diabetes. Question Now thinking about this abstract, which of the following best describes your feeling: Please choose A, B or C

Answered: 12 Skipped: 0

Table 56. Responses to Question 11

Answer Choices	Responses
A. There is a potential risk/danger to health/environment associated with bisphenol A/BPA	100.00% 12
B. There is no potential risk/danger to health/environment associated with bisphenol A/BPB	0.00% 0
C. I can't choose A or B (you can explain why if you wish below)	0.00% 0
Total	12

Source: Ostapchuk

Comments (1)

again: only last sentence is clear to me
10/30/2015 5:33 PM

My reply: A

("Thus, our findings support the notion that BPA can be considered a risk factor for the development of type 2 diabetes")

Q12: Had you had any knowledge of BPA risks/danger before you completed this questionnaire?

Answered: 12 Skipped: 0

Table 57. Responses to Question 12

Answer Choices	Responses
No	50.00% 6
Some	50.00% 6
Expert knowledge	0.00% 0
Total	12

Source: Ostapchuk

Appendix F. The list of entities used in the analysis

Table 58. The list of entities (regions and countries) used in the analysis

Country name	Region name	Entity
United States	North America	North America
Brazil	South America	South America
Austria	Western Europe	Western Europe
Belgium	Western Europe	Western Europe
Denmark	Western Europe	Western Europe
Finland	Western Europe	Western Europe
France	Western Europe	Western Europe
Germany	Western Europe	Western Europe
Greece	Western Europe	Western Europe
Iceland	Western Europe	Western Europe
Ireland	Western Europe	Western Europe
Italy	Western Europe	Western Europe
Luxembourg	Western Europe	Western Europe
Netherlands	Western Europe	Western Europe
Norway	Western Europe	Western Europe
Portugal	Western Europe	Western Europe
Spain	Western Europe	Western Europe
Sweden	Western Europe	Western Europe
Switzerland	Western Europe	Western Europe
United Kingdom	Western Europe	Western Europe
Bosnia and Herzegovina	Central Europe	Central Europe
Croatia	Central Europe	Central Europe
Macedonia	Central Europe	Central Europe
Montenegro	Central Europe	Central Europe
Serbia	Central Europe	Central Europe
Slovenia	Central Europe	Central Europe
Romania	Central Europe	Central Europe
Poland	Central Europe	Central Europe
Hungary	Central Europe	Central Europe
Czech Republic	Central Europe	Central Europe
Bulgaria	Central Europe	Central Europe
Slovak Republic	Central Europe	Central Europe
Armenia	CIS and Baltic States	CIS and Baltic States
Azerbaijan	CIS and Baltic States	CIS and Baltic States
Belarus	CIS and Baltic States	CIS and Baltic States
Kazakhstan	CIS and Baltic States	CIS and Baltic States
Kyrgyz Republic	CIS and Baltic States	CIS and Baltic States

Appendix F. The list of entities used in the analysis

Country name	Region name	Entity
Moldova	CIS and Baltic States	CIS and Baltic States
Russian Federation	CIS and Baltic States	CIS and Baltic States
Uzbekistan	CIS and Baltic States	CIS and Baltic States
Georgia	CIS and Baltic States	CIS and Baltic States
Ukraine	CIS and Baltic States	CIS and Baltic States
Estonia	CIS and Baltic States	CIS and Baltic States
Latvia	CIS and Baltic States	CIS and Baltic States
Lithuania	CIS and Baltic States	CIS and Baltic States
Turkmenistan	CIS and Baltic States	CIS and Baltic States
Israel	Middle East	Middle East
Jordan	Middle East	Middle East
Iran	Middle East	Middle East
Saudi Arabia	Middle East	Middle East
India	Indian Subcontinent	Indian Subcontinent
China	Northeast Asia	China
Japan	Northeast Asia	Japan
Republic of Korea	Northeast Asia	Republic of Korea
Taiwan	Northeast Asia	Taiwan
Singapore	Southeast Asia	Southeast Asia
Thailand	Southeast Asia	Southeast Asia
Indonesia	Southeast Asia	Southeast Asia
Malaysia	Southeast Asia	Southeast Asia
Philippines	Southeast Asia	Southeast Asia
Hong Kong	Southeast Asia	Southeast Asia

Source: Ostapchuk, based on based on Sriram, Smith, & Feng, 2014 and personal communication with the authors

Appendix G. Bisphenol A consumption

Table 59. Descriptive statistics of bisphenol A consumption per capita and GDP per capita by entity over 1990, 1995, 2000-2013 years

Entity	Obs	Bisphenol A consumption per capita				GDP per capita			
		Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
South America	16	0.0001	6.30E-06	0.0001	0.0002	6685.81	3656.07	2810.23	13042.42
CIS and Baltic States	16	0.0001	0.0001	0.0000	0.0002	4027.50	2463.99	1163.75	7941.94
Central Europe	16	0.0002	0.0001	8.38E-12	0.0003	7719.03	3402.72	2377.21	12201.15
China	16	0.0003	0.0003	0.0000	0.0008	2745.58	2120.35	316.22	6991.85
Indian Subcontinent	16	0.0000	7.50E-06	4.59E-06	0.0000	866.01	414.60	375.15	1471.66
Japan	16	0.0029	0.0007	0.0006	0.0035	37158.42	5627.50	25123.63	46679.27
Middle East	16	0.0007	0.0006	0.0001	0.0025	11403.93	4122.10	5483.95	18189.70
Republic of Korea	16	0.0052	0.0029	0.0003	0.0096	17714.26	5708.72	6642.45	25997.88
Southeast Asia	16	0.0009	0.0005	3.06E-12	0.0013	12644.44	4200.86	5103.65	19659.54
Taiwan	16	0.0102	0.0060	0.0001	0.0169	16431.88	3566.00	8216.00	21902.00
United States	16	0.0029	0.0003	0.0019	0.0033	42689.17	8185.00	23954.48	52980.04
Western Europe	16	0.0022	0.0004	0.0010	0.0026	39817.43	11355.94	21701.68	53593.93

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Table 60. Descriptive statistics.

Variable		Mean	Std. Dev.	Min	Max	Obs	
Cons_pc	overall	.002	.003	3.06e-12	.017	N	192
	between		.003	.000	.010	n	12
	within		.002	-.008	.009	T	16
GDP_curm	overall	16658.62	15267.93	316.22	53593.93	N	192
	between		14957.37	866.01	42689.17	n	12
	within		5191.99	-2076.08	30435.12	T	16
Babies	overall	16720.29	20690.58	551.3	75844.6	N	192
	between		21413.63	709.21	73993.76	n	12
	within		2359.64	11659.47	45322.97	T	16
uai	overall	63.92	19.48	30	92	N	192
	between		20.30	30	92	n	12
	within		0	63.93	63.93	T	16

Appendix G. Bisphenol A consumption

Itowvs	overall	62.25	24.48	25.69	100	N	192
	between		25.50	25.69	100	n	12
	within		1.53e-14	62.25	62.25	T	16
Produc~s	overall	222745.5	466856.1	1569.6	1861880	N	191
	between		480879.7	3008.8	1730018	n	12
	within		63255.33	-425813	354607.9	T-bar	15.92
CD	overall	29.60	24.54	.49	75	N	192
	between		24.55	1.39	67.52	n	12
	within		6.85	-21.02	37.08	T	16
DVD	overall	28.38	25.87	0	96.2	N	192
	between		16.04	1.35	61.01	n	12
	within		20.80	-32.62	63.58	T	16
Cars_U~c	overall	.0002	.0002	1.33e-06	.0005	N	192
	between		.0002	.0000	.0005	n	12
	within		.0000	.0000	.0003	T	16
Cable_TV	overall	36.00	23.21	.036	83.6	N	192
	between		21.55	6.56	73.025	n	12
	within		10.54	-31.71	53.67	T	16
Computer	overall	39.90	27.18	0	87.2	N	192
	between		22.035	3.75	71.55	n	12
	within		17.07	-24.45	71.59	T	16
Internet	overall	24.96	24.57	0	76.3	N	192
	between		16.43	2.03	59.09	n	12
	within		18.84	-34.13	64.76	T	16
Satell~V	overall	13.97	15.10	0	62.73	N	192
	between		13.61	0	42.95	n	12
	within		7.58	-28.18	33.74	T	16
PC_USD	overall	3835.00	692.90	2656.18	4841.48	N	192
	between		0	3835.00	3835.00	n	12
	within		692.90	2656.18	4841.48	T	16

Source: Ostapchuk, based on World Bank and IHS Chemical

Reduced form model

Estimates of the basic model (1) are shown in Table 61 below. Table A4 presents the results for selected coefficients. The tests for random effects, fixed vs random effects and heteroscedasticity are in Table A5. Explanatory variable is BPA consumption per capita on the log scale. Year dummies are included in the model. First, the model is estimated by the pooled OLS (Column 1). The signs of coefficients suggest an inverted N-relationship between BPA consumption per capita on the log scale

and economic growth. A negative link is a temporary phenomenon. A U-shaped relationship is followed by decrease in BPA use which means a decrease in exposure to BPA. The coefficients on the log of GDP per capita, quadratic and cubic terms are statistically significant at 10% level of significance. Column 2 and Column 3 provide results of fixed effect and random effect estimations respectively. The Breusch and Pagan Lagrangian multiplier test for random effects fails to reject the hypothesis that variances across entities is 0 which suggests that the random effect estimation procedure is preferred to the pooled OLS. The formal test for fixed vs random effects adjusted for the presence of heteroscedasticity, which suggests that random effect is appropriate. Besides, a modified Wald statistic for groupwise heteroscedasticity suggests the presence of heteroscedasticity (there is strong evidence against the hypothesis that $\sigma_i^2 = \sigma^2$, $Prob > \chi^2 = 0.0000$) (Table 62). Therefore, the corrective measures are needed. We compare the performance of random effect estimation procedure with robust standard errors (RE GLS) with Feasible Generalized Least Squares with heteroscedastic error structure (FGLS) that ignores u_i . The results are presented in Column 4 and Column 5 (Table 61). The comparison is conducted by leave one out and k-fold cross-validations which are presented in Table 62. These procedures allow to choose a model specification and estimate the predictive biases on average. According to leave one out cross-validation, the model estimated by FGLS is preferred (the pseudo R^2 for this model is higher). K-fold cross validation suggests the model estimated by FGLS is appropriate additionally to leave one out cross validation. Overfitting measure shows that a “out of sample” prediction accuracy is larger for the model estimated by RE GLS. Besides, out of sample shrinkage/expansion is larger for the model estimated by RE GLS that can be caused by both overfitting and model misspecification. However, in the sample expansion shows that in sample predictive bias is relatively serious for the model estimated by FGLS which can be corrected by inclusion of additional explanatory variables.

Therefore, we conclude that FGLS is a suitable approach to estimate the reduced form model. The obtained result (Column 5) confirms the existence of the inverted N-shaped relationship between consumption of bisphenol A and economic growth.

Figure 44 represents this relationship over the studied period and the resulting line of the prediction for consumption. The coefficients on the log of GDP per capita, quadratic and cubic terms are statistically significant at 1% level of significance. The estimated turnings points are 520 and 46509 current US\$. Only two entities in the dataset (China and India) had per capita GDP level below 520,68 US\$ and three entities (Japan, the US and the Western Europe) crossed the second turning point. To summarize, the obtained results do not support the EKC hypothesis since they show the existence of the inverted N shape relationship between consumption of bisphenol A on the log scale and economic growth. While the relationship has been suggested before (Sriram et al., 2014), to the best of our knowledge this is the first time the shape of the relationship has been examined.

Table 61. Reduced form model of the Environmental Kuznets curve, selected results. Dependent variable: log of BPA consumption per capita

VARIABLES	Model 1 reduced POLS	Model 1 reduced FE	Model 1 reduced RE	Model 1 reduced RE GLS robust	Model 1 reduced FGLS
	(1)	(2)	(3)	(4)	(5)
lnGDP_curm	-40.13*** (13.32)	-44.39*** (14.99)	-40.13*** (13.32)	-40.13 (27.08)	-26.42*** (8.227)
ln2GDP_curm	4.865*** (1.595)	5.443*** (1.823)	4.865*** (1.595)	4.865 (3.224)	3.341*** (0.968)
ln3GDP_curm	-0.187*** (0.0629)	-0.215*** (0.0742)	-0.187*** (0.0629)	-0.187 (0.126)	-0.131*** (0.0373)
Constant	92.60** (36.53)	104.5** (41.15)	92.60** (36.53)	92.60 (72.60)	54.38** (22.81)
Year dummies	Yes	Yes	Yes	Yes	Yes
Observations	192	192	192	192	192
R-squared		0.372			
Number of En_entity	12	12	12	12	12

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Source: Ostapchuk, based on World Bank and IHS Chemical

Table 62. Reduced form model. Tests for random effects, fixed vs random effects and heteroscedasticity

Test	Result
Breusch and Pagan Lagrangian multiplier test for random effects $H_0: Var(u) = 0$	$\chi^2(01)=73.88$ $Prob > \chi^2 = 0.0000$
Test of overidentifying restrictions: fixed vs random effects (robust), Sargan-Hansen statistic	$\chi^2(4) = 8.532$ $Prob > \chi^2 = 0.0739$
Modified Wald test for groupwise heteroscedasticity in fixed effect regression model $H_0: \sigma_i^2 = \sigma^2$ for all i	$\chi^2(12) = 5578.33$ $Prob > \chi^2 = 0.0000$

Source: Ostapchuk, based on World Bank and IHS Chemical

Table 63. Reduced form model. Cross-validation results

Model, method	Cross-validation type	Results	
Reduced model, RE GLS robust	Leave-One-Out	Root Mean Squared Errors	2.00
		Mean Absolute Errors	1.07
		Pseudo-R2	.47
Reduced model, FGLS	Leave-One-Out	Root Mean Squared Errors	1.96
		Mean Absolute Errors	.96
		Pseudo-R2	.50
Reduced model, RE GLS robust	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	11.33(3.70)
		In sample	-0.05(1.87)
		Overfitting	11.34(4.16)
Standard errors are in parentheses			
Reduced model, FGLS	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	-5.39(1.24)
		In sample	-9.21(.97)
		Overfitting	3.49(1.37)
Standard errors are in parentheses			

