



Technological Absorptive Capacity and Productivity Dynamics with a Special Reference to Kazakhstan

Yergali Dosmagambet

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Université d'Auvergne Clermont-Ferrand 1
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Technological Absorptive Capacity and Productivity Dynamics with a Special Reference to Kazakhstan

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Әкеме естелік

Анама арнау

La faculté n'entend donner aucune approbation ou improbation aux options émises dans cette thèse. Ces opinions doivent être considérées comme propres à son auteur.

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Clermont-Ferrand, le 2 avril 2008

Yergali Dosmagambet

CHAPTER 1

GENERAL INTRODUCTION

1.1 General Introduction

The main purpose of the present research is to measure absorptive capacity in technological catching-up with a macroeconomic model for a transition economy to evaluate its long term potential of convergence towards world technology frontier.

Economies with similar production factors and, in particular, the same average years of schooling but with more distributions of human capital in terms of the levels of educational attainment may perform better¹. Therefore, given the limited social resources for education, it is efficient to support financially all levels of education, rather than to focus on promoting one particular level of education, for example, basic education. On the other hand, the structure of human capital stock varies depending on the types of skills which derive from the demand of local labour markets and can be shaped by the attained levels and certain kinds of education². It enables labour force to perform certain jobs and functions more effectively. Thus, the main cause of the growth of labour productivity in transition economies³ is regarded in the study as the availability of human capital but focusing on its *composition*⁴ rather than the levels of educational attainment⁵.

Nelson and Phelps (1966) introduce a function of technology adoption in which higher levels of human capital facilitate the adoption and the implementation of new technologies and thereby, may raise the rate of technological catch-up for follower countries. The closer a country is to the frontier, the more growth depends on having a highly educated workforce. On the contrary, further back from the frontier university degrees matter relatively less and good primary and secondary education count for relatively more (Aghion and Howitt, 2006).

¹ The correlation with GDP growth is significant and positive in countries with better allocations of educational resources across the levels of education (Judson, 1998) and the variance of educational attainment (Park, 2006).

² See, Ramcharan (2004).

³ The convergence toward the EU is of current importance for most transition countries (Berglof, 2007; Czarnitzki and Kraft, 2006; Van Ees and Bachmann, 2006).

⁴ For example, Vinogradov (2004) refers also to the composition of education in the transition economy.

⁵ The number of graduates with technical education decreased since the transition period while the number of graduates in business gradually increased. Therefore, business occupations expanded and technical occupations declined in most transition economies. However, the situation is considerably improving and labour markets adjust to a vital need to provide a carefully tailored re-training program, or foster job creation in technical fields.

Impressive economic performance with a surprised increase in educational attainments in the East Asia countries (Collins, Bosworth and Rodrik, 1996) are assumed to be held mainly by a dramatic augmentation of labour force with vocational relative to general education. It is consistent with the recent literature (Bennett, 1967; Bertocchi and Spagat, 2004) which presents empirical evidence that the ratio of VG tends to be higher in middle income countries. Moreover, with a model of technology adoption in which households optimally obtain one of the two streams of secondary education Krueger and Kumar (2003) show that at early periods favouring vocational education as compared to general education was efficient but inefficient at later periods when new technologies were introduced with a more rapid pace. Thus, not only the levels of educational attainment but also the relevant changes in *the composition of secondary educational stock* might be conducive to higher absorptive capacity in technology adoption. Similar to Eicher (1999) we assume that technological progress and the diffusion of technology are constrained by the rate of vocational education and training that enables to the accumulation of human capital.

In contrast to Nelson-Phelps (1966), the ability to exploit new technologies is not solely related to human capital, but also to the degree of foreign direct investments (Findlay, 1978) and foreign trade (Krugman, 1979) in domestic country. Therefore, Diao et al. (2002) included both trade and FDI as the determinants of technology diffusion by using a general equilibrium analysis of catching-up for Thailand. In turn, as FDI often takes the form of new types of intermediate goods, imported by foreign firms, Stokke (2004) suggests human capital and foreign trade as the main spillover channels by focusing on the endogenous interaction between technology transfer through trade and human capital in catching-up economy.

The thesis consists in three essays. The first essay specifies absorptive capacity in terms of the distance to technology frontier and barriers to technology adoption which allows for concretizing the process of taking advantages from technology diffusion and modelling productivity dynamics. As a result, a logistic model is derived from the Nelson-Phelps linear catch-up framework, often used in clustering of developing countries⁶. Moreover, the technological catch-up can be broadly formulated in terms of the main barriers to technology adoption⁷. Human capital and openness of trade are assumed to constitute the

⁶ See, for example Graham and Temple (2006).

⁷ Technology adoption can be understood as the regulation of entry (Djankov et al., 2002).

most powerful channels of technology diffusion. Besides that, there may be other conduits⁸, for example, technological infrastructure, which can be ranged depending upon the degree of their importance. Therefore, the success of catching-up process will be seen as weakening the magnitude of country-specific barriers which should be identified and assessed depending on the availability of relevant data.

In recent attempts of modelling productivity growth, combined with human capital and technology adoption, the main pattern of productivity dynamics were properly chosen from empirical evidence, but a well-defined theoretical underpinning still lacks (Diao et al., 2002; Stokke, 2004). The generalization of the catch-up process fills this gap by confirming the appropriateness of empirical findings and presents a broader approach to modelling productivity dynamics. The properties of the logistic pattern of technology diffusion reveal that there exists a time path convergence (respectively divergence) to the locally steady states. A complex nature of productivity dynamics can be depicted by the logistic model with an endogenous threshold in barriers to technology adoption. However, only middle income economies with a sufficient level of technological absorptive capacity may overcome the productivity trap and, possess a high potential to converge to the world technology frontier. By contrast, poor countries due to their inability to decrease the magnitude of the main barriers often get into productivity traps⁹.

The second essay devotes to understanding the mechanisms which may ensure a rise of the average years of schooling in countries where educational attainments initially were at a lower level, but where vocational education and training became an important strategy for economic development. Moreover, the impressive economic performance of the East Asia economies shows that there is a positive link between a relative rise of working population with vocational education and the size of secondary education. A deep insight of these issues is provided by a model in which the interrelations between the ratio of VG education and the ratio of VG enrolments are properly examined. In particular, it is demonstrated that the ratio of VG is a better proxy only when the ratio of VG education increases. In other words, the use of VG enrolments in place of VG education is justified only for developing countries. Therefore, the conclusions, made first by Bennett (1967) and later by Bertocchi and Spagat (2004) regarding to less-developed and developed economies, are rather less

⁸ There are many channels of technology diffusion (Lee, 2006).

⁹ See, for example Berdugo et al. (2003); Foulkes (2007); Gehlbach(2007), Sadik (2008).

strong due to decline of the ratio. It is also shown that the rate of VG enrolments can serve an exact proxy for the ratio of VG education depending on a share of recently entered at universities students in labour force with general education.

The scarcity of data on the structure of attained secondary education has seemingly been restricting research on unequivocal understanding of how the size of secondary education changes depending on the ratio of VG. The essay opens up some insights by exploring the main differences stemming from raising productivity and increasing the size of secondary education and the directions in which they work altogether. A convergence (divergence) of the directions of the ratio of VG and the size of secondary education gives scope for optimizing the composition of secondary educational stock for developing (developed) economy. Moreover, based on the data of Taiwan for 1979-1998 the real dynamics of VG is reconstructed by calculated VG which means that Taiwan has apparently succeeded in increasing the average years of education from 3.2 to 8.2 years by optimizing the composition of its secondary educational stock. These results allow for specifying the ratio of VG education as a measure of human capital stock and hence, applying the modern growth theory to transition economies.

The third essay uses a computable general equilibrium model by incorporating the Nelson-Phelps framework that presents an analytical tool in evaluating the long-term catch-up potential of a transition economy. The concept of [Lucas \(1988\)](#) is revisited to show that allocating the time either to acquiring skills at secondary schools or to producing goods necessarily implies a change in the structure of working population with secondary education. The catching-up function of technology diffusion which is newly specified by the ratio of VG, is introduced for the purpose of policy analysis in Kazakhstan¹⁰. The pattern of productivity growth, measured in terms of barriers to technology adoption, reveals that the economy converges initially to lower steady state, endogenously determined by the interaction between the barriers to technology adoption and technology diffusion.

The introduction of the ratio of VG as a proxy of human capital accumulation in transition economies can be justified by the following arguments: First, it reflects greater and broader

¹⁰ [Anderson and Heyneman \(2005\)](#) analyze the educational system whereas [Pomfret \(2005\)](#) evaluates the economic potential of Kazakhstan.

technological skills, imparted through secondary education. Second, the new measure of human capital might be consistent with the concept of [Lucas \(1988\)](#). It is also shown that there exists a balanced growth path of the size of secondary education and the ratio of VG. Moreover, alongside of the balance growth path both secondary education and the ratio of VG grow positively. Therefore, it is assumed that working population with secondary education structurally adjusts to technology adoption which is conducive to productivity growth and can be entered in the production function as a simple factor of production. Third, the ratio of VG presents a broader measure of human capital accumulation as it can be applied to both developing and transition economies where the main occupation of technology adoption is imitation process. Hence, the ratio of VG may be used in place of secondary enrolments rates in the Nelson-Phelps approach to modelling productivity growth using general equilibrium analysis.

In accordance with the Strategy of the Kazakhstan's Accession to the 50 Most Competitive Economies¹¹ the country should move towards a more diversified economic structure through improving the nation's competitiveness. At the outset, the growth path in Kazakhstan is assumed to be based on low technological industries which are not characterized by R&D-intensive high skilled production¹². Analyzing the endogenous interaction between technology diffusion and improvements in the efficiency of human capital through focusing on vocational education and training the model reveals first the economy's convergence to its lower steady state. Thus, the policy implications will consist in improving the country's technological absorptive capacity through significant investment in the education system and identifying the main country-specific barriers to technology adoption and their lowering which aim at taking great advantages from technology diffusion.

The main results of the research work have been presented at the CERDI's seminar and the 4th International Conference Developments in Economic Theory and Policy in Bilbao (July 5-7, 2007) and accepted for presentation in the Asia-Pacific Productivity Conference 2008 in Taipei (July 17-19, 2008).

¹¹ It has been announced by Nursultan Nazarbayev, President of the Republic of Kazakhstan on October 14, 2006.

¹² Modern features of transition economy development are given by the studies of [Spagat \(2006\)](#) and [Parente and Rios-Rull \(2005\)](#).

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CHAPTER 2

TECHNOLOGICAL ABSORPTIVE CAPACITY, THE DISTANCE TO FRONTIER AS RELATIVE BARRIERS TO TECHNOLOGY ADOPTION¹³

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Abstract

This paper generalizes the Nelson-Phelps catching-up model of technology diffusion by introducing a new specification of the distance to technology frontier as relative barriers to technology adoption. Higher costs of technology adoption constrain the catch-up process with the world technology frontier. Moreover, it gives scope for modelling the different patterns of productivity dynamics including with the threshold gap, endogenously determined by the economy's technological absorptive capacity. New properties of technology diffusion in terms of barriers to technology adoption are of help in evaluating a country's potential of long-run catch-up. The patterns of productivity dynamics find empirical support.

JEL classification: O15; O47; F43.

Keywords: Technological absorptive capacity; nonlinear productivity dynamics.

2.1 Introduction

The growth of an economy depends on the endowment of natural resources, physical and human capital accumulation, institutional quality, geographical factors and climatic conditions. However, countries with similar production factors and economic structure may often have different levels of productivity growth, and therefore, large differences¹⁴ in output per worker. This can be explained, as recognized by many economists (Easterley and Levine, 2001; Hall and Jones, 1999; Prescott, 1998), by technology diffusion that becomes a source of development and economic growth for many developing countries.