Table 64. Test for endogeneity

Test of overidentifying restrictions: 2SLS fixed-effects IV vs 2SLS random-effects IV (robust), Sargan-Hansen statistic	$Prob > \chi^2 = 0.000$ (equation exactly identified)
2SLS fixed-effects IV regression Dependent variable: lnCons_pc Explanatory variables: lnGDP_curm ln2GDP_curm ln3GDP_curm CD Cable_TV (ln_BPA= lnGERD) Y1995 - Y2010 Instrumented: ln_BPA	
Underidentification test (Kleibergen-Paap rk LM statistic): Chi-sq(1) P-val =	22.588 0.0000
Weak identification test (Cragg-Donald Wald F statistic): (Kleibergen-Paap rk Wald F statistic): Stock-Yogo weak ID test critical values: 10% maximal IV size 15% maximal IV size 20% maximal IV size 25% maximal IV size Source: Stock-Yogo (2005). Reproduced by permission. NB: Critical values are for Cragg-Donald F statistic and i.i.d. errors.	8.0e+05 3.2e+05 16.38 8.96 6.66 5.53
Hansen J statistic (overidentification test of all instruments): (equation exactly identified) -endog- option: Endogeneity test of endogenous regressors: Chi-sq(1) P-val = Regressors tested:	0.000 0.017 0.8950 ln_BPA
Instrumented: Included instruments: Excluded instruments:	ln_BPA lnGDP_curm ln2GDP_curm ln3GDP_curm CD Cable_TV Y1995 Y2000 Y2001 Y2002 Y2003 Y2004 Y2005 Y2006 Y2007 Y2008 Y2009 Y2010 lnGERD

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Table 65. Descriptive statistics: residuals

Entity	Obs	Mean	Std.		
			Dev.	Min	Max
Brazil	16	-0.06	0.94	-1.32	1.47
CIS and Baltic States	16	-0.55	1.29	-2.40	3.06
Central Europe	16	-2.05	3.46	-14.79	0.00
China	16	1.03	0.53	0.03	1.63
India	16	-0.39	0.32	-1.05	0.05
Japan	16	-0.03	0.27	-0.29	0.84

Entity	Obs	Mean	Std.		
			Dev.	Min	Max
Middle East	16	0.12	0.36	-0.40	1.08
Republic of Korea	16	0.13	0.28	-0.34	0.64
Southeast Asia	16	-1.10	4.31	-17.00	0.65
Taiwan	16	0.22	0.42	-0.41	0.74
United States	16	-0.35	0.16	-0.57	-0.05
Western Europe	16	0.25	0.17	-0.04	0.48

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Outliers

We summarize the consumption of bisphenol A per capita again, but this time using the data without outliers. The mean consumption per capita on the log scale is -7,5 (compared to -7,73, for the data with 2 outliers), with a minimum of -12,29 (compared to -26,51), a maximum of -4,08 and a standard deviation of 2,04 (compared to 2,77). Are the obtained results substantially different?

The results of the reduced and extended model estimated by FGLS are in Table 6.6. As previously, the signs of coefficients on GDP per capita, its quadratic and cubic terms suggest N-shaped relationship between BPA consumption per capita and economic growth. These coefficients are statistically significant at 1% level of significance. The estimated turning points are \$380 and \$64323 (reduced model), \$230 and \$38411 (extended model). The difference between the turning points can be partially explained by the small sample size and partially by some degree of collinearity between GDP per capita and the possession of cable TV (which might decrease the accuracy of estimates). The coefficient of the possession of cable TV is positive and statistically significant at 1 % level of significance. The semielasticity of BPA consumption per capita with respect to the possession of cable TV is 3,3. The coefficient on the possession of CD player is statistically insignificant at 10% level of significance.

Cross-validation results are presented in Table 67. According to leave one out cross-validation, the models without outliers are preferred (the pseudo R^2 s of these models are substantially higher). Moreover, K-fold cross validations indicate that the models estimated without replacing the missing values perform better than the ones with outliers (outliers are the result of the missing values replacement). Overfitting statistics are lower. However, Figure 67 shows that the difference between the predicted consumption of bisphenol A from an extended model with and without outliers, correspondingly. As it can be seen from this figure, the difference is not crucial.

The results of lowess are presented in Figure 66. These figures show that the pattern of the relationship between the number of new scientific knowledge and over- under-consumption of bisphenol A on the log scales is roughly the same. We conclude that the models without these outliers perform slightly better, although the pattern of behavior has not changed significantly with the presence of outliers.

Table 66. Reduced and extended models (without outliers). Dependent variable: log of bisphenol A consumption per capita

	Model 1 reduced	FGLS	Model 1 FGLS
VARIABLES			
InGDP_curm	-17.09*** (4.760)		-12.90*** (4.790)
In2GDP_curm	2.210*** (0.559)		1.797*** (0.560)
In3GDP_curm	-0.0866*** (0.0215)		-0.0749*** (0.0215)
Cable_TV			0.0330*** (0.00211)
CD			0.00421 (0.00323)
Constant	29.76** (13.21)		16.53 (13.40)
Time dummies	Yes		Yes
Observations	190		190
R-squared			
Number of En_entity	12		12

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Table 67. Reduced and extended forms without outliers. Cross-validation results

Model, method	Cross-validation type	Results	
Reduced model, FGLS without outliers	Leave-One-Out	Root Mean Squared Errors	1.08
		Mean Absolute Errors	.78
		Pseudo-R2	.73
Extended model, FGLS without outliers	Leave-One-Out	Root Mean Squared Errors	.81
		Mean Absolute Errors	.61
		Pseudo-R2	.84
Reduced model, FGLS without outliers	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	1.45 (0.50)
		In sample	-0.08 (0.29)
		Overfitting	1.53 (0.61)
		Standard errors are in parentheses	
Extended model, FGLS without outliers	Repeated k-fold cross-validation, shrinkage statistics (expressed in percent), k=10, repeated 50 times	Out of sample	4.18 (0.39)
		In sample	2.88 (0.32)
		Overfitting	1.33 (0.50)
		Standard errors are in parentheses	

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

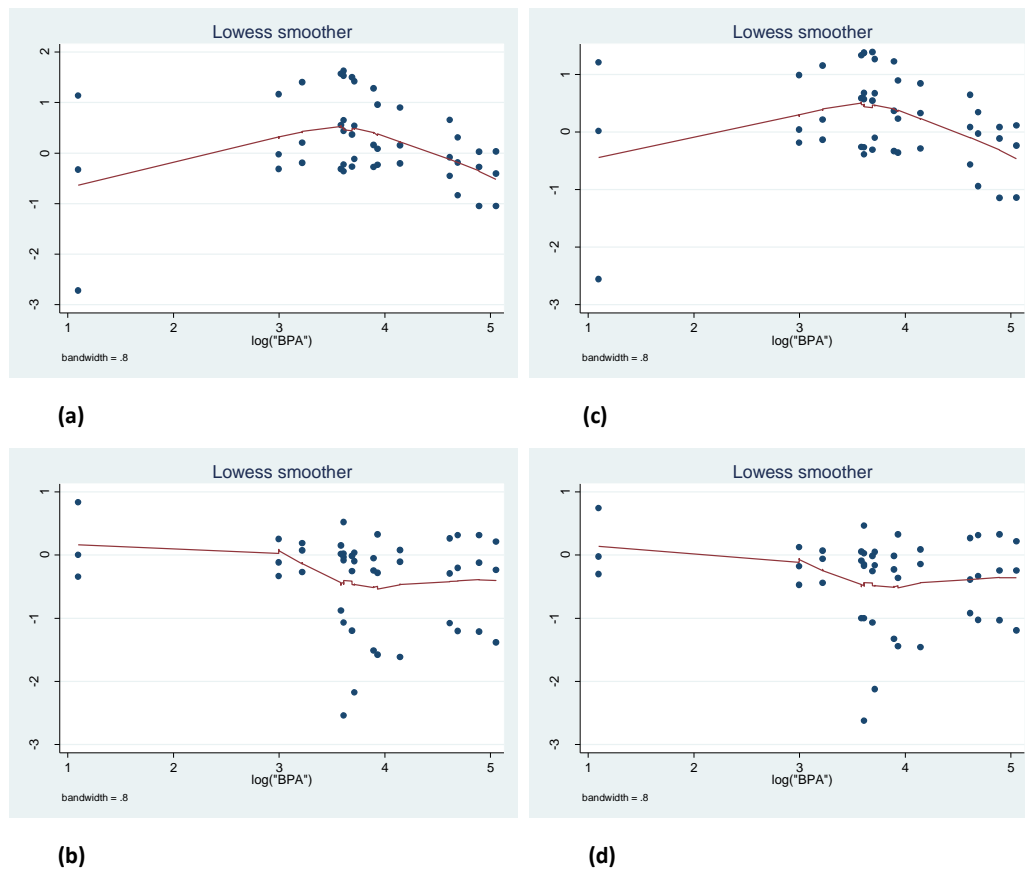


Figure 66. Scatter plots of residuals against “BPA” on the log scale for two different groups of entities with the lowest uncertainty avoidance (a and c) and the highest uncertainty avoidance (b and d)¹⁹⁶
 a-b: residuals
 c-d: residuals (without outliers)
 Source: Ostapchuk

¹⁹⁶ The first group (with the lowest UAI in the sample: $UAI < 43$) includes China, India and Southeast Asia. The second group ($43 \leq UAI < 69,5$) includes Taiwan, the US, Western Europe. The third group ($69,5 \leq UAI < 78$) consists of Brazil, CIS and Baltic States. Central Europe, the Republic of Korea and Japan are part of the fourth group ($UAI > 78$).

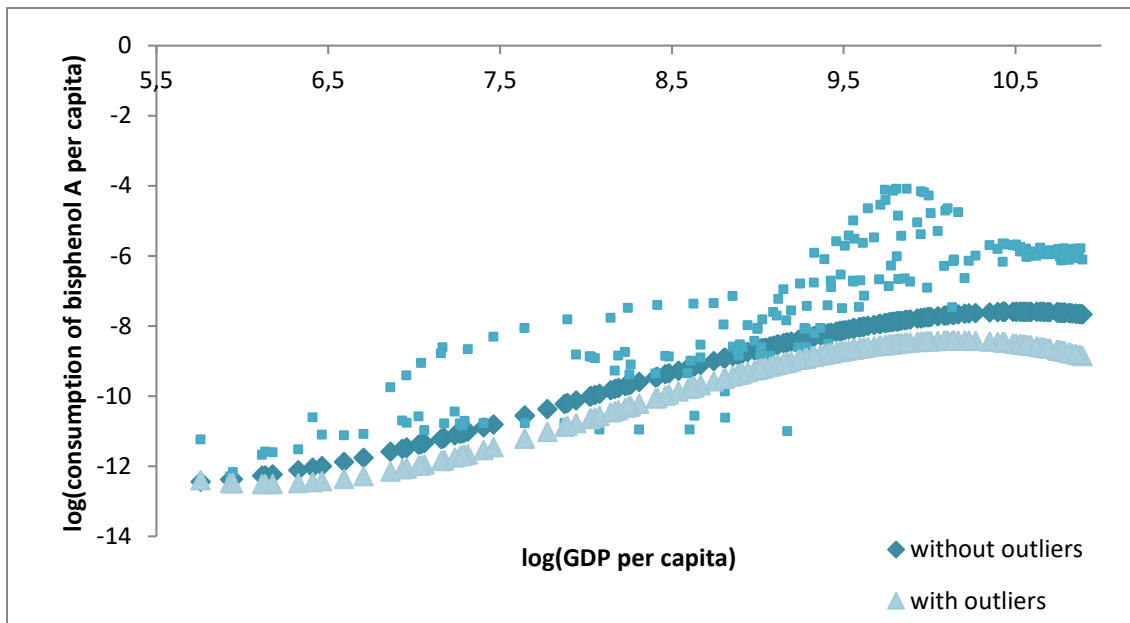


Figure 67. Scatter plot of consumption of bisphenol A per capita against GDP per capita on the log scales (squares) and the resulting line of the prediction for consumption of bisphenol A from an extended form model (rhombus) with and without outliers

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

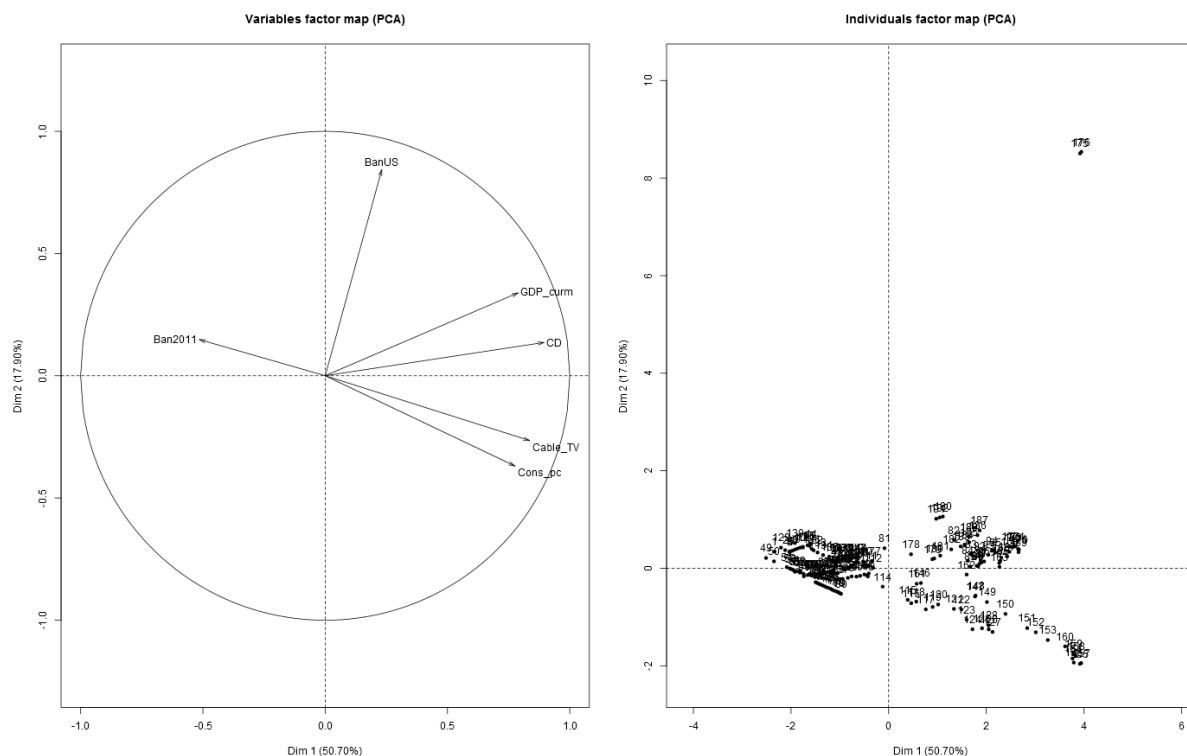


Figure 68. Principal component analysis with bans, biplot (components: 1, 2)

Source: Ostapchuk, Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Alternative measures of scientific knowledge

We use separately the following alternative measures of scientific knowledge: “Risk”, “No risk”, “Uncertain”. Figure 70a –Figure 70c below provide the lowest results for the relationship between the articles categorized under the groups “Risk”, “No risk”, “Uncertain” and under-consumption for the entities with the lowest uncertainty avoidance. Figure 70d- Figure 70f present the lowest results for the entities with the highest uncertainty avoidance. The results can be compared to the lowest results for the articles categorized under the group “BPA” (Figure 66a-Figure 66d). As it can be seen from the figures, despite the different measures of scientific knowledge, the pattern of the relationship does not change for these entities (with slight changes in downturn points). It can be concluded that any of the measures (“BPA”, “Risk”, “No risk”, “Uncertain”) can be used in the analysis in a situation of uncertainty regarding environmental and health risks which is confirmed by PCA (Figure 69).