The main channels of advanced technology diffusion are trade openness and foreign direct investment. However, a high degree of economic integration in the world economy does not necessarily lead to the technology diffusion into the economy. It depends on a country's economic structure and its trade activities. The growth of imports, namely of technological equipment and intermediate goods rather means high diffusion of advanced technology into the economy. Despite natural resources, only export of products with a higher value added will certainly contribute to technological diffusion.

The literature has recognized the importance of human capital and technology catch-up in the process of technology diffusion. Following Nelson and Phelps (1966) the rate of technology diffusion depends on both educational attainments and the gap between applied technology level and technology frontier, such that education speeds the technology diffusion, and as a result, closes the technological gap. Engelbrecht (2002) identified a positive role of human capital in the absorption of international knowledge spillovers and, therefore, supported the Nelson-Phelps hypothesis for developing countries. Recently, Xu and Chiang (2005) have identified the different patterns for a sample of 48 countries for the period of 1980-2000 dividing into three income groups and found that rich countries enjoy from domestic technology and import of foreign capital goods, middle income countries

¹⁴ Differences in capital accumulation, productivity, and therefore per capita GDP growth rates across countries can be driven by differences in institutions and government policies, called by Hall and Jones (1999) social infrastructure; in the quality of institutions (Rodrick et al, 2002); in geographical proximities to the world technology frontier (Gallup, Sachs and Mellinger, 1999); in the extent of national barriers (Girma, Henry, Kneller and Milner, 2003); in the technology-skill mismatch when having equal access to new technologies (Acemoglu and Zilibotti, 2000); and in absorptive capacity (Kneller and Stevens, 2003).

take advantages from foreign patents and foreign technology embodied in imported capital goods and poor economies benefit mainly from foreign patents.

The paper contributes to the literature by newly specifying distance to technology frontier as relative barriers to technology adoption. Higher costs of technology adoption constrain the catch-up process with the world technology frontier. Barrier to technology adoption is introduced as proxy for technological absorptive capacity. It is assumed that the magnitude of barriers can be weakened through increased investment in education, liberalized foreign trade and the existence of relevant infrastructure. The literature provides convincing empirical evidence of trade openness and human capital accumulation that favours economic growth through higher rate of productivity growth.

There exist recent attempts of modelling productivity growth, combined with human capital and technology adoption (Papageorgiou, 2002; Stokke, 2004; Diao et al. (2005a, 2005b), Howitt and Mayer-Foulkes, 2005). However, the main patterns of productivity dynamics which were appropriately chosen from empirical evidence, lack the well-defined theoretical underpinning. In contrast to linear pattern of technology diffusion, which often predicts the catching-up hypothesis, logistic model of technology diffusion generates productivity dynamics of a complex nature and can be well suited for explaining the divergence of poor economies as well as for escaping from underdevelopment traps. The conditions of the existence of steady states and time path convergence are defined in terms of the growth rate of world technology frontier (given exogenously) and barriers to technology adoption. It also shows the conditions under which a threshold in distance to technology frontier can appear. As Findlay (1978) argued, a threshold value of the technological gap is often associated with the inability of backward countries to catch up frontier technologies and which stagnate due to divergence with advanced economies.

Technology absorption might be an efficient tactic for developing countries in place of creating new technologies at home which is accompanied with huge financial and time resources. Hence we need to strengthen the country's absorptive capacity. Many countries with higher level of absorptive capacity attained higher growth whilst economies with lower level of absorptive capacity experienced underdevelopment gaps with ineffective spending on R&D investment. Therefore, countries need a certain level of absorptive

capacity before they can benefit from technology diffusion. In the next sections, we will discuss how human capital contributes to economic growth by facilitating the absorption of new technologies.

The lack of appropriate incentives for production and investment can compromise the success of technological upgrading. This is well illustrated by the former USSR economies¹⁵ where the availability of large stock of suitably qualified workers does not in itself result in efficient absorption of foreign knowledge. Therefore, catching-up with the world technology frontier is subject to our analysis.

The paper is organized as follows. The section 2 presents the main discussions on absorptive capacity and the issues as related to the technological gap as well as empirical evidence of trade and education. The Nelson-Phelps formalization of absorptive capacity is generalized in the section 3 by introducing a new specification of the distance to technology frontier, and highlighting the properties of different patterns of productivity dynamics. We conclude by discussing the main findings and policy implications.

¹⁵ Which, as [Hall and Jones \(1999\)](#) noted, had “*extremely high capital intensity and relatively high human capital but a rather low productivity level*”.

2.2 Theoretical and Empirical Studies on Absorptive Capacity

On the basis of technology diffusion there is, following [Cohen and Levinthal \(1990\)](#), *a country's ability to absorb new knowledge, so in order to adapt it to local conditions in a successful way, and to create on their basis new own ideas and technologies*. First, the notion of absorptive capacity is applied to firms. Furthermore, there is a need to judge at the macro level, as a country's absorptive capacity does not represent a simple amount of absorptive capacities of divers firms. At the micro level, firms are able to maximize efforts to absorb new knowledge and create their own new technology, but they cannot obtain great advantage from technology diffusion. Only the state is able to bring into being all the necessary prerequisites of technology diffusion in the forms of good-functioning intuitions, innovation funds and infrastructure to stimulate innovative entrepreneurship, commercialize innovation projects and to hedge investment risks for attracting private funds in those economy sectors with higher returns.

Obviously, it is much easier for late-comers in terms of economic development and industrialization to assimilate already existing technologies in the leading countries. This is often referred to as *the catching-up hypothesis*, related to [Veblen \(1915\)](#) and [Gerschenkron \(1962\)](#), which links the gap between a technology level in a backward country and that of the “advanced” region. The catching up hypothesis assumes that the rate of productivity growth in a backward country would be higher than in advanced countries. To take “*backwardness advantage*” from the growth of the world technology frontier is also known as *hypothesis of relative backwardness*. There are many examples of countries, notably South-East Asian economies, which were behind the technological frontier but experienced episodes of rapid growth driven by rapid productivity catch-up. However, there are also other examples of countries which, while having a potential advantage of backwardness, did not overcome country-specific forces that have impeded catching-up with frontier technology. Therefore, advantage of backwardness as stressed by [Pritchett \(1997\)](#) may often be transformed into a disadvantage for poor economies as the technology gap continues to widen¹⁶.

¹⁶ Owing to backwardness advantage, one may think that technology adoption acts as a force for convergence, which is however, not universal ([Howitt and Mayer-Foulkes, 2005](#)).

Beyond the well-known increase in technological change due to technology diffusion, higher human capital investment today generates a more capable work force that can absorb a greater amount of technology diffusion in the future and thus, accelerates human capital accumulation. Under these circumstances, firms will be willing to pay higher wages to their workers to increase the quality of the manufacturing applicant pool, since there are more workers who have a comparative advantage in learning about new technologies.

It is known that human capital contributes to economic growth by facilitating the absorption of new technologies. Absorptive capacity¹⁷, as discussed by [Arrow \(1969\)](#), captures the idea that countries may differ in their effort and ability to adopt new technologies developed elsewhere. [Abramovitz \(1986\)](#) noted that “*countries that are technologically backward have a potentiality for generating growth more rapid than that of more advanced countries, provided their social capabilities and sufficiently developed to permit successful exploitation of technologies already employed by the technological leaders*”. Therefore, countries need a certain level of absorptive capacity before they can benefit from technologies developed elsewhere. Seemingly, [Cohen and Levinthal \(1990\)](#) defined more precisely absorptive capacity as a country’s ability to absorb new knowledge, so in order to adapt it to local conditions in a successful way, and to create on their basis new own ideas and technologies. [Diao et al. \(1999\)](#) argue that there will be more effects of technology adoption if there is a large share of trade partners with higher level of R&D. In this case, an increase in R&D investment in innovative country will certainly imply rising domestic R&D investment.

In a formal setting [Abramovitz \(1986\)](#) and [Cohen and Levinthal \(1989\)](#) model the adoption of technology as depending on the level of human capital, whereas [Verspagen \(1991\)](#) and [Fagerberg \(1994\)](#) argue that domestic innovation improves the capacity to absorb foreign country technology. Certainly, there is a positive effect of frontier technology on domestic productivity that will vary with physical distance if the knowledge generated in one country is not instantaneously and available without cost to all countries but relies on its transmission through channels such as trade and FDI. [Keller \(2001\)](#) models domestic productivity as a function of the stock of domestic R&D and nonlinear combination of foreign R&D and physical distance, and finds strong evidence that the potency of foreign

¹⁷ As a optimum investment, defined earlier by [Guillaumont \(1971\)](#).

technology on domestic productivity declines with the physical distance between countries. Using the sample of OECD countries [Kneller \(2005\)](#) modeled absorptive capacity as a combination of human capital and domestic R&D, and came to the conclusion that the effect of technology spillovers varies according to the level of absorptive capacity and the physical distance from the source of new ideas.

There are a growing number of articles which focus on considering the economic growth as the result of learning or absorptive capacity¹⁸ especially in technological change in a host country that depends on domestic technology and on how it is positioned as regard to world advanced technologies. As frontier technology grows continuously, technology diffusion become critical. The hypothesis of relative backwardness confirms that the more backward a country is, the more potential it holds to absorb advanced technology. In other words, a deeper technological gap implies a higher rate of catching-up with frontier technology. However, the hypothesis of relative backwardness is often controversial. For example, as mentioned by [Papageorgiou \(2002\)](#) and [Stokke \(2004\)](#), poor countries are not really integrated in the world economy, and therefore, not able to absorb advanced technologies. Moreover, recently [Acemoglu, Aghion and Zilibotti \(2002a, 2002b\)](#) suggested that protectionist trade policy would be beneficial for countries in terms of their economic performance which are further from the technology frontier¹⁹.

[Nelson and Phelps \(1966\)](#) stressed the importance of absorptive capacity in technological convergence by introducing first a technology adoption function as dependent on human capital. They have attempted to model the idea that education has a major role in increasing the individual's capacity to adapt existing advanced technologies and to innovate, i.e. to create new activities, new products, new own technologies. In the Nelson-Phelps approach the growth rate of output will depend on the rate of innovation and hence the level, rather than the growth rate, of human capital. Furthermore, [Benhabib and Spiegel \(1994\)](#) formalized the two sides of absorptive capacity by introducing in the technology adoption function an additional function to capture the country's ability to innovate as it moves

¹⁸ Comparing the growth performance of Latin America and Scandinavian economies [Maloney \(2002\)](#) came to the conclusion that deficient national learning capacity led to the worth out performance in Latin America countries which have suffered from resource curse.

¹⁹ They extend analysis to a number of other policy areas like promotion of vertical integration and indigenous R&D. The larger the distance to the frontier, the greater the returns from vertically integrated companies and from reliance on imported technology.

closer to the technology frontier. This function is often called *innovative capacity*. Based on cross-country regressions over the 1965-1985 periods, they argue that there is no significant correlation between productivity growth and human capital accumulation, where human capital is measured by school enrolment, whereas human capital stocks have positive effects on growth. This is consistent with the reference that emphasizes human capital accumulation as a source of growth but is controversial in that the rate of growth depends on the rate of human capital accumulation, not upon the stock of human capital. Papageorgiou (2002) showed the existence of multiple equilibria depending on a threshold level below which the technology adoption capacity falls with distance to the technology frontier. Recently, Stokke (2005) has extended the adoption function by including openness of foreign trade and pointed out the existence of an endogenous threshold level in the technological gap within an applied general equilibrium framework to Thailand.

Instead of human capital, Howitt and Mayer-Foulkes (2005) considered a country's stock of "effective skills" that can be applied in innovation process and which depends on its level of development, relative to the world technology frontier. Then, there exist two convergences to parallel growth paths that are characterized, respectively by R&D and implementation. R&D convergence clubs embody the most technologically advanced countries while implementation as a process of assimilation and adaptation takes place in less advanced countries. Therefore technology transfer is a powerful engine to bring about the convergence paths in R&D and implementation clubs. However, it is not powerful enough to avoid "*the erosion of absorptive capacity*" causing the divergence between the stagnation club and the convergence clubs.

The literature provides convincing empirical evidence that trade openness and human capital accumulation favour economic growth through higher rate of productivity growth. The relationship between trade openness and growth is widely discussed amongst economists, and particularly, Sachs and Warner (1995), Klenow and Rodriguez-Clare (1997), Edwards (1998) and Frankel and Romer (1999) all emphasize that high productivity growth is found to be associated with openness of foreign trade. The more open the foreign trade, the greater the economic growth.

On the other hand, there exists scepticism about this relationship both of theoretical and empirical grounds, as summarised by [Rodriguez and Rodrick \(2000\)](#). Following a data-sorting method of Hansen which allows the data to endogenously select regimes, [Papageorgiou \(2002\)](#) showed that openness, as measured by the ratio of trade volume of GDP, is a threshold variable that may not be crucial for low-income countries but it is useful in dividing middle-income countries into high and low-growth groups²⁰.

Technology diffusion can take place through several channels that involve the transmission of ideas and new knowledge on advanced technologies. Imports of high-technology products, adoption of foreign technology and acquisition of human capital through various means are certainly important conduits for technology diffusion. Besides these channels, FDI incorporated by international corporations is considered a major channel for the access to advanced technologies by developing countries. However, the effects of FDI on a host country's economic growth are not obvious. Yet, there is no empirically proven relationship between technology diffusion and FDI. It is commonly believed that international corporations contribute in an efficient way to disseminating new ideas and advanced technologies amongst developing countries. However, it depends crucially on the level of human capital available in the host country. As noted [Borensztein, Gregorio and Lee \(1998\)](#) for countries that have already exceeded a certain threshold in the stock of human capital, there is a positive effect of FDI on economic growth. This implies that FDI contributes to economic growth only when the host country attains a sufficient level of absorptive capacity to adopt advanced technologies.

Concerning the relationship between FDI and absorptive capacity [Cohen and Levinthal \(1989\)](#) argued that domestic firms need to possess a certain level of absorptive capacity before they can benefit from a multinational's stock of knowledge. By contrast, [Findlay \(1978\)](#) considered the rate of technology spillovers from FDI as an increasing function of the technology gap between the backward and advanced countries. In a recent paper [Girma \(2005\)](#) applying Hansen's threshold regression techniques to the data of UK manufacturing industry over the period 1989-99 showed that there appears to be a minimum absorptive capacity, defined as the distance of the firm from the technology frontier in its industry, below which productivity spillovers are non-existent or even negative.

²⁰ This is consistent with papers that view openness as a potential source of multiple equilibria.

Catching up with the technological frontier requires a country to attract FDI or collaborative ventures between local producers and frontier buyers and to hold sufficient private and public savings. Using the data from the Penn World Tables on 95 countries between 1960 and 2000, [Aghion and Howitt \(2005\)](#) found that there is low correlation between the savings rate and the growth rate of a country very far below the frontier. By contrast, the effect of savings on growth is highly significant for the middle group of countries when all countries are divided into 3 equal-sized groups depending on the distance to the frontier. This is a new way of looking at savings which can be explained by the implementation of frontier technologies in the middle income countries where savings are more important for growth.

Allowing for learning-by-doing in imports and exports, [Chuang \(1998\)](#) came to the conclusion that trade openness is a prerequisite but an insufficient condition to accelerate growth. The technologically advanced country with which one trades (one's trading partner) is a key factor in trade-induced technology diffusion. In this case, one's growth rate will be higher than one's trading partner. Therefore, the greater the trade with developed countries, the more likely a country is to grow faster. Trading goods with a larger extent of learning accelerates the trade-induced learning and hence enduring growth. Remarkably, the trade pattern in less developed countries shifts further toward exporting more skill-intensive goods with the highest technology level mainly to advanced countries.

More generally, one might think of a country's absorptive capacity in terms of human capital, innovative infrastructure, and the depth of the domestic financial market, the quality of governance, macroeconomic stability, and innovation-enhanced policies. As mentioned by [Aitken and Harrison \(1999\)](#) and [Bailliu \(2000\)](#) foreign capital flows do not seem to generate positive productivity spillovers to domestic firms for countries with a relatively low absorptive capacity, but positive spillovers are more likely to be detected for countries with a relatively high level of absorptive capacity. This evidence is consistent with the view that countries need to build up a certain amount of absorptive capacity in order to effectively take advantage of financial globalization. In addition, backward countries should eliminate, or at best diminish, country-specific barriers which raise the costs of technology adoption.

This is consistent with the early results of [Parente and Prescott \(1994\)](#) which confirm that countries absorb technology diffusion at the different degrees and speeds depending on persistent barriers. The further the distance to the technology frontier, the more investment is likely to be needed to surmount barriers in order to absorb advanced technology. Hence, the higher the amount of investment expenditure aimed at removing barriers sufficiently, the higher productivity growth will be.

[Basu and Weil \(1996\)](#) enriched the concept of technology by introducing *appropriate technology* as dependent on the structure of production factors and on a country's distance to the technology frontier. Essentially, how much sophisticated technology is absorbed depends not only on the distance to the technology frontier but also on the large share of highly educated and qualified workers. Furthermore, [Eicher \(1999\)](#) suggested a model of endogenous accumulation of skills and technology and found that technology diffusion in backward countries as endogenous absorptive capacity critically depends on the levels of human capital. In addition, technology diffusion generates not only greater rates of technological change, but also creates a bigger stimulus to increase the quality of human capital accumulation in order to absorb even greater fractions of advanced technology in the future.

[Milner and Upadhyay \(2000\)](#) used a linear interaction approach to determining the existence of threshold, and concluded that countries must reach a critical level of openness before of human capital contributes positively to the growth of total factor productivity. Below this level the contribution of human capital to TFP is negative. When they subsequently divided into lower, middle and high-income groups, they came to the conclusion that only low income countries are keen to "the threshold effect". Hence, it is assumed that more open countries have a greater capacity to absorb new ideas from the rest of the world.

Concerning the evidence related to education, we need first to separate the effects of primary, secondary and tertiary education on technology adoption and innovation. As [Pritchett \(1996\)](#) noted, higher education does not always lead to higher economic growth if it is not accompanied by a demand for educative services. This can be explained by several reasons. Firstly, primary education does not create cognitive skills which is necessary to the

catching-up process. Secondly, the marginal return to education falls if demand for qualified workforce decreases. Thirdly, lower wages for high qualification do not stimulate the absorption of new technologies. Fourthly, the insufficiency of technically educated engineers does not contribute to technology diffusion. [Krueger and Lindahl \(2001\)](#) stated that in backward countries education has a significant positive link with economic growth. However, the lack of relevant incentives often leads to a lower propensity in obtaining high education in such economies. Recently, [Vandenbussche, Aghion and Meghir \(2004\)](#) have provided an analysis of human capital effects on technological progress based on the data of 19 OECD countries, and found evidence of a lack of any positive links between primary and secondary education and economic growth in technologically advanced countries. This confirms again the conclusion that secondary education is needed for technology adoption while high education is a prerequisite to the innovation process.

The presentation of the distance to technology frontier (1.5) allows also for taking into account many other barriers to technology adoption. With high absorptive capacity a country has the opportunity to acquire technologies available in technologically advanced economies by importing capital from them, but is required to develop local educational and technological “infrastructure” to exploit these technologies. In this case, the incentives to acquire education, to invest in new technologies and implementation environment at home are interacted. It is known that the level of human capital and the tariff rates affect differently the growth rate of productivity. While the former has a positive impact on the profits from adopting new technologies, the latter affects it negatively. Devoting additional resources to infrastructure investment can payoff in terms of sizeable increases in GDP. However, more infrastructure investment may have no effects on welfare improvements²¹.

²¹ See, for example, [Rioja \(1999\)](#).

2.3 Measuring Technological Absorptive Capacity

Viewing human capital as “simply another factor in growth accounting” [Nelson-Phelps \(1966\)](#) are the first to have attempted at modelling absorptive capacity. The growth rate of the aggregate productivity level A_t is formalized as (t is time period):

$$\frac{\Delta A_t}{A_t} = \varphi(H) \frac{T - A_t}{A_t} \quad (1.1)$$

where T is the productivity level of the world frontier, $\varphi(.)$ is a linear increasing function for some $0 < \varphi \leq 1$ ²². The right-hand side represents the rate of technology diffusion from the world technology frontier. The linearity comes from the fact that the function measures the change in host country’s productivity as a difference between the world technology frontier and the current productivity or a technological gap. Hence, we can rewrite (1.1) in terms of distance to technology frontier $a_t = \frac{A_t}{T}$ as follows $\frac{\Delta A_t}{A} = \varphi(H) \cdot (a_t^{-1} - 1)$.

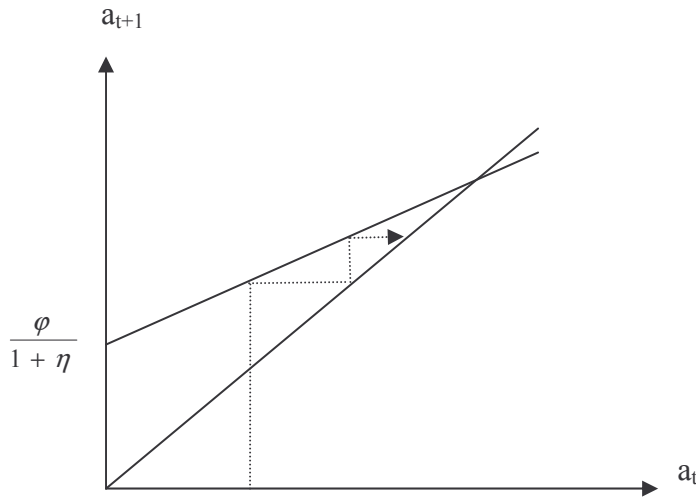


Figure 2.1 The Nelson-Phelps model of technology diffusion

²² $A_{t+1} > A_t$ implies that $\frac{T - A_{t+1}}{T - A_t} < 1$, then $\varphi = \frac{A_{t+1} - A_t}{T - A_t} = \frac{T - A_t - (T - A_{t+1})}{T - A_t} = 1 - \frac{T - A_{t+1}}{T - A_t} < 1$

Assume that technology frontier grows with a rate η or $T_{t+1}=T_t (1+\eta)$. As

$$\frac{\Delta A_t}{A_t} = \frac{A_{t+1}}{A_t} \frac{T_t(1+\eta)}{T_{t+1}} - 1 = \varphi(a_t^{-1} - 1) \text{ then we will see that } a_{t+1} = \frac{\varphi}{1+\eta} + \frac{1-\varphi}{1+\eta} \cdot a_t. \text{ In addition}$$

since $\frac{1-\varphi}{1+\eta} < 1$, there exists a unique solution at the intersection of two lines. We can see

from the specification in equation (1.1) that the rate at which the technological gap is closed depends on the level of human capital H . In the Nelson-Plepls version a higher stock of human capital facilitates the absorption and the adaptation to more advanced technologies and allows for “catching-up” frontier technology. Furthermore, we will interpret a_t as a “*technological absorptive capacity*” since the defined above absorptive capacity is assumed to be acting as closing a technological gap between backward country and the world technology frontier. Based on cross-country regressions over the 1965-1985 periods, [Benhabib and Spiegel \(1994\)](#)²³ showed that there is no significant correlation between productivity growth and human capital accumulation, where human capital measured by school enrolment, whereas human capital stocks have positive effects on growth. [Papageorgiou \(2002\)](#) proposed a model of productivity growth²⁴ which is determined by a combination of human capital and technology adoption. They assume that the quadratic relationship between the rate of technology adoption and productivity growth explains the absorption of advanced technology in a certain distance. Countries that are far from the technology frontier would be unable to take advantages of existing technologies and hence, grow faster. The policy implication is that unlike the neoclassical growth theory, only middle-income countries are considered to have a catching-up potential for rapid growth. Whereas poor countries will have to count on their own innovation which is in many cases nil or they will have to make huge investment to avoid a slow growth.