It is interesting to note that a turning point (corresponding to the number of scientific articles where the downturn begins) is lower for the “No risk” measure than for the other measures in the situation of uncertainty about environmental and health risks. One possible explanation is that this level of article categorized under the group “No risk” coincides with a relatively high quantity of articles categorized under the group “Risk”. Therefore, it is suggested using “BPA” measure or its equivalent in future studies in the situation of uncertainty about environmental and health risks.

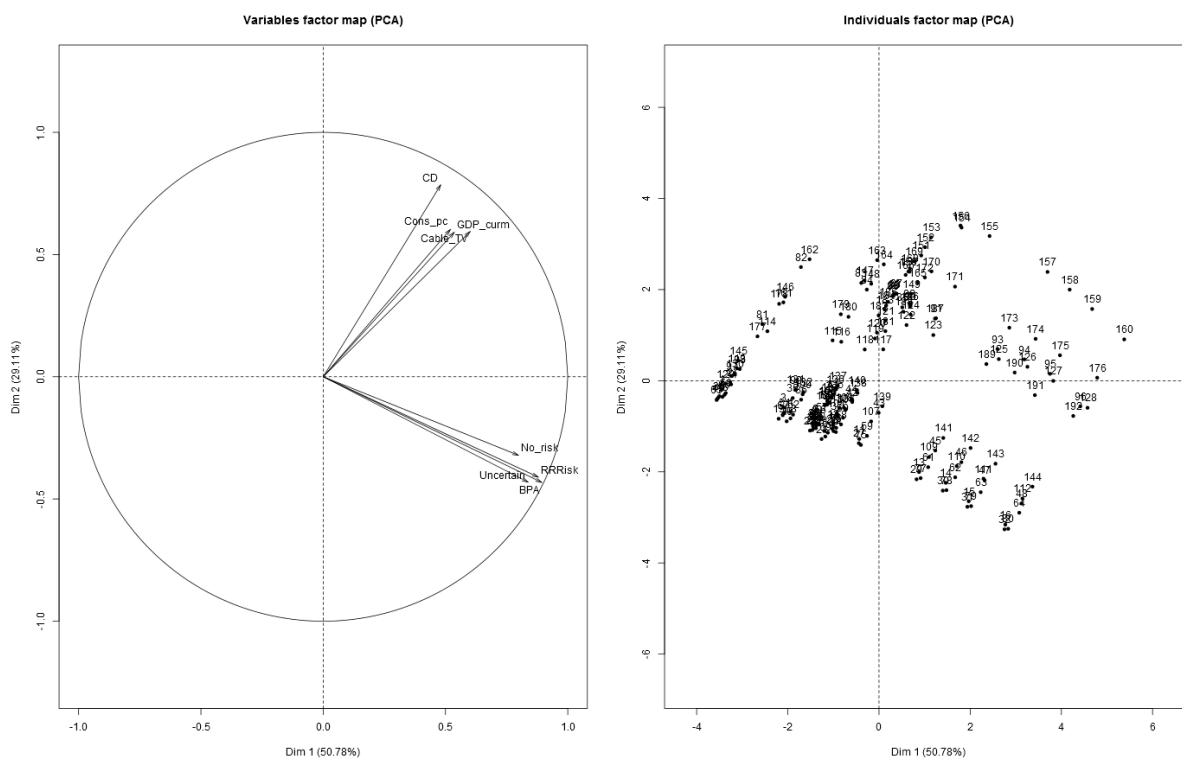


Figure 69. Principal component analysis with different scientific knowledge measures, biplot (components: 1,2)

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

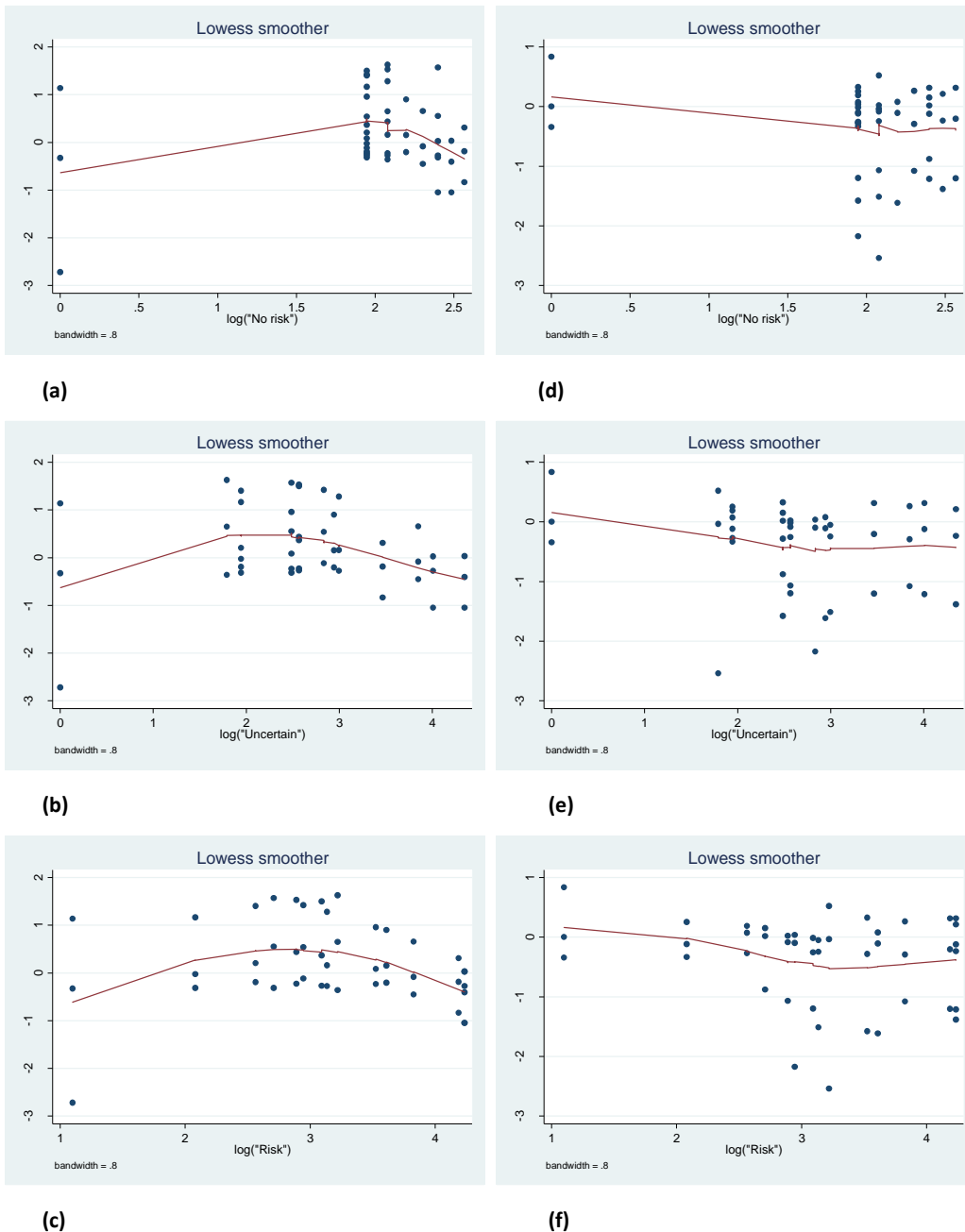


Figure 70. Scatter plots of BPA over- and under-consumption per capita against “No risk”, “Uncertain”, “Risk”

a–c results for the relationship between the articles categorized under the groups “Risk”, “No risk”, “Uncertain” and under-consumption for the entities with the lowest uncertainty avoidance (China, India, Southeast Asia)

d–f results for the entities with the highest uncertainty avoidance (Central Europe, the Republic of Korea and Japan)

Source: Ostapchuk, based on World Bank, Passport/Euromonitor International, PIE: Plastics Information Europe and IHS Chemical

Appendix H. Polycarbonate sales value

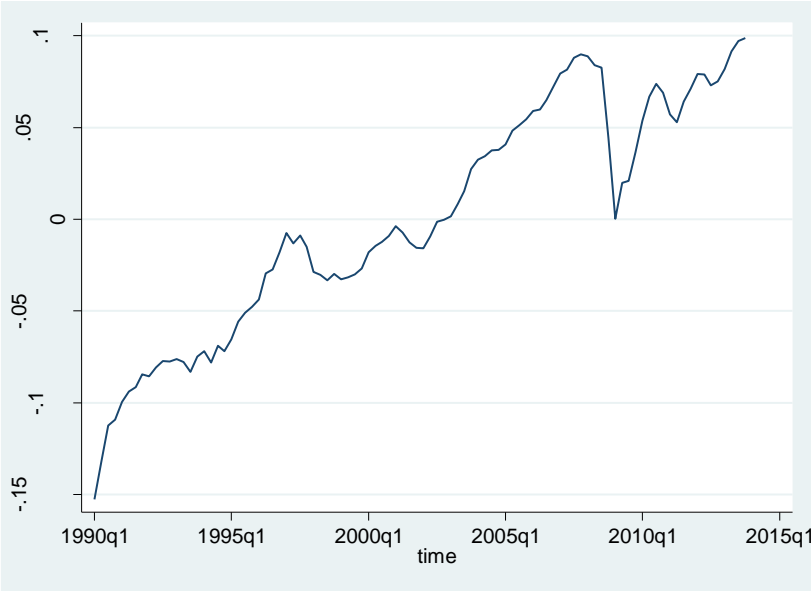


Figure 71. *Seasonally adjusted GDP centered on mean per capita, log scale, 1990:Q1 – 2013:Q4*
Source: Ostapchuk, based on Datastream

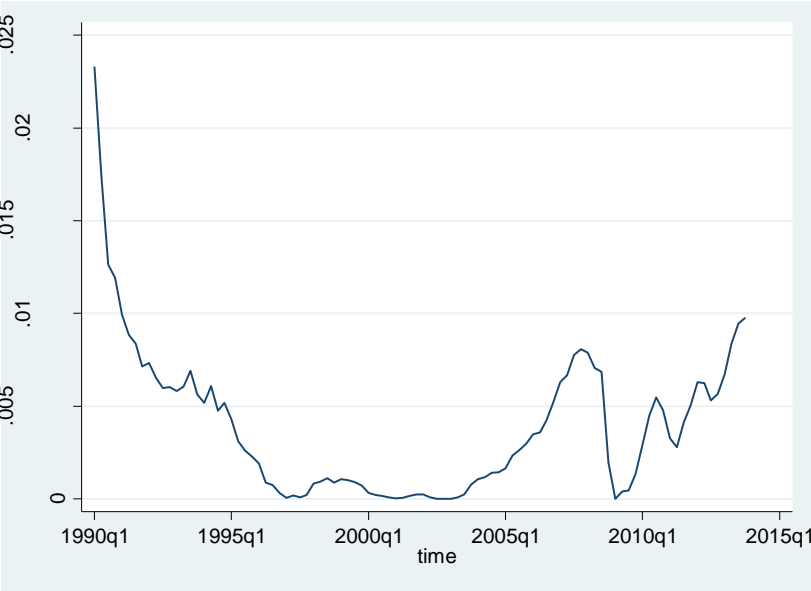


Figure 72. *Squared term of seasonally adjusted GDP centered on mean per capita, log scale, 1990:Q1 – 2013:Q4*
Source: Ostapchuk, based on Datastream

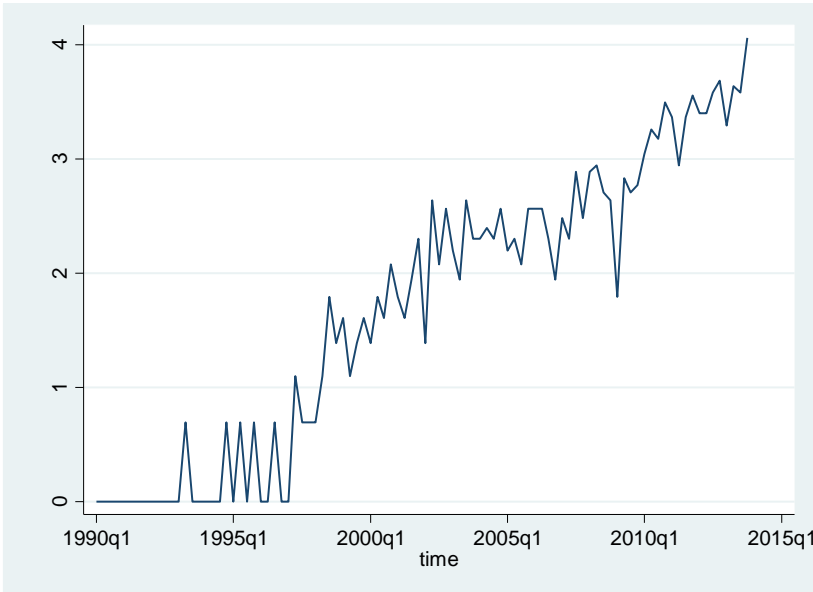


Figure 73. Quantity of scientific articles assigned to group BPA, log scale, 1990:Q1 – 2013:Q4
Source: Ostapchuk, based on Datastream

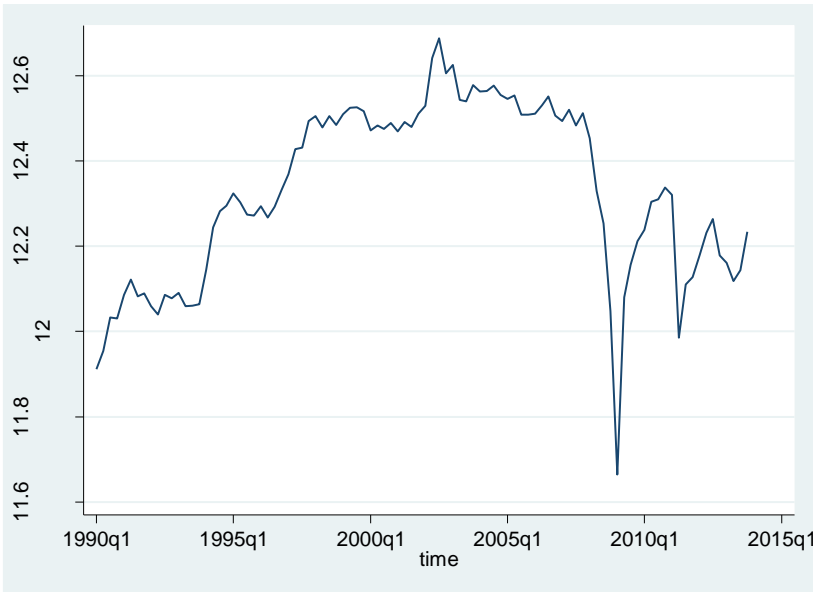


Figure 74. Sales of PC in volume at constant prices, log scale, 1990:Q1 – 2013:Q4
Source: Ostapchuk, based on Datastream

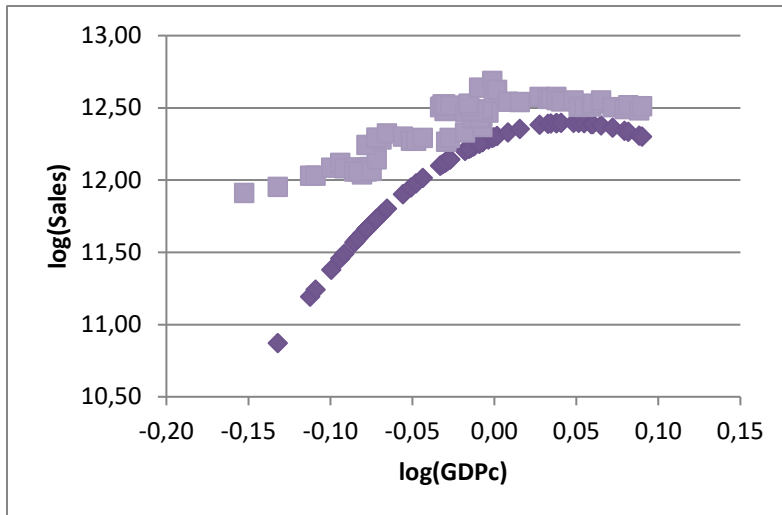


Figure 75. Scatter plot of consumption of polycarbonate per capita against GDP per capita on the log scales (squares) and the resulting line of the prediction for consumption of polycarbonate from a reduced form model (rhombus)
 Source: Ostapchuk, based on Datastream

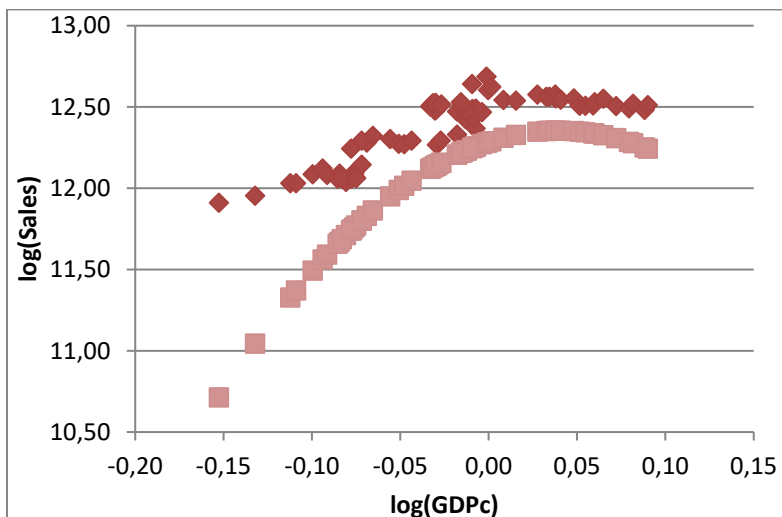


Figure 76. Scatter plot of consumption of polycarbonate per capita against GDP per capita on the log scales (squares) and the resulting line of the prediction for consumption of polycarbonate from an extended model form model (rhombus)
 Source: Ostapchuk, based on Datastream

Table 68. Impulse responses, selected results

step	oirf	oirf	oirf	oirf
	1	2	3	4
0	.036117	0	0	0
1	.036929	-.000869	.000547	-.000415
2	.03757	-.001556	.000979	-.000743
3	.038077	-.002098	.00132	-.001002
4	.038476	-.002526	.00159	-.001207
5	.038792	-.002864	.001802	-.001369
6	.039041	-.003131	.00197	-.001496
7	.039238	-.003342	.002103	-.001597
8	.039394	-.003508	.002208	-.001676
9	.039516	-.00364	.00229	-.001739
10	.039613	-.003744	.002356	-.001789

(1) irfname = order1*, Impulse variable: log(Sales), response variable: log(Sales)

(2) irfname = order1*, Impulse variable: log(GDPc), response variable: log(Sales)

(3) irfname = order1*, (log(GDPc))², response variable: log(Sales)

(4) irfname = order1*, Impulse variable: log(BPA), response variable: log(Sales)

*Order1: log(Sales), log(GDPc), (log(GDPc))², log(BPA)

Source: Ostapchuk, based on Datastream

Appendix I. Mission statement

Table 69. Mission statement (stakeholders related to bisphenol A)

Name	Mission statement	Sources, accessed in April 2017
Women's Voices for the Earth	"Women's Voices for the Earth amplifies women's voices to eliminate the toxic chemicals that harm our health and communities"	http://www.womensvoice.org/about/mission-and-vision/
60 Millions de consommateurs	"60 Millions est intrinsèquement objectif, en particulier sur l'une de ses missions, l'un de ses points forts : les essais comparatifs de produits et de services" ¹⁹⁷	http://www.60millions-mag.com/resultats/recherche/bisphenol%20a , http://www.60millions-mag.com/qui-sommes-nous
Réseau Environnement Santé (RES)	RES is created in 2009. It takes actions to place an environmental health at the core of public policy. In 2010, RES launched its first campaign against BPA in baby bottles. As this campaign illustrates, RES seeks to start public debate on available scientific knowledge and to ensure that institutional and economic stakeholders implement the precautionary principle to establish the regulations and transform the industrial processes.	http://www.reseau-environnement-sante.fr/le-res/
UFC-Que Choisir	"Enquêtes, tests, combats judiciaires, actions de lobbying... l'UFC-Que Choisir est au service des consommateurs pour les informer, les conseiller et les défendre". ¹⁹⁸	https://www.quechoisir.org/dossier-ufc-que-choisir-t587/
American Chemistry Council	"The American Chemistry Council (ACC) represents a diverse set of companies engaged in the business of chemistry. An innovative, \$797 billion enterprise, we work to solve some of the biggest challenges facing our nation and our world. Our mission is to deliver value to our members through advocacy, using best-in-class member engagement, political advocacy, communications and scientific research. We are committed to fostering progress in our economy, environment and society."	https://www.americanchemistry.com/About/
PlasticsEurope	"As an industry, we see plastics' mission as being simply: "to meet people's needs better". PlasticsEurope represents the plastics industry's views by: <ul style="list-style-type: none"> • Providing fact based information and data to European opinion formers; • Networking with relevant stakeholders both at European and national level; 	http://www.plasticseurope.org/plastics-industry/plasticseurope/mission-and-values.aspx , http://www.bisphenol-a-europe.org/en_GB/subnav/about-us

¹⁹⁷ 60 Millions is objective, in particular, about one of its missions, one of its strengths: comparative tests of products and services

¹⁹⁸ Surveys, tests, lobbying efforts... The UFC-Que Choisir serves consumers to inform, guide and defend them.

Name	Mission statement	Sources, accessed in April 2017
	<ul style="list-style-type: none"> Presenting the industry's view at European and national levels; Safeguarding fair trade for its products. <p>PlasticsEurope highlights the sustainability of plastics as a raw material by:</p> <ul style="list-style-type: none"> Explaining best practices on the production, use and waste management of plastics; Providing the environmental fingerprints - the so called eco-profiles - of more than 75 polymers and their intermediates; Confirming the contribution of plastics as a protector of energy and resources; Highlighting the economic and environmental benefits of plastic as a recyclable and recoverable material. <p>PlasticsEurope endeavours to make people aware of the benefits of plastic products by:</p> <ul style="list-style-type: none"> Demonstrating benefits and sustainability of the use of plastics materials; Promoting a balanced view of plastics as the material for the 21st century." <p>Besides, the group makes an attempt "to provide accurate, science-based information about BPA and their two main applications: polycarbonate and epoxy resins."</p>	
BPA Coalition	<p>"The BPA Coalition is an association that provides informed industry views on Bisphenol-A (BPA) and its uses. The objective of the BPA Coalition is to have an open and constructive dialogue about BPA with anyone interested.</p> <p>There are those who believe that BPA poses a risk to our safety and our health.</p> <p>The Coalition hopes to address concerns about BPA and validate what international regulatory bodies and scientific research continues to clearly state – that the safe use of BPA poses no known health risk to people."</p>	http://www.bpa-coalition.org/about-us/

Table 70. Mission statement (stakeholders related to nanosilver)

Name	Mission statement	Sources, accessed in April 2017
Woodrow Wilson International Center for Scholars	"The Wilson Center, chartered by Congress as the official memorial to President Woodrow Wilson, is the nation's key non-partisan policy forum for tackling global issues through independent research and open dialogue to inform actionable ideas for the policy community"	https://www.wilsoncenter.org/about-the-wilson-center
Nanotechnology Industries Association (NIA)	<p>"To support nanotechnology industries by</p> <ul style="list-style-type: none"> Ensuring a strong industry voice is present in global nanotech policy and regulatory discussions. Communicating the essential role of nanotechnology in improving our daily lives and advancing our world. 	http://www.nanotechia.org/about-nia

Name	Mission statement	Sources, accessed in April 2017
	<ul style="list-style-type: none"> • Forming focused research collaborations with stakeholders across the public and private sector to help build a positive regulatory, policy and acceptance environment for nanotechnology. • Identifying untapped portions of the supply chain where nanotechnologies can provide a unique and beneficial value. • Creating partnership opportunities between NIA Members that can help bring new nanotech innovations to the market. • Demonstrating our responsible commitment to developing and stewarding safe, sustainable and beneficial nanotech innovations. • Helping NIA Members, especially SMEs, deliver new products to market. • Ensuring NIA Members are up-to-date on global nanotech legislative and regulatory developments. <p>To support regulators and policymakers by</p> <ul style="list-style-type: none"> • Being a transparent and collaborative industry stakeholder. • Providing clear industry perspectives and positions on nanotech issues. • Collaborating with other stakeholders to support predictable, effective regulatory environments that enable nanotech innovations to safely and efficiently reach consumers. <p>To support the general public by</p> <ul style="list-style-type: none"> • Helping consumers better understand nanotechnology in our daily lives. • Working with media to ensure nanotechnology is accurately reported. • Respectfully addressing any questions about the use of nanotechnology, including risks and safe development” 	
Bureau Européen des Unions de Consommateurs, BEUC	<p>“BEUC acts as the umbrella group in Brussels for its members and our main task is to represent them at European level and defend the interests of all Europe’s consumers.</p> <p>BEUC investigates EU decisions and developments likely to affect consumers, with a special focus on five areas identified as priorities by our members: Financial Services, Food, Digital Rights, Consumer Rights & Enforcement and Sustainability”</p>	

Name	Mission statement	Sources, accessed in April 2017
Association de Veille et d'Information Civique sur les Enjeux des Nanosciences et des Nanotechnologies (Avicenn)	<p>« Répondre à un besoin d'information citoyenne Obtenir une plus grande transparence et démocratisation du domaine des nanotechnologies Permettre à la société civile de prendre part aux choix concernant les nanos Favoriser le développement d'une vigilance collective par l'ensemble des acteurs concernés</p> <p>- Nos actions</p> <ul style="list-style-type: none"> • La veille d'informations • Le questionnement • L'analyse, la production et la diffusion d'informations • L'alerte et la mise en relation des acteurs concernés »¹⁹⁹ 	http://avicenn.fr/wakka.php?wiki=ObjectifsActions
The European Chemical Industry Council (Cefic)	<p>“Cefic is a committed partner to EU policymakers, facilitating dialogue with industry and sharing our broad-based expertise. We represent 29,000 large, medium and small chemical companies in Europe, which directly provide 1.2 million jobs and account for 17% of world chemical production. Based in Brussels since our founding in 1972, we interact every day on behalf of our members with international and EU institutions, non-governmental organisations, the international media, and other stakeholders.</p> <p>Cefic is the forum and the voice of the chemical industry in Europe</p> <p>Cefic is a committed partner to EU policymakers, facilitating dialogue with industry and sharing our broad-based expertise. We represent 29,000 large, medium and small chemical companies in Europe, which directly provide 1.2 million jobs and account for 17% of world chemical production. Based in Brussels since our founding in 1972, we interact every day on behalf of our members with international and EU institutions, non-governmental organizations, the international media, and other stakeholders. Cefic is an International Non Profit Association (AISBL-IVZW) under Belgian law. The Association is governed by its present Statutes. Cefic is registered in the EU Transparency Register: see here our entry.</p> <p>Our 670 members and affiliates form one of the most active networks of the business community, complemented by partnerships with industry associations representing various sectors in the value chain.</p> <p>Representing the entire range of chemicals production, Cefic is organised around 6 programmes covering:</p> <ul style="list-style-type: none"> • HSSE, Energy and Climate Action • Industrial Policy • Legislation & Institutional Affairs • Product Stewardship • Research & Innovation 	http://www.cefic.org/About-us/About-Cefic/

¹⁹⁹ Meet citizens' needs of obtaining information. Achieve a high degree of transparency and democratization of nanotechnology. Enable a civil society to be involved in making choices related to nanotechnology. Encourage the development of collective attention. Our actions: questioning; analysis, production and diffusion of innovation; warning and putting different actors in contact.