²³ [Benhabib-Spiegel \(1994\)](#) extended by introducing an additional function in the technology adoption of

Nelson-Plepls as $\frac{\Delta A_t}{A_t} = g(H) + \varphi(H) \frac{T - A_t}{A_t}$, where $g(\cdot)$ represents a country's ability to develop its own technological innovation.

²⁴ $\frac{\Delta A_t}{A_t} = \delta H + (1 - \delta) H \left[-\left(\frac{A_t}{T}\right)^2 + (1 + b)\left(\frac{A_t}{T}\right) - b \right]$, where $0 < b < 1$

The technology diffusion which is described by the equation (1.1) is also known as the *exponential* diffusion process. An alternative formulation that is similar in spirit of our discussion is the *logistic* model of technology diffusion²⁵ which is given by:

$$\frac{\Delta A_t}{A_t} = v(H) \cdot \frac{T - A}{T} \quad (1.2)$$

where $v(\cdot)$ is a nonlinear function. Similarly, we rewrite (1.2) in terms of distance to technology adoption as follows $\frac{\Delta A_t}{A} = v(H) \cdot (1 - a_t)$. The difference of the dynamics under a logistic model of technology diffusion is that $v(\cdot)$ acts to dampen the rate of technology diffusion as host country closes the distance to technology frontier likely reflecting the difficulty of adopting frontier technologies.

2.3.1 Properties of the logistic pattern of technology diffusion

As technology frontier grows with η and $\frac{\Delta A_t}{A_t} = \frac{A_{t+1}}{A_t} \frac{T_t(1+\eta)}{T_{t+1}} - 1 = v(1 - a_t)$ then we will get after simplifying so called *the law of motion*

$$a_{t+1} = \frac{v+1}{1+\eta} \cdot a_t \left(1 - \frac{v}{v+1} a_t \right) \quad (1.3)$$

The right-hand side of the equation (1.3) holds the following properties:

$$(P1) \quad F(a_t) = \begin{cases} 0, & \text{when } a_t = 0, \\ < 1, & \text{when } a_t = 1. \end{cases}$$

$$(P2) \quad F' = \frac{1}{1+\eta} [1 + v - 2va_t] > 0, \quad \text{for any } a_t < 1 \quad \text{and} \quad v > 1$$

(because $a_t < \frac{1}{2v}(1+v) < 1$)

$$(P3) \quad F'' = \frac{-2v^2}{1+\eta} < 0$$

²⁵ See Banhabib and Spiegel (2002).

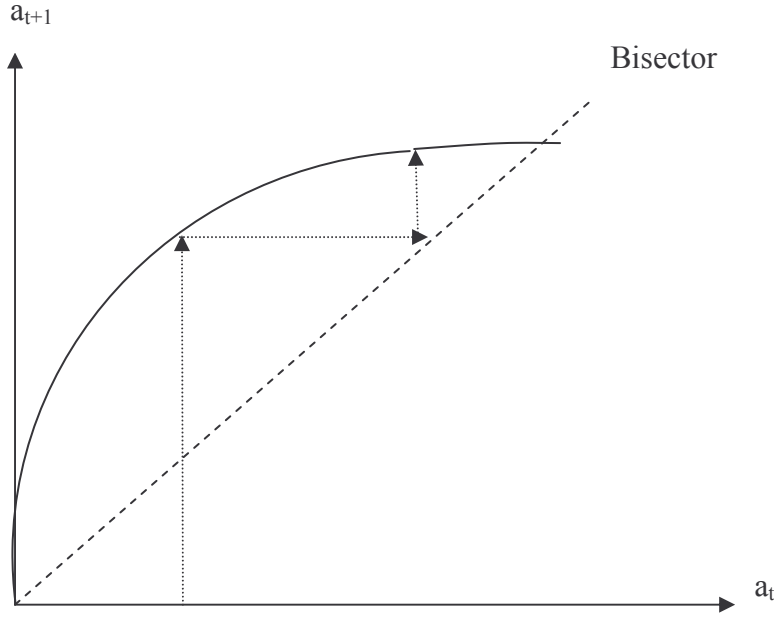


Figure 2.2 *The logistic model of technology diffusion*

(P4) $\eta < \frac{v-1}{2}$, if $a^{\max} < a^*$

(P5) *In the long-run the rate of productivity growth $g_t = \frac{a_{t+1}}{a_t}(1+\eta) - 1$ is equal to the growth rate of technology frontier, or $g^* = \eta^*$.*

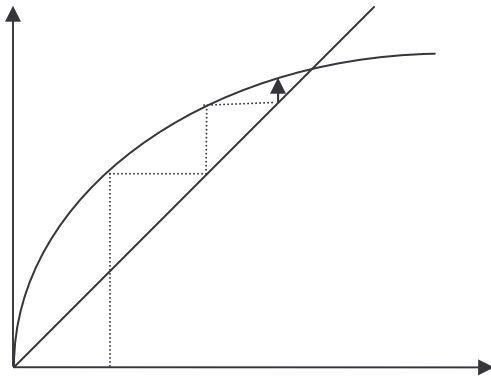
(P2) and (P3) mean that $F(\cdot)$ is an increasing concave function. The law of motion can reach its maximum level at $a^{\max} = \frac{1+v}{2v}$ and steady state at $a^* = 1 - \frac{\eta^*}{v}$.

It is known²⁶ that a first order nonlinear difference equation (1.3) can yield an extremely complex time path depending on its parameter $\mu = \frac{v+1}{1+\eta}$ and display eventually in the interval [3,4] sharp qualitative changes which will be looked as chaotic dynamics. Therefore, the main results of the convergence of productivity dynamics (1.3) to the long-run steady state are given in the following proposition.

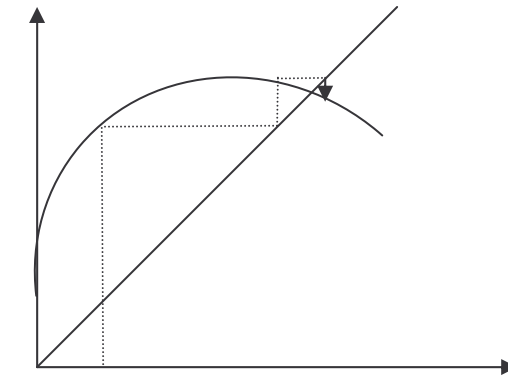
²⁶ See for example Baumol and Benhabib (1989).

Proposition 2.1 *In the long-run there exists the unique stable state of the law of motion. Namely, if $\eta < v \leq 1+2\eta$ productivity dynamics will converge (not cyclically) monotonically and when $1+2\eta < v \leq 2+3\eta$ by damped cycles to $a^* = 1 - \frac{\eta}{v}$.*

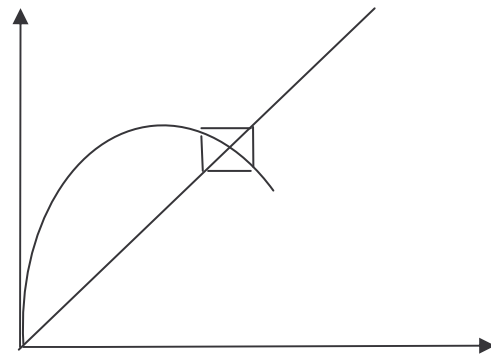
It is easy to show that if $\mu < 1$ the curve will be entirely below the 45° ray and it will not be an interesting case for our study. Otherwise, there will be an intersection point E (steady state) between the curve and the 45° ray. If $1 < \mu < 2$, the curve's slope at the intersection point will be positive, and the time path will converge monotonically to the steady state (Figure 2.3a). In case, when $2 < \mu < 3$ the slope will be negative but less than one in absolute value and the time path will converge cyclically in a damped manner to the steady state (Figure 2.3b).



(a) *Monotonic convergence*



(b) *Damped cycles*



(c) *Two period cycle equilibrium*

Figure 2.3 *Types of time path convergence*

When μ increases slightly above 3, there exists first 2-period cycle, then for higher value of μ , the two-period cycle will in turn give rise to a cycle of four-period length. Speaking very roughly, there exist stable 2^n -cycles to which the time path will converge²⁷ (Figure 2.3c). As the value of μ rises the time path will be subject to a sequence of period-doubling bifurcations, and then with that period tending to infinity as μ approaches a limit point μ' between 3 and 4. For other values of μ , belonged to $\mu' < 4$, the law of motion produces chaotic dynamics, and the time path will diverge²⁸.

The following proposition summarizes the findings of time path divergence in terms of the growth rate of technology frontier and the value of the logistic function of technology diffusion.

Proposition 2.2 *In the long-run for $2+3\eta < v \leq 3+4\eta$ there is no convergence to the unique stable state, and productivity dynamics will be attracted by equilibrium cycles or may diverge.*

These properties of the law of motion and the conditions under which the time path convergences (respectively divergences) are likely taking place, will be helpful further in evaluating possible catching-up with frontier technology and explaining the complex nature of productivity dynamics.

2.3.2 Barriers to technology adoption versus technological absorptive capacity

It has long recognized the role of barriers in technology adoption. For instance, the development miracle of South Korea is often explained by the result of impressive reduction of barriers to technology adoption (Parente and Prescott, 1994). The size of barriers differs and accounts for huge income disparities amongst countries. Acemoglu, Aghion and Zilibotti (2002) have already analyzed separately economies depending upon their proximity to the technology frontier by distinguishing them as ‘low-barrier’ and ‘high-

²⁷ Strongly, if there is a a_t such that when it rises for two successive periods $a_{t+1} = F(a_t) > a_t$ and $a_{t+2} = F(a_{t+1}) > a_t$, and but it falls back to below its initial value in the next period, that is $a_{t+3} = F(a_{t+2}) \leq a_t$, then for any integer $k > 1$ there exists a k -period cycle of time path (Theorem of Li and Yorke). See Baumol and Benhabib (1989).

²⁸ The existence of cycle-period lengths and its order were first proven by Sarkovskii (1964).

barrier'. We will use the notion of barriers to technology adoption in modelling technological absorptive capacity of backward countries. Thus, closing technological gaps would be interpreted as gains of absorptive capacity over whole barriers of domestic economy. Country-specific barriers can be classified, for example as internal and external. Domestic barriers are often linked to the restrictions of competition like entry barriers, inefficient financial systems, a shortage of relevant infrastructure and subsidized state-owned enterprises that restrain productivity growth. Monopolistic activities of incumbent enterprises, which often limit competition, the lack of English language skills by locals and others may be considered as internal barriers. An alternative understanding of domestic barriers can be related to human capital or its absorptive capacity. The geographical location, including a lack of access to the sea, and the openness of foreign trade constitute external barriers. In common, domestic and international barriers determine an economy's ability to take advantage from advanced foreign technologies. The larger these aggregate barriers, the greater the investments are needed to overcome them.

The process of technological catching-up according to [Boucekkine and Martinez \(2003\)](#) can be associated with the high expenditure of absorbing new technologies. Certainly, the higher the magnitude of barriers the more investment is needed to adapt advanced technologies to local conditions. Foreign expertise is often required in absorbing new technologies and this can constitute the main spending of the budget. Study of local students at foreign universities, particularly in technical specialties, may serve as an alternative to attracting foreigners.

Barriers to technology adoption can take different forms such as related to human capital in the Nelson-Phelps sense or regulatory, legal and other constraints as [Parente and Prescott \(1994\)](#) discussed. There exist many barriers to technology adoption as technology transfer requires high skill-intensity. [Niosi, Hanel and Fiset \(1995\)](#) carried out an empirical research on the nature of technology transfer costs, and defined the factors of the unsuccessfulness of technology transfer are a lack of appropriate experience and a weak level of human capital accumulation. High costs will be associated with the adaptation to local conditions of technology by foreign expertise. [Parente and Prescott \(1994\)](#) proved that the disparities in terms of technology adaptation costs explain the differences in income amongst different countries. First, there exist costs, linked to the apprenticeship of advanced technology and

its diffusion within host country. Additional high costs often can be occurred when imported expertise²⁹ is needed notably at the apprenticeship period. The second-type barriers are related to the implementation of appropriate trade and education-enhanced policies, and take into account innovation infrastructure costs. For example, any restrictions for foreign firms of getting the ownership can be served also an example of barrier in host country.