Name	Mission statement	Sources, accessed in April 2017
	<ul style="list-style-type: none"> • Sustainability <p>A Public Affairs Unit bringing together the core competencies of Communications and Advocacy/ Public Affairs plans the preparation and delivery of messages on key subjects which are of key importance to the sustainability of the Chemical Industry.”</p>	
American Chemical Society (ACS)	<p>“To advance the broader chemistry enterprise and its practitioners for the benefit of Earth and its people.</p> <p>Advance science Through peer reviewed journals, research, conferences, grants, awards, and educational resources.</p> <p>Advocate for chemistry Support for innovation, science education, and environmentally- and socially-responsible public policy.</p> <p>Educate the public Through public outreach programs, such as Chemists Celebrate Earth Day, National Chemistry Week, and Landmarks in Chemical History.”</p>	https://www.acs.org/content/acs/en/about.html
Agir pour l'Environnement	« <i>Le but de l'association est de faire pression sur les responsables politiques et décideurs économiques en menant des campagnes de mobilisation citoyenne réunissant un réseau d'associations et de citoyens le plus large possible.</i> » ²⁰⁰	http://www.agirpourenvironnement.org/association
Friends of the Earth	<p>“To collectively ensure environmental and social justice, human dignity, and respect for human rights and peoples' rights so as to secure sustainable societies.</p> <p>To halt and reverse environmental degradation and depletion of natural resources, nurture the earth's ecological and cultural diversity, and secure sustainable livelihoods.</p> <p>To secure the empowerment of indigenous peoples, local communities, women, groups and individuals, and to ensure public participation in decision making.</p> <p>To bring about transformation towards sustainability and equity between and within societies with creative approaches and solutions.</p> <p>To engage in vibrant campaigns, raise awareness, mobilize people and build alliances with diverse movements, linking grassroots, national and global struggles.</p> <p>To inspire one another and to harness, strengthen and complement each other's capacities, living the change we wish to see and working together in solidarity.”</p>	http://www.foei.org/about-foei/mission-and-vision
European Environmental Bureau, EEB	“The EEB is the environmental voice of its members and European citizens. It focuses on influencing EU policymaking and implementation and assessment of its agreed policies. It aims to be effective by combining knowledge with representativeness, active involvement of its members and coalition building.”	http://www.eeb.org/index.cfm/about-eeb/the-eebs-mission/

²⁰⁰ The goal is to exert pressure on political leaders and economic decision makers by undertaking citizen mobilization campaigns, which brings together a network of associations and citizens as large as possible.

List of Abbreviations

INERIS	Institut national de l'environnement industriel et des risques
BPA	Bisphenol A
NNI	National Nanotechnology Initiative
EU	European Union
KETs	Key enabling technologies
OECD	Organisation for Economic Co-operation and Development
WHO	World Health Organization
GMOs	Genetically Modified Organisms
PP	Precautionary principle
DNA	Deoxyribonucleic acid
PLC	product life cycle
NGOs	Non-governmental organizations
EKC	Environmental Kuznets Curve
IRI	Industrial Research Institute
WOM	Word-of-mouth ²⁰¹
Avicenn	Association de Veille et d'Information Civique sur les Enjeux des Nanosciences et des Nanotechnologies
SIR	Susceptible-infected-recovered
GDP	Gross domestic product
GNP	Gross national product
USA	United States of America
UK	United Kingdom
INRA	French National Institute for Agricultural Research
PC	Polycarbonate (PC)
RE GLS	generalized square procedure
VECM	Vector Error Correction Model
QUAN/QUANT	Qualitative/quantitative
DES	Diethylstilbestrol
RES	Réseau Environnement Santé
EFSA	European Food Safety Authority
ANSES	Agence Nationale Sécurité Sanitaire Alimentaire Nationale
ECHA	European Chemical Agency

²⁰¹ Word-of-mouth can be defined as an informal oral communication (“Random House Kernerman Webster’s College Dictionary,” 2010)

DGCCRF	Direction Générale de la Concurrence, de la Consommation et de la Répression des Fraudes"
TBBPA	Tetrabromobisphenol A
PEI	Polyetherimide
FDA	Food and Drug Administration
EPA	Environmental Protection Agency
GmbH	Gesellschaft mit beschränkter Haftung
NIA	Nanotechnology Industries Association
ETUI	European Trade Union Institute
CFDT	Confédération française démocratique du travail
CEFIC	European Chemical Industry Council
KRFT	Kraft
GIS	General Mills
HSY	Hershey
NSRGY	Nestle
UL	Unilever
SJM	Smucker's
SMP	SINOPEC Mitsubishi Polycarbonate
ASEF	Association Santé Environnement France
NSM	Nano Silver Manufacturing Sdn Bhd
PEN	Project on Emerging Nanotechnologies
NGT	Suzhou NanoGrid Technology
MassDPH	Massachusetts Department of Public Health
SSMC	Bayer MaterialScience, Shanghai SINOPEC Mitsui Chemicals
WECE	Women in Europe for a Common Future
HEA	Health & Environment Alliance
WWF	World Wildlife Fund
EMA	European Medicines Agency
APE	Agir pour l'Environnement
ECDC	European Centre for Disease Prevention and Control
SCCS	Scientific Committee for Consumer Safety
SCENIHR	Scientific Committee on Emerging and Newly Identified Health Risks
SCOEL	Scientific Committee on Occupational Exposure Limits
ECHA	European Chemicals Agency
OSHA	Occupational Safety and Health Administration
DGS	Direction générale de la santé
DGT	Direction générale du travail
DGAL	Direction générale de l'alimentation
DGPR	Direction générale de la prévention des risque
FNE	France Nature Environnement
ICTA	International Center for Technology Assessment

FIPEC	Fédération des Industries des Peintures, Encres, Couleurs, Colles et Adhésifs
CNRS	Centre national de la recherche scientifique
ANR	Agence Nationale de la Recherche
OEHHA	Office of Environmental Health Hazard Assessment
DTSC	Department of Toxic Substances Control
FS	Forest Service
CPSC	Consumer Product Safety Commission
DOC	Department of Commerce
NIST	National Institute of Standards and Technology
DOD	Department of Defense
DOE	Department of Energy
DHHS	Department of Health and Human Services
FDA	Food and Drug Administration
NIOSH	National Institute for Occupational Safety and Health
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
DOEd	Department of Education
DOI	Department of the Interior
USGS	U.S. Geological Survey
DOJ	Department of Justice
NIJ	National Institute of Justice
DOL	Department of Labor
OSHA	Occupational Safety and Health Administration
DOS	Department of State
DOTreas	Department of the Treasury
IC	Intelligence Community
ODNI	Office of the Director of National Intelligence
NRS	Nuclear Regulatory Commission
USITC	U.S. International Trade Commission
DHS	Department of Homeland Security
DOT	Department of Transportation
FHWA	Federal Highway Administration
ACS	American Chemical Society
NIFA	National Institute of Food and Agriculture
NASA	National Aeronautics and Space Administration
NSF	National Science Foundation
USDA	U.S. Department of Agriculture
ARS	Agricultural Research Service
ETIPC	White House Emerging Technologies Interagency Policy Coordination Committee

NNCO	National Nanotechnology Coordination Office
NRDC	Natural Resources Defense Council
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
WPMN	Working Party on Manufactured Nanomaterials
AFFSSET	Agence Francaise De Securite Sanitaire De L'environnement Et Du Travail
HSE	Health, Safety and Environment
RIVM	Netherlands National Institute for Public Health and the Environment
DGCCRF	Direction générale de la concurrence, de la consommation et de la répression des fraudes
JRC	European Commission's Joint Research Centre
FAO	Food and Agriculture Organization of the United Nations
CLP	Classification, Labelling and Packaging of substances and mixtures
NMSP	The US EPA established the Nanoscale Materials Stewardship Program
BfR	Federal Institute for Risk Assessment
LENS	Lake Ecosystem Nanosilver
WPMN	Working Party on Manufactured Nanomaterials
NanoREG	Common European approach to the regulatory testing of Manufactured Nanomaterials
Labex	Laboratory of Excellence for Safe(r) Ecodesign Research and Education
SERENADE	applied to NANomaterial DEVELOPMENT
OLS	Ordinary least squares
Bis-GMA	bisphenol A-glycidyl methacrylate
LICARA	Life Cycle Approach and human Risk Assessment
SMEs	Small and medium-sized enterprises
CPI	Nanotechnology Consumer Product Inventory
ABA	American Beverage Association
PVC	Polyvinyl chloride
CIS	Commonwealth of Independent States
DGEBA	or BADGE or bisphenol A diglycidyl ether
FE	Fixed effect (FE) estimator
RE	Random effect
FGLS	Feasible generalized square procedure
RE GLS	Random effect generalized square procedure
PCA	Principal component analysis
ILO	International Labour Organisation
PIE	Plastics Information Europe,
GERD	Gross domestic expenditure on R&D
FE IV	fixed effect instrumental variable approach
UAI	Uncertainty Avoidance Index
PPI	Producer price index
VAR	Vector Auto Regression

SA	Seasonal adjustment
VECM	Vector Error Correction
AIC	Akaike Information Criterion
CI	Cointegration analysis
SBIC	Schwarz's Bayesian information criterion
HQIC	Hannan and Quinn information criterion
ILC	Industry Life Cycle
ACC	American Chemistry Council
BEUC	Bureau Européen des Unions de Consommateurs
MLE	Maximum likelihood estimation
NLLS	Nonlinear least squares estimation procedures
EEB	European Environmental Bureau

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Résumé de l'introduction et les conclusions principales en français

Contexte de la thèse

Les récentes avancées dans les technologies d'analyse et d'imagerie ont rendu possible la fabrication de nanomatériaux qui ont mené aux innovations nanotechnologiques (Wiesner, Lowry, Alvarez, Dionysiou, & Biswas, 2006). Les propriétés physiques et chimiques des nanoparticules peuvent aujourd'hui être maîtrisées et adaptées pour des applications particulières (Wiesner & Bottero, 2007). Mais l'incertitude sur les risques sanitaires et environnementaux, qui couvrent le domaine des nanotechnologies pose la question du succès de l'innovation. Le marché des nanotechnologies se développe et l'intérêt managérial pour la compréhension des facteurs d'adoption des nano-matériaux augmente. Toutefois, en raison d'un manque de données cohérentes, il existe une quantité limitée de littérature empirique sur les déterminants de la diffusion de l'innovation. C'est ainsi que nous sommes conduits à tenter de répondre à la question suivante : quels sont les facteurs qui influencent l'adoption de l'innovation dans une situation d'incertitude sur les risques sanitaires et environnementaux ?

Ce chapitre est organisé comme suit. Premièrement, celui-ci établit le contexte et l'importance de notre recherche. Deuxièmement, nous présentons notre principale hypothèse de travail. Troisièmement, ce chapitre liste les questions de recherche spécifiques que nous aborderons dans cette thèse et donne un bref aperçu de sa structure.

Introduction

En 2000, la National Nanotechnology Initiative (NNI) était établie par le Président Clinton aux Etats Unis d'Amérique. L'objectif étant de développer une recherche sur les nanotechnologies, afin de favoriser la conception de nouveaux produits basés sur ces nouvelles technologies, d'encourager la formation d'une main d'œuvre hautement qualifiée, de développer une infrastructure dédiée aux nanotechnologies et de prôner un développement « nano-responsable ». Le rapport « The Nanotechnology Research Directions report » (IWGN, 1999)

a recommandé d'accompagner cette initiative et d'un financement gouvernemental d'environ 500 millions de dollars par an (deux fois plus élevée qu'en 1999). Avec l'aide et le soutien à cette initiative plus de 23 milliards ont été investis aux Etats Unis dans les nanotechnologies depuis 2001 (National Science and Technology Council Committee on Technology, 2016). En Europe, le financement public a augmenté d'environ 200 millions d'euros en 1997 à d'environ un milliard en 2004 (European Commission, 2004). Les nanotechnologies ont été ou sont encore financées par la Commission Européenne au travers du Seventh Framework Programme (2007-2013) et Horizon 2020 (2014-2020) (European Commission, 2013). Ce ne sont que quelques exemples, parmi d'autres, de financement de recherche des nanotechnologies. En comparaison aux nanotechnologies, le budget pour le financement du programme de l'Union Européenne de satellite Galileo (pour la navigation des satellites) est limité à 100 millions d'euros pour 2014-2020 avec le financement pour les programmes de recherche spatiale dans les environs de 13,5 millions d'euros (Reillon, 2015, 2017). Qu'est-ce que la nanotechnologie et pourquoi a-t-elle autant d'importance dans les programmes de recherche et d'innovation à travers le monde entier ?

Le terme de nanotechnologie englobe les sciences, l'ingénierie, et technologie appliquées à l'échelle nanométrique. Un nanomètre est un milliardième de mètre. A titre de comparaison, une feuille de papier présente une épaisseur d'environ 100 000 nanomètres. La matière à l'échelle nanométrique peut présenter des comportements différents de ceux généralement observés aux échelles plus importantes. Par exemple, le point de fusion d'un matériau, sa couleur, ou encore sa réactivité chimique peuvent changer à l'échelle nanométrique (National Science and Technology Council Committee on Technology, 2016, p.1). A ce jour, nous ne disposons pas d'une définition généralement convenue de la nanotechnologie. En 2011, la Commission Européenne (Commission Recommendation du 18 octobre 2011 sur la définition du nanomatériau, 2011) a donné une définition d'un nanomatériau : « un matériau naturel, formé accidentellement ou manufacturé contenant des particules libres, sous forme d'agrégat ou sous forme d'agglomérat, dont au moins 50 % des particules, dans la répartition numérique par taille, présentent une ou plusieurs dimensions externes se situant entre 1 nm et 100 nm. Dans des cas spécifiques, lorsque cela se justifie pour des raisons tenant à la protection de l'environnement, à la santé publique, à la sécurité ou à la compétitivité, le seuil de 50 % fixé pour la répartition numérique par taille peut être remplacé par un seuil compris entre 1 % et 50 % ». Cependant, la Recommandation sur la définition d'un nanomatériau

(2011/696/EU) n'a pas, à ce jour, valeur de norme et la discussion autour d'une définition générique applicable dans la réglementation est en cours (Bernard, 2016a).

L'impact économique attendu des nanotechnologies est gigantesque. C'est notamment la raison pour laquelle leur commercialisation est présentée comme un des objectifs de la NNI. Ce plan stratégique entend en effet « faciliter le transfert des nanotechnologies en produits pour la croissance économique, les emplois, et les services publics » (cité dans Bozeman, Hardin, & Link, 2008, p.753). De son côté, la Commission Européenne met en lumière l'importance des technologies clés génériques (KETs) dont font partie les nanotechnologies pour contribuer à une croissance et à la compétitivité de l'Europe sur les marchés mondiaux. Un impact important est notamment pressenti dans les secteurs de l'énergie, de la santé, et de l'environnement. Les nanotechnologies ont été choisies non seulement grâce à leur potentiel économique, mais aussi leur potentiel impact sociétal, leur intensité de savoir et un effet omniprésent sur les différents types d'innovation. Par ailleurs, les technologies clés génériques peuvent renforcer l'avantage comparatif au niveau régional. KETs sont supposées avoir un grand potentiel pour l'exploitation et l'éventuelle transformation des compétences accumulées au niveau local au fil du temps (Evangelista et al., 2017, p.4). Il se pourrait par exemple qu'elles contribuent à résoudre des questions relatives à la contamination environnementale, au traitement de l'eau potable et des déchets, etc. (O'Rourke, Winans, Pasanen, Werner & Brand, 2001). En outre, elles sont d'ores et déjà utilisées dans les domaines de la médecine, des technologies de l'information, de la production et du stockage de l'énergie, dans le domaine agro-alimentaire, etc. (European Commission, 2004 ; Nowack, Krug & Height, 2011 ; Pulit-Prociak & Banach, 2016). Lorsque le cancer étant une des causes de mortalité dans le monde, une innovation technologique est nécessaire pour diagnostiquer et mieux guérir le cancer. Un traitement du cancer est un des domaines de recherche de nanotechnologie incluant un diagnostic du cancer et cela pourrait offrir des solutions les plus porteuses à ce problème (Gmeiner & Ghosh, 2014).

Pendant ce temps, plusieurs groupes de travail sur les nanotechnologies ont été créés à travers le monde. Ainsi, l'Organisation de Coopération et Développement Economiques (OCDE) a établi un groupe de travail sur la sécurité des nanomatériaux manufacturés (WPMN) en 2006. Elle a également préparé dès 2008 un guide relatif à l'exposition aux nanomatériaux dans les laboratoires et pour les tests de nanomatériaux, et en 2016 rapports portant sur l'évaluation de l'exposition aux nanomatériaux ont été publiés. De nombreux ateliers

nationaux et internationaux, conférences et écoles d'été liés aux nanotechnologies sont aussi organisés dans le monde entier pour discuter de toutes les questions liées aux risques relatifs aux nanomatériaux. Pourquoi existe-t-il autant d'attention autour de ces questions ?

Les nanotechnologies sont devenues un sujet de débat considérable en raison de l'incertitude entourant les risques sanitaires et environnementaux dont leur production et leur usage pourraient être porteurs. Cette incertitude s'ajoute aux différentes incertitudes inhérentes à toute innovation. L'incertitude sur les risques sanitaires et environnementaux est une conséquence du manque de connaissance sur l'exposition et du niveau de danger. Aujourd'hui, le niveau d'exposition aux différents nanomatériaux est difficile à définir, les données de production (méthodes, volume et capacité) sont rarement divulguées (Scientific Committee on Emerging and Newly Identified Health Risks, 2014; Hendren, Mesnard, Dröge, & Wiesner, 2011). En plus du niveau d'exposition, les autres facteurs devraient être considérés, par exemple, forme et dimension des particules et leur concentration. L'exposition professionnelle aux nanomatériaux n'a pas été complètement examinée. Davantage d'investigation est requis pour mieux comprendre la génotoxicité des nanomatériaux (Scientific Committee on Emerging and Newly Identified Health Risks, 2014).

Une expérience antérieure avec les organismes génétiquement modifiés (OGM) dans l'alimentation suggère que ces types de risques et incertitudes peuvent mener vers un rejet de l'innovation (Paddock, 2010 ; Steenis & Fischer, 2016). Par ailleurs, des applications de nanomatériaux relatives à l'alimentation sont fréquemment comparées aux OGM en termes d'acceptation sociétale (Gupta, Fisher, George, & Frewer, 2013).

Cette brève discussion sur les promesses et périls liés aux nanotechnologies conduit naturellement à s'interroger sur la capacité de diffusion réelle des nanotechnologies. Qu'est-ce qui rendrait possible leur diffusion ? Une exploration des facteurs d'adoption et rejet d'innovation dans une situation d'incertitude sur les risques sanitaires et environnementaux peut aider à répondre à cette question. Nous verrons que si des études récentes ont permis d'identifier certaines tendances propres à la diffusion des nanotechnologies, beaucoup reste à faire. La littérature sur la diffusion de l'innovation étudie les facteurs qui influencent l'adoption et diffusion de l'innovation (Tidd & Bessant, 2013). A ce jour, un nombre déjà important de facteurs ont été identifiés. Il n'est pas évident aujourd'hui de savoir comment les facteurs « conventionnels », qui ont été montrés d'influencer la diffusion d'innovation,

impactent la diffusion des nanomatériaux dans une situation d'incertitude relative aux risques sanitaires et environnementaux.

Les travaux précédents sur la diffusion de l'innovation ont montré, que dans la plupart des cas, le profil d'adoption des innovations au fil du temps se présente sous la forme d'une courbe en « S » telle que présentée en Figure 1 (Rogers, 2003).

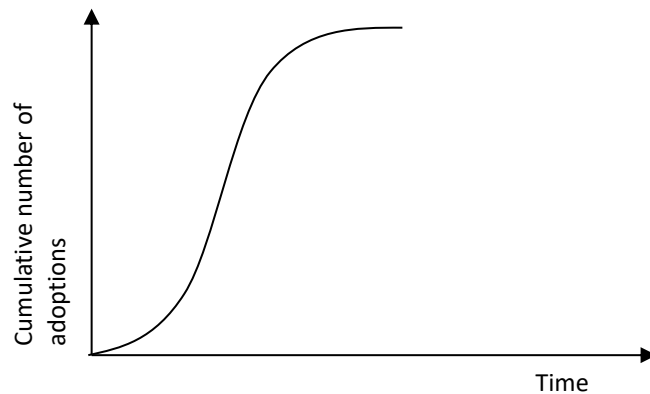


Figure 1. S-curve

Source: Reproduced from Rogers (2003)

Cette courbe décrit principalement une phase de croissance du cycle de vie du produit. Cette courbe laisse apparaître dans un premier temps l'adoption de l'innovation par quelques acteurs, appelés « innovateurs », puis une croissance rapide, et enfin une phase de stagnation (Rogers, 2003). Lorsque cela peut être supposé que l'adoption de nanotechnologie suit une courbe de forme S (Working Party on Nanotechnology Organisation for Economic Cooperation and Development, 2012), quelles sont les raisons d'une diffusion de nanotechnologie qui réussisse ? Cela mène à se poser plusieurs questions : quels facteurs influencent la diffusion de l'innovation dans une situation d'incertitude sur les risques sanitaires et environnementaux ? Quels facteurs (conventionnels) ont une influence spécifique sur l'adoption d'un bien industriel dans le contexte ?

La quantité d'articles scientifiques examinant conjointement le nano-argent et la toxicité est en pleine croissance (voir Figure 2). Cette croissance de l'attention portée par les scientifiques sur un potentiel d'un effet indésirable peut être le signe de l'émergence d'une controverse scientifique susceptible de toucher les préoccupations du public. Cette controverse est alimentée par la rapide expansion de quantité de nouvelle connaissance scientifique relative au risque qui pourrait mener vers la diminution de sa consommation (adoption). Les conclusions de recherche sur le risque divergent de manière significative. Certaines études

concluent qu'il existe un risque potentiel pour la santé et l'environnement associé au nano-argent, tandis que d'autres concluent qu'il n'y a pas de risque potentiel. Il peut arriver également que certaines recherches publiées ne soient pas conclusives.

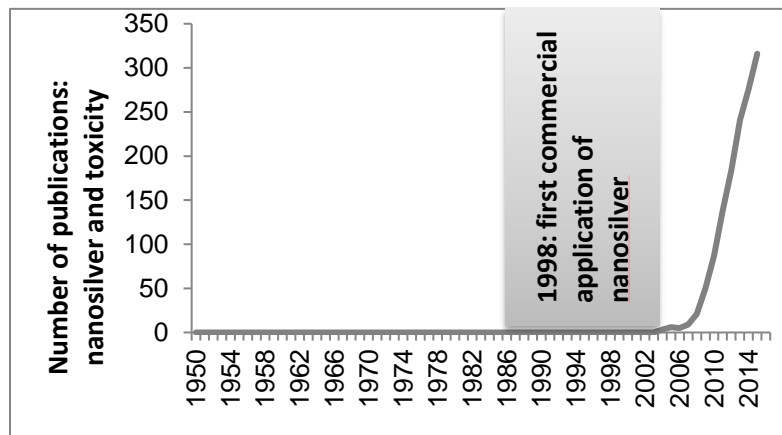


Figure 2. *Number of publications: nanosilver and toxicity*
Source: Ostapchuk, based on PubMed

Notre principale hypothèse de travail porte sur l'impact de la connaissance scientifique sur le risque. En nous appuyant sur le principe de précaution (PP) et un modèle d'impact des « événements malheureux » (unfortunate events (Slovic, 1987)), nous formulons l'hypothèse que l'augmentation de nouvelle connaissance scientifique concernant des risques a des effets négatifs sur la diffusion de l'innovation dans une situation d'incertitude sur les risques sanitaires et environnementaux. Plus la quantité des connaissances scientifiques au sujet des risques liés au produit est importante, plus la vente de ce produit est faible.

En effet, Godard (2003) souligne l'importance de la connaissance scientifique pour la prise de décision en contexte d'incertitude. En effet, commençons par rappeler ce type de contexte est précisément le cadre d'application du Principe de Précaution (PP), selon lequel, depuis la conférence de Rio de 1992 sur l'Environnement et le Développement déclare que « pour protéger l'environnement, des mesures de précaution doivent être largement appliquées par les Etats selon leurs capacités. En cas de risque de dommages graves ou irréversibles, l'absence de certitude scientifique absolue ne doit pas servir de prétexte pour remettre à plus tard l'adoption de mesures effectives visant à prévenir la dégradation de l'environnement » (Report of the United Nations Conference on the Environment and development A/CONF.151/26 (Vol. I), 1992). Depuis, en 2005, ce principe a notamment été intégré dans la Charte de l'Environnement qui est adossé à la Constitution Française, enrichi d'une notion importante : celle de la proportionnalité des mesures à mettre en œuvre. La signification de

cette notion est plurielle : elle comprend bien entendu une intention de prise en compte de la faisabilité économique des mesures ; mais elle intègre par ailleurs l'idée que ces mesures doivent être cohérentes avec la plausibilité scientifique des hypothèses de risques (voir Godard, 2003). Le volume de connaissance scientifique est une des caractéristiques de la plausibilité. Le principe de précaution sous-tend la plupart des règlements issus l'Union Européenne. Par ailleurs, la Commission Européenne recommande d'adopter un Code de Conduite pour des recherches responsables en nanoscience et nanotechnologie qu'évoque le PP.

La communication de la Commission Européenne sur le principe de précaution (2000) indique que : « le principe de précaution devrait être considéré dans le cadre d'une approche structurée de l'analyse du risque, fondée sur trois éléments : l'évaluation du risque, la gestion du risque et la communication du risque. Il est particulièrement pertinent dans le cadre de la gestion du risque... La mise en œuvre d'une approche fondée sur le principe de précaution devrait commencer par une évaluation scientifique aussi complète que possible et, si possible, déterminant à chaque stade le degré d'incertitude scientifique... La Commission considère donc que le principe de précaution est un principe d'application générale qui doit être notamment pris en compte dans les domaines de la protection de l'environnement et de la santé humaine, animale ou végétale ».

L'idée de base derrière le principe de précaution est que la réglementation devrait prendre des mesures pour protéger contre des préjudices potentiels, même si les chaînes de causalité ne sont pas claires et même si nous ne savons pas que ces dommages aboutiront (Sunstein, 2005). Une variété d'outils réglementaires existe : financement de recherche, des actions d'information, suspension provisoire, interdiction, etc. qui ne sont pas au service d'une interprétation extrême du PP selon lequel il conviendrait de « de ne pas prendre de risque », mais de sa définition institutionnelle qui recommande de réagir suivant la proportionnalité de la gravité du risque potentiel et la cohérence scientifique de l'hypothèse sur le risque. Nous discuterons certaines interprétations dans les prochains chapitres, mais ce qui a été dit permet d'observer que le principe de précaution incite naturellement à davantage de recherche. Contre l'idée populaire que la logique du principe de précaution est fidèle au dicton « il vaut mieux prévenir que guérir » (Sunstein, 2005, p.13), l'approche française tâche de répondre à « plus nous en savons, mieux nous pouvons décider ».

Le principe de précaution s'applique aux nano-argents dans la situation d'incertitude sur les risques sanitaires et environnementaux. Cela nous permet de construire notre propre hypothèse de travail basé sur le PP. Par ailleurs, nous nous appuyons sur un modèle d'impact pour les « événements malheureux ». Selon ce modèle, la réponse du public aux événements malheureux dépend de la propagation des impacts qui dépend à son tour, entre autres choses, de caractéristiques liées au risque telles que le manque de contrôle, la nouveauté, etc. (Slovic, 1987).

La découverte d'un risque potentiel peut être considérée comme un événement malheureux qui pourrait mener à une diminution des ventes, à une opposition de la collectivité, etc. A priori, toute connaissance scientifique nouvelle n'est pas un événement indésirable. Des découvertes scientifiques sont réalisées tout le temps. Certaines sont plus importantes que d'autres. Nous ne posons pas l'hypothèse que les différentes améliorations technologiques ou autres découvertes, comme, par exemple, la structure en double hélice de l'ADN sont des événements malheureux. Nous posons l'hypothèse qu'une nouvelle preuve scientifique concernant un dommage potentiel à l'environnement et/ou à la santé peut être un événement malheureux. Il se pourrait que les effets indésirables de nouveaux produits soient inconnus aux premiers stades du cycle de vie d'un produit. De plus, les aspects de sécurité n'apparaissent pas à être souvent intégrés à la phase conception des (nano) produits. La découverte de preuve scientifique d'effets indésirables potentiels d'un nouveau produit pourrait mener à des conséquences sérieuses pour la diffusion de ce nouveau produit. On pourrait soutenir que la découverte initiale du risque potentiel pourrait impacter les ventes de nouveaux produits. Cependant, les controverses scientifiques actuelles peuvent être alimentées par le nombre croissant de rapports scientifiques avec des conclusions divergentes. Les rapports scientifiques s'accumulent. Cela n'aide pas à résoudre une controverse. Dès que le sujet apparaît à nouveau, cela rappelle une controverse existante. Sur la base de ces arguments, nous nous attendons à ce que la quantité croissante de nouvelles publications scientifiques liées au risque (qui alimentent donc la controverse) ait une conséquence économique importante. C'est une des hypothèses que nous vérifierons par la suite.