Benhabib and Spiegel (2002) presented the generalization of Nelson-Phelps catch-up model of technology diffusion to allow for exhibiting positive catch-up with technology frontier. When logistic diffusion was used it allowed for explaining slower TFP growth in 22 countries than in the United States over the 35 years. Finally, they argue that the logistic specification has been more suited than the exponential one in the empirical studies.

Harding and Rattso (2005) suggested explicitly a barrier model of productivity growth, based on the exponential diffusion process. Namely, they express the aggregate productivity from (1.1) as dependent on *barrier function* $\varphi(B_t)$ as follows $A_t = \frac{\varphi(B_t)}{g + \varphi(B_t)} T$

As barrier acts inversely to technological absorptive capacity in the Nelson-Phelps pattern³⁰, it is assumed that the derivative of barrier function is negative. Barriers function as constraining catching-up process with world frontier technology. Therefore, we assume that higher barriers imply lower technological absorptive capacity and inversely, higher technological absorptive capacity is associated with lower barriers. However, in contrast to Harding and Rattso (2005) approach, we specify a barrier function based on the logistic pattern of technology diffusion, and then the aggregate productivity will be given as:

$$A_t = \frac{v(B_t) - g}{v(B_t)} T \quad (1.4)$$

²⁹ The interaction between country's absorptive capacity and imported expertise cost is analyzed by Markusen and Rutherford (2004).

³⁰ In fact, $\varphi(H)$ is to be written as $\varphi\left(\frac{1}{B}\right)$, however, for the simplicity we will use $\varphi(B)$.

where g is the long-term value of the growth rate of aggregate productivity. Moreover, we infer that barrier in (1.4) only refers to education, and hence we will name *education-related barrier*.

In fact, there exist many other barriers of a complex nature that constrain catching-up process with technology frontier due to higher costs of technology adoption³¹. Therefore, we introduce *barrier abundance* $\lambda(\cdot)$ that reflects a barrier's magnitude in general. Then, the distance to technology frontier can be also expressed as a ratio of the education-related barrier to barrier abundance:

$$a_t = \frac{\varphi(B)}{\lambda(B)} \text{ or } a_t = \frac{v(B)}{\lambda(B)} \quad (1.5)$$

The intuitive setting of (1.5) is that the closeness of the technological gap depends directly on the gain by higher technological absorptive capacity over the whole barriers. Thus, higher absorptive capacity lowers the magnitude of barriers which, in turn, closes technology gap with world frontier. The following schema is rather valid.

$$B \downarrow \Rightarrow \begin{cases} v(B^H) \uparrow \Rightarrow a \uparrow \\ \lambda(B) \downarrow \Rightarrow a \uparrow \end{cases}$$

Deriving from (1.5) the gap with technology frontier closes provided that technological absorptive capacity will increase and the abundance of barriers will be weakened. Therefore, education-related barriers become important to decrease the distance to technology frontier. Seemingly, the distance to technology frontier as expressed by a relative barrier function is consistent with the accumulation of human capital, derived from good education and appropriate training of labour force. It refers to the findings of [Parente and Prescott \(1994\)](#) that productivity differences are due to the different barriers to technology adoption. An empirical study of trade policy in South Africa, provided by [Harding and Rattso \(2005\)](#), shows that the reduction of trade tariffs (barrier) can explain about 1/3 of the growth productivity in 1970-2003. The further the technology distance to

³¹ [Boucekkine and Martinez \(2003\)](#) provided a model prediction of the lowest convergence speeds of countries supporting the highest adoption costs, to the steady state.

technology frontier, there is more to gain from reduced tariffs or barriers to technology adoption.

Interestingly, the specification of the distance to technology frontier (1.5) allows also for taking into account many other barriers to technology adoption. With high absorptive capacity a country has the opportunity to acquire technologies available in technologically advanced economies by importing capital from them, but is required to develop local educational and technological “infrastructure” to exploit these technologies. In this case, the incentives to acquire education, to invest in new technologies and implementation environment at home are interacted. Obviously, the level of human capital and tariff rates affect differently the growth rate of productivity. While the former has a positive impact on the profits from adopting new technologies, the latter affects it negatively. Devoting additional resources to infrastructure investment can payoff in terms of sizeable increases in GDP. However, more infrastructure investment may have no effects on welfare improvements³².

³² See, for example, [Rioja \(1999\)](#).

2.4 Modelling Productivity Dynamics

It is noteworthy to emphasize that if we substitute φ in (1.1) by $a_t \lambda(B)$ and keep in mind that the growth rate of productivity is equal to $\frac{a_{t+1}}{a_t}(1+\eta)-1$, then we will get a specification, similar to (1.3) $a_{t+1} = \frac{\lambda+1}{1+\eta} a_t \left(1 - \frac{\lambda}{\lambda+1} a_t\right)$. Certainly, all properties of the law of motion (P1)-(P4) are held. It gives scope to the linear pattern of technology diffusion (1.1) for depicting complex trajectory. With similar technique [Howitt and Mayer-Foulkes \(2005\)](#) cluster some laggard countries into R&D and implementation convergence clubs while others are considered as stagnated. Analogically, if we substitute v in (1.2) by $a_t \lambda(B)$ we will have:

$$a_{t+1} = \frac{\lambda}{1+\eta} \cdot a_t \left(\frac{1}{\lambda} + a_t - a_t^2 \right) \quad (1.6)$$

which depicts a totally different time path from that of the law of motion (1.3). It is easy to show that the curve will lie entirely below the 45° ray if and only if the discriminant of the quadratic form $a = \frac{\lambda^*}{1+\eta} a \left(\frac{1}{\lambda^*} + a - a^2 \right)$ is negative, where λ^* – at the steady state. Otherwise, the curve will intersect the ray 45° in two points. Therefore, the following proposition states the steady-states in terms of the growth rate of technology frontier and barrier abundance.

Proposition 2.3 *There exist two locally steady-states of the productivity dynamics (1.6) if and only if $\lambda^* > 4\eta$.*

The second derivative confirms that the right-hand side of (1.6) has a turning point $a_t = \frac{1}{3}$,

and is convex in $[0; \frac{1}{3}]$ and concave in $[\frac{1}{3}; \frac{1 + \sqrt{1 - 4\frac{\eta}{\lambda^*}}}{2}]$. Therefore, dynamics described below by (1.6) holds a threshold level.

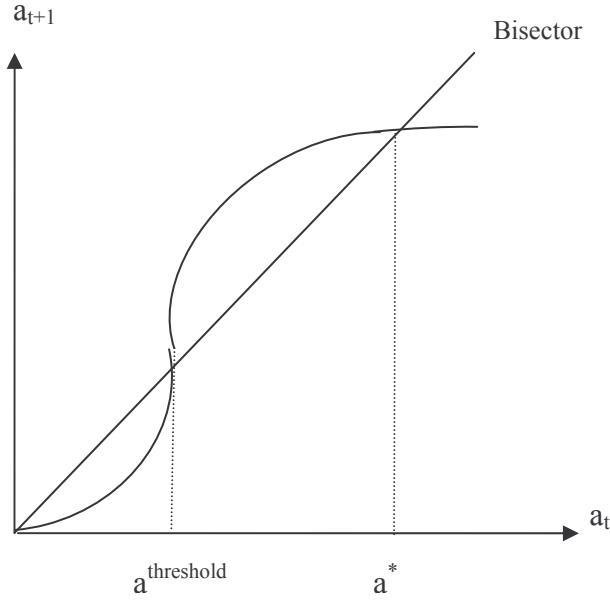


Figure 2.4 *The productivity dynamics under logistic barrier function*

Certainly, the convergence to the first steady-state occurs rapidly as country is far from the technology frontier. Further to the technology frontier, there is more room for copying and adopting well-existing abroad technologies. However, productivity growth-enhancing can later reduce growth and cause non-convergence trap. Thus, previous policies that initially increased growth and then led to slower growth fail to converge to the world technology frontier (Figure 2.4).

The policy implication of the properties in (1.6) is the existence of a threshold level in productivity dynamics which is stated by the following.

Proposition 2.4 *There exists a threshold in the productivity dynamics (1.6) at*

$$a^{threshold} = \frac{1 - \sqrt{1 - 4\frac{\eta}{\lambda^*}}}{2}.$$

It implies that countries at the same technological level may face different thresholds depending on country-specific barriers affecting their technological absorptive capacity. More backward countries will converge only to $a^{threshold}$. Despite that initially productivity growth will be higher in accordance with the hypothesis of [Gerschenkron \(1962\)](#) the potential of catching-up will be depleted. Hence, only new policies that envisage the importance of innovation relative to imitation as a source of productivity growth can

overcome the trap and encourage economy to converge to the higher equilibrium. The next proposition establishes the necessary and sufficient conditions of catching-up with the world technology frontier and the convergence to the steady state³³.

Proposition 2.5 *Productivity dynamics will converge to $a^* = \frac{1 + \sqrt{1 - 4\frac{\eta}{\lambda^*}}}{2}$ if and only if the distance to technology frontier exceeds $a^{threshold}$.*

The new approach to catching-up with technology frontier reinforces the role of human capital. Thus, a rapid increase in educational attainments speeds technology diffusion and becomes crucial for backward economies. Technology gap can be considered as a trade-off between absorptive capacity and abundant barriers to technology adoption. The greater the absorptive capacity and the lower the barriers to technology adoption the smaller the technology gap with technology frontier. However, an economy that has a potential for technology adoption may get stuck in a trap due to inappropriateness of absorbing technologies. Despite that backward economies possess high potential of productivity growth, but as long as they close technology gap, barriers make further convergence more difficult. In other words, the magnitude of barriers can be different depending upon the closeness to technology frontier.

Economies can escape from the trap by using new policies that enhance productivity growth and reduce barriers to technology adoption and innovation. Trade liberalization and investment in human capital can affect the gap for catching-up and might get economy growing.

2.4.1 The abundance of barriers to technology adoption

The new approach to barriers to technology adoption implies that the abundance of barriers can be expressed by introducing the main constraints such as education-related barrier and barriers notably, linked to foreign trade and others. Following the specification of barriers, given by [Parente and Prescott \(1999\)](#) we have as:

³³ The speed of convergence to the steady states depends on how the values the first derivative of the right-hand side of (1.6) varies in the interval of [1;4].

$$\lambda(B) = b \cdot \prod_{j=1} Barrier_j^{\gamma_j} \quad (1.7)$$

where $b > 0$ is a constant parameter, *Barrier* is the main barriers to technology adoption. The share parameter of each barrier is positive and no superior one. As earlier discussed there are many types of barriers that can be classified and ranged depending upon their importance and the magnitude of persistence in technology adoption. Certainly, the evaluation of each barrier depends upon the availability of relevant statistical data. Therefore, the number of barriers, included in technology adoption is restricted by the main channels of technology diffusion.

The persistence of barriers to technology adoption depends not only on their magnitudes, but also their elasticities. The determination of share parameter of each barrier can be defined by values of the main variables such as technology gap and technical progress at the steady states. It is known that technology gap at the steady states becomes constant (a_{SS}) or the growth rate of technology gap is zero. Thus, it implies that technical progress will be growing with the growth rate of technology frontier³⁴. Thus, we calibrate the parameters γ_j from (1.7) in the following form³⁵:

$$\log Trade_t = c_0 - \sum_{j=1} c_j \cdot \log Barrier_{tj} \quad (1.8)$$

where $c_0 = \frac{b}{\gamma_{trade}}$ and $c_j = \frac{\gamma_j}{\gamma_{trade}}$. For the simplicity we put that $\gamma_{trade} = 1$. Above all, we will focus on the combined role of international and domestic barriers, measured by foreign trade and human capital, respectively. The interaction with the rest of economy through foreign trade serves as a channel of the transfer of foreign technology. The level of human capital affects the ability to use effectively advanced technologies. Trade liberalization and investment in human capital can lower aggregate barriers, and as a consequence, decrease

³⁴ In details, the discussion will be provided in the Chapter 4.