Dans le cadre d'un programme de recherche sur les nanotechnologies et dans le but de concevoir une étude de référence pour l'étude des nanotechnologies, l'objectif de cette thèse

est d'explorer les déterminants de l'adoption des innovations dans une situation d'incertitude sur les risques sanitaires et environnementaux. Nous appliquerons différentes méthodes économétriques dans le but de caractériser les effets de connaissance scientifique et d'autres variables sur la diffusion des innovations en situation d'incertitude au sujet des risques sanitaires et environnementaux. En termes de cycle de vie, plusieurs nanomatériaux peuvent être actuellement considérés comme dans une phase de transition entre l'introduction sur le marché et l'étape de développement plus important, mais aucun n'a encore atteint un stade de maturité tel que l'on pourrait disposer de données des ventes historiques. Afin de pallier ce manque, nous avons recherché un exemple d'innovation présente sur le marché depuis longtemps.

L'objectif est double. Premièrement, il s'agit de fournir une meilleure compréhension du processus de diffusion d'un bien intermédiaire dans une situation d'incertitude sur les risques sanitaires et environnementaux. Nous avons donc recherché une innovation présente de longue date sur le marché. Deuxièmement, le choix de l'exemple devait permettre une comparaison avec le nano-argent, notamment en s'accompagnant d'une incertitude sur les risques sanitaires et environnementaux.

Notre choix s'est ainsi porté sur une substance chimique, le bisphénol A (BPA) pour plusieurs raisons : (1) nano-argent et bisphénol A font face à une incertitude épistémique sur les risques sanitaires et environnementaux dus à une connaissance scientifique incomplète, (2) séquences temporelles de la diffusion d'une connaissance scientifique relative aux risques sanitaires et environnementaux, (3) positions similaires du BPA et nano-argent dans la chaîne de valeur, (4) similarités dans la distance psychologique perçue (ces sujets sont discutés dans les chapitres suivants). Ces similarités entre bisphénol A et nano-argent font du bisphénol A un candidat approprié pour notre analyse.

Cela apparaît que le cas du BPA est particulièrement pertinent pour illustrer la relation entre la nouvelle connaissance scientifique sur le risque et la diffusion de l'innovation. Ce cas satisfait au challenge méthodique de la collecte de données comme données statistiques sur la consommation du bisphénol A sont disponibles pour diverses régions dans le monde (contrairement au cas du nano-argent).

Une large quantité de produits comportant des nanomatériaux a été commercialisée depuis le début des années 2000, de crèmes solaires à des chaussettes antibactériennes en passant par des raquettes de tennis. Le champ d'utilisation des nanomatériaux est très large, à la

mesure des applications très variées qu'ils permettent. Face à ce spectre très large, nous avons décidé de mettre l'accent sur le nano-argent, pour des raisons de faisabilité de l'étude tout d'abord (il n'était pas possible de s'intéresser à tous les nanomatériaux (NMs) et toutes leurs applications), mais aussi parce qu'il est l'un des NMs présents dans le plus grand nombre de produits de consommations (Hendren et al., 2011 ; Tran, Nguyen, & Le, 2013). Le nano-argent est utilisé dans les domaines de la médecine, des textiles, des cosmétiques, de la purification de l'eau, des emballages et dans l'industrie électronique, notamment à cause de ses propriétés antibactériennes (Cantuarias-Villessuzanne et al., 2016; Köhler & Som, 2014; Scientific Committee on Emerging and Newly Identified Health Risks, 2014; Tran et al., 2013). La "première application commerciale de nanotechnologie" généralement référencée est d'ailleurs un pansement anti-microbien, à base de nano-particules d'argent susceptible d'accélérer le processus de guérison grâce à ses propriétés anti-inflammatoires (Burell, 2009, p.24).

Depuis 2015, la quantité globale de nanomatériaux manufacturés à travers le monde est d'environ 11,5 millions de tonnes pour une valeur de marché d'environ 20 milliards par an (cité dans Pult-Prociak & Banach, 2016). Le marché global du nano-argent est présenté en Figure 3, montrant notamment une croissance continue depuis 2010.

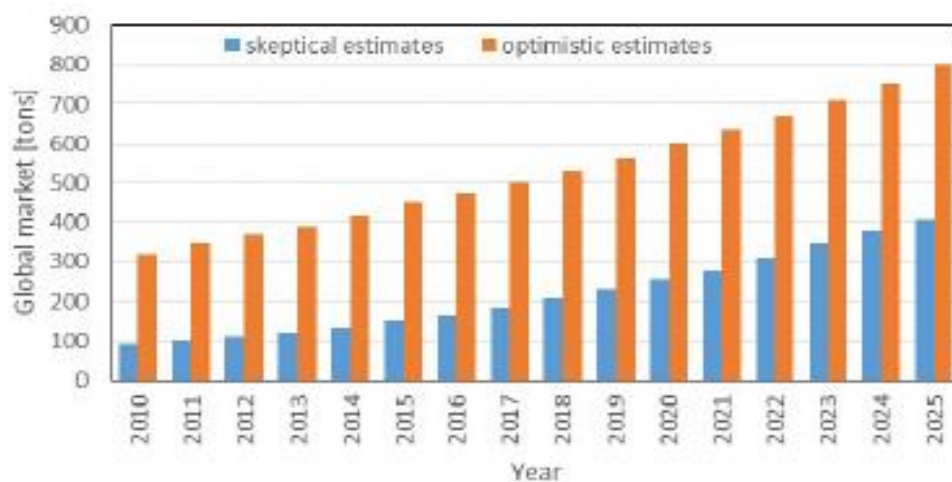


Figure 3. Global market for nanosilver

Source: Reproduced from Pult-Prociak & Banach (2016)

Selon le Ministère de l'Environnement, de l'Energie et des Affaires Maritimes (2015), le volume de substance produite localement ou importée sous forme nano qui était déclaré en France en 2014, était d'environ 415 000 tonnes. Le volume de nano-argent qui était déclaré

en 2014 était extrêmement faible, de l'ordre de 0,1 à 1 kg qui est assez similaire au volume reporté en 2013. Une des possibles explications de ce phénomène était que le nano-argent a été intégré dans les produits avant son arrivée en France (Avicenn).

Le développement du nano-Ag est bien là, mais que peut-on dire concernant les risques éventuellement liés à son usage ? Concernant le nano-argent, les scientifiques indiquent que son emploi pourrait avoir des effets indésirables puisque la toxicité de l'argent est bien connue (Pulit, Banach, & Kowalski, 2011). Un des effets indésirables de l'argent, une décoloration bleue-grise, est un résultat d'une exposition chronique. Nombre d'études suggèrent une intoxication du foie comme résultat possible de l'ingestion du nano-particulaire d'argent. In vivo, il est démontré que le système immunitaire peut être affecté par le nano-argent. Un effet géno-toxique a par ailleurs été montré in vitro. Cependant, plus de données seront encore nécessaires pour déboucher sur une conclusion consensuelle. D'autant plus que les voies d'exposition potentielles sont diverses (inhalation, l'administration épidermique, orale ou combinée) et les dangers liés à chacune spécifiques. Comme nous avons déjà mentionné, le niveau d'exposition est difficile à définir comme nanomatériaux ne sont pas souvent indiqués comme composants (Scientific Committee on Emerging and Newly Identified Health Risks, 2014). En complément, les facteurs suivants devraient être considérés : forme, dimension des particules, leur concentration et la probabilité des particules d'argent de diffusion d'ions d'argent. Davantage de recherche est nécessaire pour mieux comprendre la géno-toxicité du nano-argent in vivo, réponse de la flore bactérienne à l'exposition du nano-argent et mécanisme de la résistance bactérienne au nano-argent (Scientific Committee on Emerging and Newly Identified Health Risks, 2014). Les nano-particules d'argent peuvent être distribuées dans l'environnement, par exemple, à travers l'utilisation de nano-textile, savon, cosmétiques ou matériaux de construction (Pulit-Prociak, Stokłosa, & Banach, 2015). Alors, ils peuvent pénétrer dans les eaux de surface et eaux de souterrain et / ou sol. Ils peuvent déposer dans les sédiments, ou ils peuvent alors être accumulés, transformés ou remis en suspension. Il y a un débat en cours parmi les scientifiques par rapport aux effets indésirables sur l'environnement. Cependant, les expérimentations montrent que la proportion de particule de nano-argent rejetée boues d'épuration à l'eau est très petite (Pulit-Prociak et al., 2015; Scientific Committee on Emerging and Newly Identified Health Risks, 2014).

Afin de conduire une analyse empirique, les données sur la consommation du BPA et sur les variables explicatives, qui pourraient l'affecter ont été collectées sur la base de différentes sources. Partant de notre principale question de recherche « Quels sont les principaux facteurs qui influencent l'adoption d'innovation dans une situation d'incertitude sur les risques sanitaires et environnementaux ? », nous sommes conduits à en traiter deux questions plus spécifiquement :

- Premièrement : Quels sont les déterminants-clés de l'adoption internationale de l'innovation dans une situation d'incertitude sur les risques sanitaires et environnementaux ?
- Deuxièmement : Est-ce que le nombre de publications scientifiques liées aux risques impactent la consommation ?

Le BPA est un exemple d'innovation présente sur le marché depuis plus de 60 ans. Nous sommes conduits à focaliser notre étude sur une phase du cycle de vie comprise entre la fin de l'état de croissance et le début de l'étape de déclin. Ceci alors que la plupart du travail sur la diffusion des innovations explore principalement l'étape de croissance du cycle de produit de vie. Les études sur les facteurs qui influencent un temps de décollage ne sont pas répandues. Il y a même moins de travaux sur les déterminants en période de ralentissement de cycle de vie du produit. Le terme décollage est défini par Chandrasekaran & Tellis (2007) pour se référer à la première augmentation considérable et durable dans la vente d'un nouveau produit (Chandrasekaran & Tellis, 2007). Le ralentissement est identifié comme le début d'une période d'une augmentation lente ou une diminution temporaire de la vente de produits après décollage (Chandrasekaran & Tellis, 2007).

Le décollage et le ralentissement de la diffusion de nouveaux produits sont des points importants dans le cycle de vie du produit (PLC). Savoir comment les différents facteurs influencent la croissance des ventes selon les différentes phases du cycle de vie du produit (PLC) peut s'avérer utile aux décisions de marketing. A la suite de l'introduction de la connaissance scientifique sur le risque potentiel d'un bien industriel sous les conditions d'incertitude, pouvons-nous observer que la forme du cycle de vie du produit illustre la substitution, l'extension ou autres stratégies ?

Comme nous le verrons, les courants de recherche sur les théories de la communication et sur la diffusion des innovations peuvent contribuer à la compréhension des facteurs qui ont un impact sur l'adoption du BPA. Mais ils laissent également des lacunes que cette thèse cherche à combler. Par rapport aux contributions à la théorie, notre objectif avec cette thèse est de mettre en lumière sur un ensemble de facteurs qui sont vraisemblablement pour influencer la diffusion de l'innovation, en particulier la phase de maturité et de la façon dont ils sont reliés à l'innovation dans une situation d'incertitude sur les risques sanitaires et environnementaux. Notre objectif est d'utiliser les résultats de cette thèse pour boucler la boucle avec la littérature comme ils ont d'importantes implications pour la compréhension de l'adoption du nano-argent. Par ailleurs, un objectif de notre recherche est de donner des aperçus sur le rôle potentiel d'une nouvelle connaissance dans l'adoption de l'innovation et dans la littérature consacrée au rejet de l'innovation.

Nous conduirons une étude qualitative pour vérifier comment nos résultats sont connectés avec les actions des parties prenantes qui peuvent contribuer d'une certaine manière à une nouvelle connaissance scientifique et/ou qui sont engagés dans l'échange des expertises. Nous faisons une première tentative pour clarifier le lien entre les différentes parties prenantes et la nouvelle connaissance scientifique.

Ce développement implique une troisième question de recherche spécifique à laquelle nous tâcherons de répondre :

- Quel est le lien entre la nouvelle connaissance scientifique et les parties prenantes dans une situation d'incertitude sur les risques sanitaires et environnementaux ?

Plan de la thèse

La thèse contient 9 chapitres. Ce chapitre est introductif et définit le cadre de notre étude. En Chapitre 2, la littérature existante sur la diffusion de l'innovation est examinée. Cela présente une revue sélective qui contient différents travaux existants dans divers secteurs connectés avec notre sujet. Ces éléments servent de point de départ pour notre analyse et ils aident à comprendre des discussions ultérieures. Notre travail se fonde essentiellement sur la théorie de diffusion de l'innovation dans le champ du marketing et la littérature sur le cycle de vie de produit. Par ailleurs, nous examinons brièvement la littérature qui nous aide à comprendre le

rôle d'une nouvelle connaissance scientifique sur le risque dans la diffusion de l'innovation (information négative et marketing, science et incertitude, le principe de précaution).

De plus, nous examinons les études empiriques qui mettent l'accent sur la diffusion internationale des innovations et ses moteurs étant donné que le champ de notre étude. Il y a une large quantité de différentes variables explicatives qui pourraient impacter la diffusion de l'innovation. Nous présentons ces facteurs en Chapitre 2. Nous notons que les controverses se produisent au sujet de l'impact des différents facteurs sur la diffusion de l'innovation aux différentes phases du cycle de vie, nous discutons de ces controverses et nous soulignerons les différents écarts existants dans la littérature dans le Chapitre 2.