³⁵ It derives from $TRADE_t^{\gamma_{trade}} = \frac{\eta}{b \cdot (a_{SS} - a_{SS}^2)} \cdot \prod_{j=1} Barrier_{tj}^{-\gamma_j}$

the technology gap with the world frontier. Thus, the abundance of barriers can look as follows³⁶:

$$\lambda(B) = b \cdot (1 - u)^{\gamma_1} \cdot Trade^{\gamma_2} \quad (1.9)$$

γ_1 and γ_2 are the share parameters of barriers or the elasticities with respect to education and trade. $(1-u)$ represents the share of human capital as in Lucas (1988) and *trade* is the share of foreign trade in GDP³⁷. A constant share of labour force at every time is defined as the number of pupils in secondary education in the group of people 15-65 years old. The elasticity of technical progress with respect to education share means that one percent increase in the share of total work force, engaged in secondary education, aiming at acquiring skills generates γ_1 percent increase in productivity growth.

Therefore, persistent effects of barriers to technology adoption can be removed as a result of increased investment in education and liberalized foreign trade. Certainly, more open economy grows faster relative to countries with less open foreign trade. More educated workforce may have presumably higher skills, and is able to absorb and adapt more frontier technologies than less educated labour that lack appropriate skills to take advantage from technology diffusion. However, as it refers to transition economies, where educational endowments are already at higher level, education-related barrier in (1.9) can not detect the efficiency of human capital stock. Therefore, a relevant measure of human capital endowments aimed at re-establishing the relationship with productivity growth, remains of current importance for transition economies. Kejak et al. (2004) analyze the accession potential of CEE countries by introducing knowledge capital in the endogenous growth model. Ragnitz (2007) explains a low productivity in Eastern Germany by deficits in the stock of human capital in spite of higher educational attainments of labour force.

There are several approaches to human capital accumulation. An issue may be dealt with the transfer of technology, associated with the import of advanced knowledge by acquiring higher skills through opportunities abroad. A massive transfer of knowledge can be flowed in host economy through renewing the domestic stock of capital, foreign trade and

³⁶ Other barriers are assumed to be equal to one.

³⁷ With infrastructure-related barrier (7) can be like $\lambda(B) = b \cdot (1 - u)^{\gamma_1} \cdot Trade^{\gamma_2} \cdot Infrastructure^{\gamma_3}$

migratory flows. Rogers (2004) suggested the number of students abroad as a new proxy of absorptive capacity and come to the conclusion that countries with relatively high numbers of students studying science and engineering abroad experience faster subsequent productivity growth. Countries with low income cannot often finance a large number of students to study in advanced countries because of the relatively high cost of education there. Therefore, particularly for transition economies there exists a strategy for subsidizing students for foreign study in developed countries, especially, those who study in technology-oriented fields, which may contribute to fostering economic development.

2.5 Conclusion

This paper has explored a new specification of the distance to technology frontier as relative barriers to technology adoption in the Nelson-Phelps formalization of the catch-up model of technology diffusion. The main argument is that higher costs of technology adoption constrain the catch-up process with the world technology frontier. It is assumed that the magnitude of barriers can be weakened through increased investment in education and liberalized foreign trade. The consistent setting of a new barrier function is that the closeness of the technological gap depends directly on the gain by higher technological absorptive capacity over the whole barriers.

The properties of the logistic pattern of technology diffusion reveal that there exists a time path convergence (respectively divergence) to the locally steady states. A complex nature of productivity dynamics can be depicted by the logistic model with an endogenous threshold in barriers to technology adoption. Therefore, only middle income economies with a sufficient level of technological absorptive capacity may overcome the trap and, consequently converge to the world technology frontier. By contrast, poor countries due to their inability to decrease the magnitude of the main barriers often get into productivity traps.

In recent attempts of modelling productivity growth, combined with human capital and technology adoption, the main patterns of productivity dynamics were properly chosen from empirical evidence, but a well-defined theoretical underpinning still lacks ([Diao et al., 2005](#)). The present generalization of the catch-up process fills this gap and confirms the appropriateness of the empirical findings of productivity dynamics.

Therefore, the policy implications consist in evaluating the main barriers to technology adoption and hence, improving a country's technological absorptive capacity through targeted investment in educational system and opening foreign trade in order to take great advantages from technology diffusion. A computable general equilibrium model as a normative setting will be provided later to analyze the interaction between technology adoption and productivity growth.

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CHAPTER 3

OPTIMIZING THE COMPOSITION OF SECONDARY EDUCATIONAL STOCK³⁸

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Abstract

East Asia's impressive economic performance has shown that there is a strong link between a relative increase in vocational education and the size of secondary education. Nevertheless, the inefficiency of human capital stock can not be detected by the levels of educational attainments, for example, due to the comparative high educational endowments in transition economies. Recent literature presents empirical evidence that the ratio of vocational to general education tends to be higher in middle income countries. Thus, it substantially strengthens that secondary education is important in technology adoption and thereby, seemingly allows for applying the modern growth theory in transition economy. This also opens up some insights by exploring the main differences stemming from raising productivity and increasing the size of secondary education, and the directions in which they work altogether.

JEL classification: I2; J24; O4.

Keywords: Transition; Human capital stock; Secondary education.

“Getting the VET (vocational education and training) system right is critical – a labour force without the right skills will not succeed against tough global competition”

Angel Gurría, OECD Secretary-General, Opening remarks to the Informal Meeting of OECD Education Ministers on Vocational Education and Training, Copenhagen, January 22, 2007

3.1 Introduction

Countries with similar production factors and particularly the same size of secondary education may have different levels of productivity growth, and therefore large differences in output per worker (Hall and Jones, 1999). The new growth theory (Nelson and Phelps, 1966; Lucas, 1988; Romer, 1990) and empirical research (Benhabib and Spiegel, 1994; Pritchett, 1996) present evidence that productivity growth can be explained by the level of human capital stock which depends on educational attainments. However, the inefficiency of human capital stock can not detected by the standards measures of human capital stock such as the average years of education³⁹ and the enrolment rates due to the comparative high educational endowments in transition economies. Empirically, the contribution of labour inputs in Central and Eastern European (CEE) countries is found as weaker, in most cases negative in comparison with East Asian economies (Crafts and Kaiser, 2004). Therefore, a relevant measure of human capital endowments aimed at re-establishing the relationship with productivity growth, is of current importance for transition economies (Kejak et al., 2004; Ragnitz, 2007).

Unlike the average years of education which mask essential differences in human capital stock, the enrolment rates distinguish the levels of educational attainments. Empirical evidence shows the importance of secondary education for technology adoption (Kalaitzidakis et al., 2001; Petrakis and Stamatakis, 2002). Generally, a better measure is to determine human capital stock as related to the kinds of employment. For example, industrial technology adoption requires specific skills which can be obtained mostly through vocational education and training. Therefore, the changes in the structure of secondary education, namely an increase in the ratio of vocational (V) to general (G) education contribute to productivity growth in middle income countries (Bennett, 1967; Bertocchi and Spagat, 1998).

³⁹ Mulligan and Sala-I-Martin (2000) conclude that using the average years of schooling may be misleading in empirical studies.

The transition from a command to market-oriented economy induced rapid and deeper changes in production structure and considerable reallocation of labour across sectors. The sudden access to international know-how has deteriorated formerly gained production skills. Nevertheless, technology adoption brings about an increased demand for newly trained workforce. Transition economies differ from each other depending on how successfully they are furthered on the transition way. For example, due to high educational stock the CEE economies converge toward the EU whilst the former Soviet Union countries are still laggard in economic progress by losing past educational achievements. Hence, targeted investments in educational systems are likely needed for effectively converting accumulated knowledge into more useful ways.

Statistically, vocational (*V*) and general (*G*) education is more distinguished at the enrolments rates than at educational attainments. As a result, the rate of VG enrolments is often used in place of the ratio of VG education (Bennett, 1967; Bertocchi and Spagat, 2004). However, as we show, the ratio of vocational over general enrolments is a better proxy only when the ratio of vocational to general education increases, e.g. for developing countries. It is also shown that policies aimed at increasing the size of secondary education and the ratio of vocational to general education can not act in the same directions except for developing economies which allows for optimizing the composition of secondary educational stock.

The paper consists in two sections. The first section discusses theoretical and empirical studies on VG education. The evolution of VG education is illustrated in an intuitive setting for the different types of economies. A deep insight of the mechanisms which may ensure a rise of the average years of schooling in countries where educational attainments initially were at a lower level, but where VET became an important strategy for economic development (Collins, Bosworth and Rodrik, 1996) is given by a model in the first chapter. The second chapter provides modelling VG education dynamics which distinguishes policies on maximizing the size of attained secondary education and the ratio of VG education. Policy implications consist in suggestions on optimizing the composition of secondary educational stock.

3.2 Theoretical and Empirical Studies on VG Education

The structure of human capital stock varies depending on the types of skills, consistent with the demand of local labour markets, which as [Ramcharan \(2004\)](#) argues, differently influence economic growth. The composition of educational stock is consisted by the different levels of education. Primary education which covers at least 6 years from age 7 remains compulsory in most developing countries. Secondary education, on the other hand, is not always compulsory, is divided in two levels. Lower secondary education aims to get literacy and numerical skills while at the upper level students choose between two streams of education; namely general education (curricula) or vocational education.

Instead of primary education, there exists a divide into the types of skills, shaped by the attained levels of secondary and higher education. Individuals with vocational education acquiring specific knowledge and skills influence productivity growth. On the contrary, general education gives to individuals an opportunity to reveal their innate abilities provided they are taught by a wider spectrum of various knowledge and skills which, in turn, contributes to higher mobility of workforce and following further higher education ([Iwahashi, 2007](#)).

By the average years of education transition economies are often similar to developed countries. However, by the enrolment rates they should differ as the main mismatch lies between imitation and innovation. Transition economies like middle income developing countries face toward technology adoption whilst an essential occupation in developed economies is rather innovation process. Hence, the contribution of human capital to technological improvements in diverse economies is different. Hence, following [Aghion and Howitt \(2006\)](#) we assume that higher education is most important for developed economies while secondary education is most relevant for transition countries. High secondary educational endowments in transition economy reveal that secondary education is a necessary, but not sufficient condition for technology adoption. Hence, a relative increase in vocational labour with technical skills should become a priority of technological development.

Analyzing the reason of growth retarding in the middle of 1980 [Krueger and Kumar \(2004\)](#) came to the conclusion that the west-European countries within 1960-1970 have strengthened excessively vocational education and training compared to general secondary education. Now, to reduce the US-Europe growth gap, the authors suggest that a greater focus should be done on general education which favours essentially higher education.

There exists empirical evidence of the interrelations of VG education and enrolments in East Asian economies. Rapidly growing economies where the main emphasis was given to technology adoption show that the average years of education increased considerably and attained a maximum level of 7.2 years for the 1960-94 periods while in other regions the rise was modest. Even some of them, for example South Korea and Taiwan, came close to the level of industrial economies by the end of the period. Almost of the East Asia countries, as [Collins, Bosworth and Rodrik \(1996\)](#) point out, have experienced a surprised increase in educational attainments (table 3.1).

Table 3.1 *Educational attainments in East Asia*

	Average years of schooling		Growth rate, %
	1960	1994	
China	1.7	5.3	312
East Asia	2.7	7.2	267
Indonesia	1.1	5.0	455
South Korea	3.2	9.7	303
Malaysia	2.3	7.0	304
Philippines	3.8	7.4	195
Singapore	3.0	6.1	203
Thailand	3.5	7.5	214
Taiwan	3.2	8.2	256
South Asia	1.3	3.4	262
Africa	1.6	3.5	219
Middle East	1.4	4.9	350
Latin America	3.0	5.5	183
Industrial countries	7.3	9.8	134

Source: [Collins, Bosworth and Rodrik \(1996\)](#), p. 149.