Le Chapitre 3 dresse une présentation des différents facteurs qui pourraient être associés avec la consommation du bisphénol A. D'ailleurs, des sources de données et méthodes d'analyse des données sont présentées en Chapitre 3. Un échantillon relativement faible de données ne nous permet pas de traiter de tous les déterminants potentiels de la diffusion des innovations. Nous expliquerons comment nous avons choisi les facteurs pertinents dans ce chapitre. Pour expliquer un des déterminants, une variable originale a été construite. Cette variable est une nouvelle connaissance scientifique sur le risque potentiel. L'effet d'une information scientifique sur la consommation dans une situation d'incertitude sur les risques sanitaires et environnementaux n'a pas fait l'objet d'étude approfondie à ce jour. Dans le but de pallier ce manque nous utilisons des méthodes mixtes. Pour répondre aux deux premières questions de recherche, des données quantitatives sont obtenues de sources différentes. Pour répondre à la troisième question, une étude qualitative a été réalisée. Des sources primaires et secondaires de données ont été collectées. Plus de détails sur ce sujet sont décrits dans le Chapitre 3.

Le Chapitre 4 présente une comparaison descriptive entre l'histoire du BPA et le début de l'histoire du nano-argent. Premièrement, nous déterminons les positions du BPA et nano-argent dans le cycle de vie du produit durant les périodes étudiées. Nous avons identifié que le BPA est dans la transition de l'étape de croissance jusqu'à l'étape de déclin. Nous listons différentes parties prenantes liées au BPA et nano-argent et les attribuons dans différentes catégories. Alors nous reportons des faits généraux et des cadres réglementaires liés au BPA et nano-argent suivis par différentes activités qui peuvent être classifiés comme développement responsable entrepris par différents acteurs. Finalement, nous présentons les réactions des entreprises à la nouvelle connaissance scientifique suivie par les activités des

ONG liées à la nouvelle connaissance scientifique sur les risques environnementaux et de la santé. Les données ont été collectées dans le cadre d'entretiens avec des experts et des sources secondaires.

La construction des variables ainsi que le travail de collecte des données liée au BPA sont décrits dans le Chapitre 5. Ce chapitre essaie de proposer une classification d'une nouvelle connaissance scientifique sur les risques basée sur les conclusions d'articles scientifiques liés aux potentiels de BPA. Par ailleurs, l'information de base sur les sujets liés à l'utilisation du bisphénol A, les risques potentiels sur la santé et l'environnement liés au BPA, est présentée et la tendance de consommation du bisphénol A est présenté.

Les chapitres 6 et 7 présentent alors le cœur de notre travail de modélisation. Ces chapitres tentent de mettre en lumière sur les déterminants de ralentissement des produits dans une situation d'incertitude sur les risques sanitaires et environnementaux utilisant les données appropriées. Dans ce contexte, le but du Chapitre 6 est d'explorer les changements dans la consommation du bisphénol A (BPA). La littérature sur la Courbe Environnementale de Kuznets (EKC) est examinée en plus pour faire la lumière sur la relation entre la croissance économique et la consommation de BPA. L'EKC représente un lien représentable graphiquement sous la forme d'un U inversé traduisant généralement l'idée que la croissance est d'abord responsable de dégradation environnementale avant que le phénomène ne s'inverse une fois atteint un certain niveau de richesse. L'idée est donc ici de tester si un lien similaire peut être établi entre croissance et consommation d'une substance potentiellement dangereuse. Nous utilisons la consommation de composant à la place des indicateurs de pollution pour tester l'EKC. Alors, nous examinons si et dans quelle mesure le processus est influencé pour la nouvelle connaissance sur les risques en plus des autres variables dans une situation d'incertitude concernant ces risques. En Chapitre 7, nous effectuons une analyse pour les ventes de polycarbonate, dérivé du BPA, au Japon. Nous analysons si les ventes d'un bien intermédiaire secondaire, à savoir le polycarbonate, sont affectées par les chocs d'information liés au BPA.

Dans le chapitre 8, nous annonçons les principaux résultats de l'étude en tâchant de répondre à nos questions de recherche. Nous discutons dans quelle mesure le bisphénol A est un candidat approprié pour l'analyse de la relation entre les nouvelles connaissances scientifiques et l'adoption d'innovations. Nous revenons sur le lien entre les nouvelles connaissances scientifiques et les parties prenantes en nous basant sur les données

présentées dans le Chapitre 4. Nous mettons l'accent ensuite sur le rôle d'un prescripteur dans cette relation. Nous relierons cette étude à d'autres littératures (Chapitre 9). Cette discussion est suivie par des suggestions pour d'autres recherches. Nos conclusions sont tirées dans le dernier chapitre.

Conclusions principales

Dans cette thèse, nous avons étudié les déterminants de l'adoption de l'innovation dans une situation d'incertitude sur les risques sanitaires et environnementaux. Nous avons examiné la consommation du BPA dans 8 régions du monde. En plus, les ventes de consommation du polycarbonate ont été explorées.

Nous avons choisi le BPA comme un point de départ pour l'étude du nano-argent parce que celui-ci est un exemple d'un produit qui existe sur le marché depuis longtemps dans une situation d'incertitude sur les risques sanitaires et environnementaux. Les données détaillées sur le nano-argent ne sont pas encore disponibles. D'autres raisons ont guidé notre choix : l'ordre chronologique de diffusion de connaissance scientifique liée aux risques, les positions similaires dans la chaîne de valeur et similarités dans la distance psychologique perçue.

Les résultats-clé de cette thèse sont les suivants :

- Largement discuté, sauf au début de la période étudiée, la consommation du BPA par habitant a augmenté avec l'augmentation du revenu par habitant jusqu'au point où la consommation a diminué avec l'augmentation du revenu sur la période étudiée. Les trois entités franchissent un point d'inflexion : Japon, les Etats-Unis d'Amérique et l'Ouest de l'Europe. La consommation du BPA suit le modèle de la courbe environnementale de Kuznets (EKC). Lorsque la consommation du BPA est en transition entre la phase de maturité et la phase de saturation dans la majorité des régions dans la période étudiée, la consommation globale a encore augmenté. Une des explications possibles pourraient être la délocalisation de l'industrie d'une région développée à une région moins développée avec une réglementation environnementale moins stricte.
- Une relation d'U inversé entre la croissance économique par habitant et un bien intermédiaire secondaire réalisée du BPA a été trouvée au Japon dans la période étudiée. Nos résultats suggèrent qu'une augmentation du revenu peut être associée avec une augmentation dans une probabilité de ralentissement d'un bien

intermédiaire primaire ou (et) un bien intermédiaire secondaire dans une situation d'incertitude sur les risques sanitaires et environnementaux.

- La consommation de BPA a augmenté avec un niveau d'accès aux informations plus élevé.
- Une augmentation dans la consommation du BPA était associée avec une augmentation des ventes de biens finaux.
- Les prix de polycarbonate ne sont pas corrélés avec la consommation du BPA par habitant.
- L'effet des interdictions sur l'utilisation du BPA dans les productions des biberons en plastique dans l'Union Européennes, Chine, Brésil et Malaisie en 2011 sur la consommation agrégée était positive, mais statistiquement non significatif.

Suite à l'hypothèse principale posée au début de cette étude, il est maintenant possible de déclarer qu'il y avait une faible relation entre la nouvelle connaissance scientifique sur les risques et la consommation du BPA dans une situation d'incertitude sur ces risques. En d'autres termes, nous ne pourrions pas connecter de manière concluante une diminution dans la consommation du BPA à une nouvelle connaissance sur le risque. Un facteur culturel a expliqué en partie cette relation. Une légère réduction dans la consommation était observée dans des régions avec un fort indice d'incertitude d'évitement alors que la quantité d'articles sur le risque augmente. D'autres analyses sont nécessaires dès que des données détaillées (données sectorielles) sur le BPA et nano-argent seront disponibles.

D'ailleurs, nos résultats sembleraient démontrer qu'il n'existe pas de changements continus dans la forme du cycle de vie du produit qui pourrait être expliqué par des chocs d'information.

En se fondant sur l'interprétation du principe de précaution et du modèle des événements malheureux, nous avons posé l'hypothèse que plus le nombre d'articles scientifiques liés aux risques potentiels du BPA est important, plus la consommation du BPA est faible. Nous reformulons le paradoxe que notre recherche semblerait suggérer : le principe de précaution s'applique au BPA, la prise de décision en cas d'incertitude nécessite la connaissance scientifique, nos résultats amènent à penser que plus de recherche ne donne pas lieu à dans une utilisation proportionnelle d'outils et une application correcte du principe de précaution par rapport à la connaissance scientifique disponible.

Dans le but d'expliquer ce résultat et comparer le BPA avec le nano-argent, nous avons étudié le lien entre un produit et les utilisateurs, qui impliquent des interactions entre les différentes parties prenantes. Nous avons étendu la classification existante des acteurs en discutant de leur lien avec la nouvelle connaissance scientifique (consultation passive, engagement actif). Nous avons observé que les événements « l'innovation et recherche responsable » ont ajouté plus de poids aux connaissances scientifiques et augmenté un nombre d'influence bidirectionnel parmi les parties prenantes. Ces événements ont une influence particulière pour le nano-argent. La situation peut changer. Mais cela ne signifie pas nécessairement un ralentissement de l'innovation du fait qu'une nouvelle connaissance scientifique sur les risques est introduite. Cela pourrait mener à une plus large application d'une approche « Safer by design » utilisant une nouvelle connaissance scientifique sur le risque. L'approche « Safer by design » peut être définie comme une atténuation des risques potentiels du nano-argent ou des autres nanomatériaux durant la phase de conception (Morose, 2010).

Nous avons identifié une variété d'activités que différentes parties prenantes pourraient utiliser en réponse à une nouvelle connaissance scientifique sur le risque (similaire aux industries du tabac et de l'alcool). Ces activités comprennent : le financement de recherche, le façonnement de la preuve, la délimitation du groupe de risque, l'autorégulation et systèmes volontaires de signalement, un argument de suppression d'emploi et de lobbying.

Par ailleurs, nous avons discuté du rôle du prescripteur dans la relation entre un produit et les consommateurs. Nous avons conclu que les organisations du consommateur liées au BPA et nano-argent pourraient être définies comme prescripteurs basés sur leur activité. Les associations de l'industrie liées au BPA et nano-argent pourraient être perçues comme prescripteurs basés sur leur activité. Nous pouvons aussi émettre l'hypothèse qu'une indisponibilité de substituts pour divers applications peuvent être comparées à un manque de levier d'actions. Cela aide à expliquer pourquoi un produit pourrait être encore utilisé malgré l'existence d'une connaissance scientifique sur les risques.

Le débat sur le BPA et nanotechnologies est important puisqu'il permet de faire avancer le débat entre la science et l'innovation. Nos résultats suggèrent que la preuve scientifique des risques devient inefficace au regard de la gestion du risque dans une situation d'incertitude. Plusieurs types d'action peuvent être entrepris par des régulateurs et/ou utilisateurs d'un bien intermédiaire ou un bien final contenant ce bien intermédiaire.

L'information a été transmise, mais les actions attendues ne sont pas entreprises, qui mène à l'inefficacité de l'information. Il y a une faible relation entre la consommation et le choc d'information dans une situation d'incertitude sur les risques sanitaires et environnementaux. Nos résultats suggèrent que la relation entre le choc d'information et le comportement des consommateurs n'est pas automatique. C'est un résultat important. Plusieurs mécanismes pourraient expliquer l'inefficacité de l'information :

- l'absence de substituts, qui peuvent être comparés à un manque de levier d'actions, rendent plusieurs actions impossibles. Cela pourrait expliquer l'utilisation répandue. Entre-temps, une utilisation intensive d'un bien ne suggère pas toujours que le bien est accepté
- les activités entreprises par les parties prenantes en réponse à la nouvelle connaissance scientifique
- la présence d'acteurs intermédiaires dans la relation entre vendeurs et acheteurs.

Résumé

L'incertitude est présente dans toute innovation. Dans le domaine des nanotechnologies, l'incertitude qui entoure les risques sanitaires et environnementaux dont ces technologies pourraient être porteuses est si importante que la question de leur succès se pose.

En partie du fait du manque de données cohérentes, il n'existe qu'une littérature empirique limitée sur les déterminants de la diffusion des nanotechnologies. Dans le cadre d'un programme de recherche sur les nanotechnologies, cette thèse a pour but d'investiguer les déterminants de l'adoption d'innovations dans une situation d'incertitude sur les risques environnementaux et sanitaires. Dans cette optique, nos travaux visent dans un premier temps à fournir une meilleure compréhension de la diffusion d'un produit qui est présent sur le marché depuis longtemps. Nous avons choisi une substance chimique très utilisée, le bisphénol A (BPA). Différentes méthodes économétriques sont appliquées afin de mieux comprendre la relation entre la consommation, la croissance économique, les nouvelles connaissances scientifiques concernant le risque et d'autres variables utilisant les données relatives au BPA. Les résultats illustrent un ensemble de facteurs qui influencent la consommation de BPA au niveau international.

Dans un second temps, nous montrons dans quelle mesure cette étude permet d'éclairer la réflexion initiée sur la diffusion des nanotechnologies, notamment le nano-argent. Le comportement des différents acteurs en réponse à la production de connaissances scientifiques nouvelles sur les risques est étudié, ce qui nous permet d'aboutir à une compréhension approfondie de "développement nanoresponsable".

Mots Clés

Innovation, diffusion des innovations, cycle de vie du produit, nanotechnologie, bisphénol A, risque, incertitude, environnement, santé, principe de précaution, Safer by Design, développement responsable

Abstract

Uncertainty is immanent in every innovation. Uncertainty about environmental and health risks that surround nanotechnology raises the questions of innovation success. Due in part to a lack of consistent data, there is limited empirical literature on determinants of the diffusion of nanotechnology. As part of a research program on nanotechnology, this research aims to investigate determinants of uptake of innovation in a situation of uncertainty about environmental and health risks.

With this goal, as a first step, this work seeks to provide better understanding of the diffusion of a product that has been on the market for a long time. We have chosen a chemical, bisphenol A (BPA), because of the lack of historical data on nanomaterials. As a second step, we compare the results of the BPA study to nanosilver. We apply different econometric methods to gain insights into the relationship between consumption, economic growth, new scientific knowledge about risk and other variables using the data on BPA. The results illustrate a set of factors that influences the consumption of BPA at international level.

The comparative study between BPA and nanosilver helps to refine the interpretation of main results and to obtain additional insights into the determinants of uptake of nanosilver. An explanatory analysis sheds light on the actions that different stakeholders undertake in response to new scientific knowledge about risk and deepens our understanding of "nanoresponsible development".

Keywords

Innovation, diffusion of innovation, product life cycle, nanotechnology, bisphenol A, risk, uncertainty, environment, health, precautionary principle, Safer by Design, responsible development