Technological development of East Asia was accompanied by the dramatic changes in the structure of educational attainments in labour force. Analyzing of Labour Force Survey data for 1979-1998 and 1989-1995 [Vere \(2005\)](#) and [Moenjak and Worswick \(2003\)](#) conclude that the size of secondary education has increased with raising the ratio of

vocational to general education in Taiwan and Thailand correspondingly. For the period of 1979-1998 the growth rate of vocational education, defined as a sum of senior vocational education and vocational/technical college, is composed 240 percent (table 3.2). At the same time, labour force with general education which consists of lower and upper secondary education, increased by only 115 percent. As a result, the ratio of vocational to general education reached from 0.67 to 1.4 or augmented by 240 percent.

Table 3.2 *Educational Composition of Taiwan's Labour Force (%)*

	Percent total by year					Growth rate 1979-98
	1979	1984	1989	1994	1998	
Illiterate	7.97	6.09	4.11	2.59	2.11	26
Self-educated	3.07	2.36	1.75	1.02	0.49	16
Primary	42.96	36.14	30.43	24.55	18.86	44
Lower secondary (LS)	17.96	19.28	19.80	20.68	19.05	106
Upper secondary (US)	6.58	7.24	8.11	8.90	9.27	141
Senior vocational (SV)	11.69	16.78	20.76	23.53	25.61	219
Vocational/technical college (VT)	4.84	6.42	8.33	10.94	13.98	289
University and higher	4.92	5.70	6.71	7.80	10.64	216
Memo:						
<i>General education (LS+US)</i>	24.54	26.52	27.91	29.58	28.32	115
<i>Vocational education (SV+VT)</i>	16.53	23.20	29.09	34.47	39.59	240
<i>The ratio of VG education</i>	0.67	0.87	1.04	1.17	1.40	208

Source: Vere (2006), p. 718 and the author's calculation

The structure of the demand for labour with vocational and general education varies depending on the level of country's economic development. Empirically analyzing the data on secondary enrolments of UNESCO for 70 countries Bennett (1967) hypothesized that equally rich and poor countries are at a lower level and by contrast, developing countries remain at a higher level of the ratio of vocational to general education. In other words, there exists a U-inverted curvilinear between the GDP per capita and the ratio of vocational to general education. Furthermore, Bertocchi and Spagat (2004) confirm the hypothesis of Bennett for 149 countries with data of 1950-1991 and moreover, construct a model showing that at early stages of economic development vocational education tends to expand and at later stages, inversely, general education tends to widen.

In the process of industrialization the size of secondary education and a relative proportion of vocational education will certainly grow. Following Bennett (1967) economic growth is

accompanied also by a rise of working population with secondary education due to a simultaneous increase of general and vocational education in developing countries. On the contrary, developed countries need more highly skilled workers with general or academic education. Furthermore, analyzing the data on the rates of secondary enrolments in the west-European countries for 1950-1975, [Benavot \(1983\)](#) found out a decrease in the relative share of the rates of vocational enrolments almost in all countries.

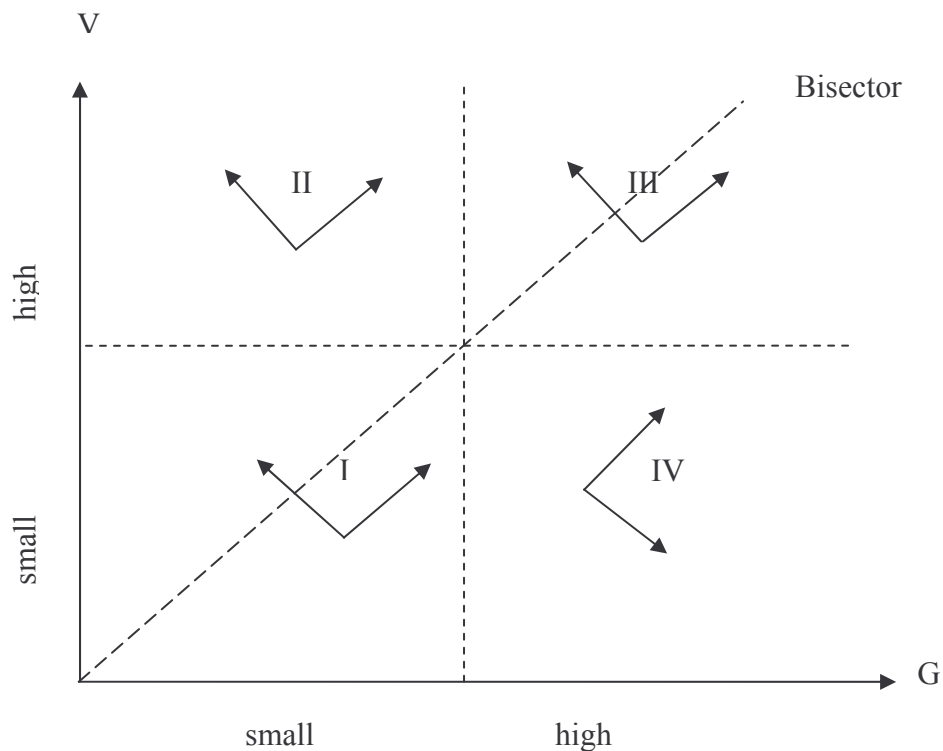


Figure 3.1 *The evolution of VG education in the different types of economies*

Now, the above statement can be depicted by distinguishing the four quadrants (figure 3.1). The first quadrant (I) which corresponds to small both vocational and general education is referred to least-developed while the second quadrant (II) with small general but high vocational education is rather linked to developing economies. The fourth quadrant (IV) which is situated in the cross of small vocational but high general education describe developed countries, while transition economies tend to be placed in the area (III) with higher both vocational and general education. Thus, following [Bennett \(1967\)](#) the directions of the evolution in the ratio of vocational to general education for least-developed, developing and transition economies will be intuitively the same and oriented from bottom to top in contrast to developed countries.

In the formal setting an economy evaluates from a lower level of vocational and general education to its higher level depending on how successfully going through the industrialization process and hence, attaining economic development. Thus, the higher the level of economic development the greater the per capita rate of general and vocational education. However, one can not able to analyse the composition of secondary educational stock as there are difficulties with data on working population with vocational and general education. Therefore, the rate of vocational to general enrolments is often used in place of the ratio of vocational to general education (Bennett, 1967; Bertocchi and Spagat, 2004). Indeed, the composition of secondary educational stock can not be unambiguously described by the rates of secondary enrolments. Below, we will introduce a model which explores unambiguously the interrelations between the composition of secondary educational stock and the enrolment rates.

3.2.1 VG enrolments versus VG education

We assume that working population with secondary education (S_t) consists of employment with both vocational (V_t) and general education (G_t), a growth rate of population is constant⁴⁰ and there is no unemployment⁴¹. Furthermore, following Bertocchi and Spagat (2004) we shall accept the following production function

$$Q_t = A_t \cdot V_t^\alpha \cdot G_t^{1-\alpha} \quad (2.1)$$

where, Q_t - output. Technological progress is assumed to be exogenously given by an increasing sequence $A_t = \gamma \cdot A_{t-1}$ with $\gamma > 1$. Hence, vocational labour gets a wage $w^V = \alpha A_t V_t^{\alpha-1} G_t^{-\alpha}$ and general labour receives $w^G = (1-\alpha) A_t V_t^\alpha G_t^{-\alpha}$. If a parameter $\alpha \geq \frac{1}{2}$, then a contribution of vocational labour will be more than a contribution of general labour, and vice versa.

⁴⁰ This means in our case that a growth rate of secondary enrolments and retires is also constant.

⁴¹ Usually, data on unemployment contains vocational and general education which we may subtract from the types of working population correspondingly.

Obviously, working population is regularly added by new graduates with higher modern skills. Therefore, we assume that at time $t+1$, working population with vocational education consists in vocational labour at time t and former graduates of vocational schools (V^s) who are working now⁴².

$$V_{t+1} = V_t + V_{t-1}^s \quad (2.2)$$

Similarly, working population with general secondary education at time $t+1$ consists of already working with general education at the previous period and former graduates of academic schools (G^s), minus the number of recently entered at universities students (T_t) during the current period.

$$G_{t+1} = G_t + G_{t-1}^s - T_t \quad (2.3)$$

Further, dividing the expressions (2.2) and (2.3) by V_{t-1} и G_{t-1} correspondingly and replacing the left parts in the form of logarithms, and taking their difference, we will get

$$\frac{\frac{V_t}{G_t}}{\frac{V_{t-1}}{G_{t-1}}} = e^{\frac{V_{t-1}^s}{V_{t-1}} \cdot \frac{G_{t-1}^s}{G_{t-1}} \left(1 - \frac{T_t}{G_{t-1}^s}\right)} \quad (2.4)$$

We introduce a parameter k so that $\frac{V_t}{G_t} = \frac{V_{t-1}}{G_{t-1}} \cdot e^k$. Then, on the other hand from (2.4) we

will have $\frac{V_t^s}{V_t} = \frac{G_t^s}{G_t} \cdot \left(1 - \frac{T_{t+1}}{G_t^s}\right) + k$. Multiplying both sides by G_t and consequently transforming we will get

$$\frac{G_t}{V_t} = \frac{G_t^s}{V_t^s} \cdot \left(\left(1 - \frac{T_{t+1}}{G_t^s}\right) + \frac{G_t}{G_t^s} \cdot k \right) \quad (2.5)$$

Thus, the following properties are valid depending on the sign and the value of parameter k .

⁴²Assume, that all graduates of secondary schools by sequence find job.

- (P1)** *At the same growth rate of working population with G and V ($k=0$) the ratio of general to vocational education will be equivalent to the ratio of general to vocational enrolments, rectified by a share of former graduates with G , and vice versa.*

The degree of the exponent in (2.4) is equal to zero. Hence, from (2.5) we will have the expression

$$\frac{G_t}{V_t} = \frac{G_t^s}{V_t^s} \cdot \left(1 - \frac{T_{t+1}}{G_t^s}\right) \quad (2.6)$$

On the other hand, from $\frac{V_t}{G_t} = \frac{V_{t-1}}{G_{t-1}}$ we see that the growth rates of labour with V and G are the same, e.g. $\frac{V_t}{V_{t-1}} = \frac{G_t}{G_{t-1}}$. In this case, the rates of change in secondary, general and vocational education will be the same.

- (P2)** *If working population with G exceeds that with V ($k < 0$), then the ratio of general to vocational education will be equivalent to the ratio of general to vocational enrolments, rectified by a smaller multiplier than a share of former graduates with G , and vice versa.*

A negative degree in the exponent in (2.4) which is equivalent to an inequality $\frac{G_t}{V_t} < \frac{G_t^s}{V_t^s} \cdot \left(1 - \frac{T_{t+1}}{G_t^s}\right)$ means that a ratio of vocational to general education will monotonously decrease. Then, it is easy to show, that the right side in (2.5) is always positive⁴³. Hence, the multiplier in the right side in (2.6) is superior to a similar multiplier in (2.5). Taking into account (5.2) in Appendix we will show that a rate of change of working population with secondary education will be less, than a rate of change in general education, but superior than a rate of change in vocational education.

⁴³Since $G_t^s - T_{t+1} > G_t \cdot \log k$, where the left side is always negative due to $k < 0$

(P3) *If working population with V exceeds that with G at a rate, equal to $\frac{T_{t+1}}{G_t}$ ($k>0$), then the ratio of vocational to general education will be exactly the same as the ratio of vocational to general enrolments, and vice versa.*

A positive degree in the exponent in (2.4), equivalent to an inequality $\frac{G_t}{V_t} > \frac{G_t^s}{V_t^s} \cdot \left(1 - \frac{T_{t+1}}{G_t^s}\right)$,

means that the ratio of vocational to general education will monotonously increase. The

greatest interest represents a special case, when $k = \frac{T_{t+1}}{G_t^s}$. Then, from (2.5) follows

$$\text{that } \frac{G_t}{V_t} = \frac{G_t^s}{V_t^s}.$$

(P4) *If working population with V exceeds that with G at the rate of $\frac{T_{t+1}}{G_t}$ ($k>0$), then the rates of change of education and enrolments with G and V will be the same, and vice versa.*

Thus, the above-stated properties establish that the ratio of vocational and general enrolments can be used as a better proxy for the ratio of vocational to general education when the latter decreases. It should be also noted that if we express (2.1) for t and $t-1$ the periods in the form of logarithms, then the difference looks as

$$\log \frac{Q_t}{Q_{t-1}} = \log \frac{A_t}{A_{t-1}} + \log \frac{G_t}{G_{t-1}} + \alpha \cdot \log \frac{\left(\frac{V}{G}\right)_t}{\left(\frac{V}{G}\right)_{t-1}} \quad (2.7)$$

Then, with the earlier introduced parameter k the expression (2.7) under P3 is equivalent

$$\text{to } \dot{Q}_t = \dot{A}_t + \frac{G_t - G_{t-1}}{G_t} + \alpha \cdot \frac{T_{t+1}}{G_t}. \quad \text{The latter is equivalent to}$$

$$G_t \left(\dot{Q}_t - \dot{A}_t - 1 \right) = \alpha \cdot T_{t+1} - G_{t-1} \text{ Hence, if the rates of change } Q_t \text{ and } A_t, \text{ the value of } \alpha \text{ are}$$

known, then employment with general and vocational education at the steady state can be

$$\text{defined as } G_t = \frac{\alpha \cdot T_{t+1}}{\dot{Q}_t - \dot{A}_t} \text{ and } V_t = S_t - \frac{\alpha \cdot T_{t+1}}{\dot{Q}_t - \dot{A}_t} \text{ respectively.}$$

This approach indicates that the ratio of vocational over general enrolments is a better proxy only when the ratio of vocational to general education increases, e.g. for developing countries. Hence, the empirical conclusions, made first by [Bennett \(1967\)](#) and later by [Bertocchi and Spagat \(2004\)](#) regarding to less-developed and developed economies, will be less strong since the ratio declines. Indeed, the dynamics of the ratio of vocational to general education in these countries might be rather depicted at comparatively higher levels. Moreover, it is also shown that the rate of vocational over general enrolments can serve an exact proxy for the ratio of vocational to general education depending on a share of recently entered at universities students in working population with general education. In this case, if the rates of change in vocational and general education are known, then we would be able to find approximately the size of working population with these types of secondary education. The main conclusions can be illustrated below as follows.

Table 3.3 *The different patterns of the ratio of vocational to general education*

	$k < 0$	$k > 0$	$k = \frac{T_{t+1}}{G_t} > 0$
DE	$\left(\frac{V}{G}\right)_t^s < \left(\frac{V}{G}\right)_t^{k=0} < \left(\frac{V}{G}\right)_t^{k<0}$ $\dot{V}_t < \dot{S}_t < \dot{G}_t$		
DG		$\left(\frac{V}{G}\right)_t^{k>0} < \left(\frac{V}{G}\right)_t^{k=0} < \left(\frac{V}{G}\right)_t^{k<0}$ $\dot{G}_t < \dot{S}_t < \dot{V}_t$	$\left(\frac{V}{G}\right)_t^{k=\frac{T_{t+1}}{G_t}} = \left(\frac{V}{G}\right)_t^s$
TE			$\left(\frac{V}{G}\right)_t^{k>\frac{T_{t+1}}{G_t}} < \left(\frac{V}{G}\right)_t^s < \left(\frac{V}{G}\right)_t^{k<\frac{T_{t+1}}{G_t}}$ $\dot{G}_t = \dot{G}_t^s ; \dot{V}_t = \dot{V}_t^s$

Notes: DE – developed economy; DG – developing economy; TE – transition economy.

3.3 Modeling VG Education Dynamics

Now, we shall describe the dynamics of working population with vocational and general education by representing as a couple of coordinates and its transformation into another couple, so that⁴⁴

$$(V_t, G_t) \mapsto (V_{t+1}, G_{t+1}) \quad (3.1)$$

where, $V_{t+1} = V_t + \sin \alpha$ and $G_{t+1} = G_t + \cos \alpha$ with $45^\circ < \alpha_t < 135^\circ$. The change in secondary education is defined as $\Delta S_t = \sin \alpha_t + \cos \alpha_t$. Then, taking into account (2.2) and (2.3) we will get that

$$V_t^s = \sin \alpha_t \quad (3.2)$$

$$G_t^s = \cos \alpha_t + T_{t+1} \quad (3.3)$$

We shall also formulate a policy which consists in maximizing the size of working population with secondary education.

$$\max_{\alpha_t} [\sin \alpha_t + \cos \alpha_t] \quad (3.4)$$

subject to $\alpha_t \in [45^\circ; 135^\circ]$

Thus, it can be shown that there exists a solution of (3.4) which is defined, when $\alpha^* = 45^\circ$.

Proposition 3.1 *Maximizing the size of working population with secondary education is attainable only along the direction of bisector, and vice versa.*

Furthermore, taking into account (3.2) and (3.3) the growth rate of the ratio of vocational to general education in (2.4) can be expressed as an $e^{\frac{\sin \alpha}{V_t} - \frac{\cos \alpha}{G_t}}$. Then, a policy which consists in maximizing the ratio of vocational to general education can be formulated by

⁴⁴For simplicity we assume that $|A, B| = 1$

$$\max_{\alpha_t} \left[\frac{\sin \alpha_t}{V_t} - \frac{\cos \alpha_t}{G_t} \right] \quad (3.5)$$

subject to $\alpha_t \in [90^\circ; 135^\circ]$

Thus, it can be shown that the derivative in (3.5) can be equal to zero only when $90^\circ < \alpha_t < 135^\circ$. Secondly, we denote an angle of slope which corresponds to A by β with $0 < \beta_t < 45^\circ$. Thus, the solution of (3.5) will be

$$\sin \alpha_t^* = \frac{G_t}{\sqrt{V_t^2 + G_t^2}} \text{ and } \cos \alpha_t^* = \frac{V_t}{\sqrt{V_t^2 + G_t^2}} \quad (3.4)$$

Hence, we see that $\sin \beta_t = \cos \alpha_t^*$ and $\cos \beta_t = \sin \alpha_t^*$. Similarly, the change of secondary education can be expressed in terms of β as $\Delta S_t = \sin \beta_t + \cos \beta_t$. In other words, at the maximized growth rate of the ratio of vocational to general education the change of secondary education is invariant relative to the angle of slope.

Proposition 3.2 *Maximizing the growth rate of the ratio of vocational to general education is attainable only along a direction which angle of incidence is equal to an angle of slope by subtracting from the right angle, and vice versa.*

The above formulated propositions have some implications which consist in distinguishing economic policies on increasing the size of secondary education and the rate of the ratio of vocational to general education. In other words, any efforts on maximizing the size of secondary education are not always consistent with the maximized rate of the ratio of vocational to general labour, and vice versa. In general, both policies can act at different ways. Moreover, depending on an initial slope there can a convergence or divergence between both policies. For instance, if the angle of slope is inferior to 45° then, the angles between both directions will be obtuse, and otherwise – acute. It means that for developing economy there is a convergence between the two-indicated policies. On the contrary, a divergence for developed economy means rather the importance of general, hence higher education (Vandenbussche, Aghion and Meghir, 2006) relative to vocational education.

Proposition 3.3 *There exists a convergence (divergence) between economic policies on maximizing the size of secondary education and the growth rate of the ratio of vocational to general education for developing (developed) and hence, transition economy.*

If an initial slope coincides with the bisector or the size of vocational labour is equal to the size of general labour, then any efforts on maximizing the size of secondary education and the growth rate of the ratio of vocational to general education will be carried out at perpendicular directions. Thus, as regard to middle income developing countries the directions of the ratio of vocational and general education and the size of secondary education are originated from the bottom right side to the top left side. As the angles of slopes of two polarized directions are known, there exists a resulting direction which optimizes the composition of secondary educational stock. The angle of resulting direction

will be defined by dividing in half as follows $\frac{90^\circ - \beta + 45^\circ}{2} + 45^\circ$.

Besides, we remind that $\frac{\left(\frac{V}{G}\right)_{t+1}}{\left(\frac{V}{G}\right)_t} = e^{\frac{\sin \alpha}{V_t} - \frac{\cos \alpha}{G_t}} = \theta_t$. It is easy to show that the term in the right

hand side is positive and superior to one. Now, we need to calculate the values of the trigonometric functions at the angles, equal to $\frac{225^\circ - \beta}{2}$. Taking into account that

$\beta_t = \text{acrtg}\left(\frac{V}{G}\right)_t$ we will get⁴⁵

$$\theta_t = \exp \left(\frac{\cos \frac{45^\circ - \text{acrtg}\left(\frac{V}{G}\right)_t}{2}}{V_t} + \frac{\sin \frac{45^\circ - \text{acrtg}\left(\frac{V}{G}\right)_t}{2}}{G_t} \right) \quad (3.5)$$

⁴⁵ $\sin \frac{225^\circ - \beta}{2} = \cos \frac{45^\circ - \beta}{2}$ and $\cos \frac{225^\circ - \beta}{2} = -\sin \frac{45^\circ - \beta}{2}$

Therefore, an optimized trajectory of VG education dynamics can be depicted as indicated in Figure 3.2.

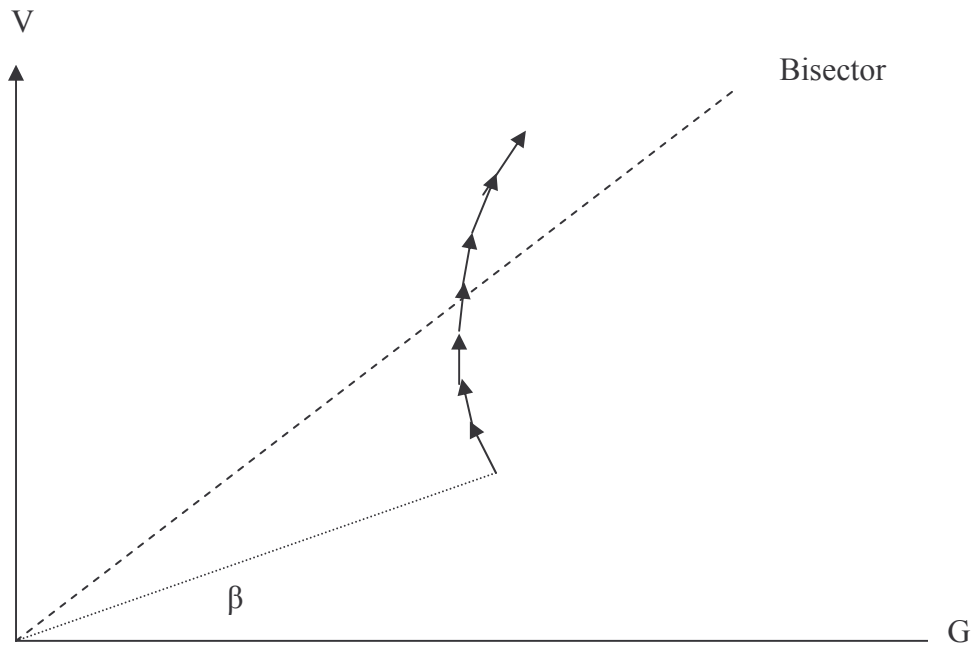


Figure 3.2 *An optimized trajectory of VG education in developing economy*

Now, using the data of the composition of Taiwan's secondary educational stock from the Table 3.2 we calculate the dynamics of VG education, derived from (3.5) and compare with VG, defined as a ratio of V and G secondary educational stocks. The results are given in Table 3.4⁴⁶. Surprisingly, as we see from the Figure 3.3 two trajectories are almost similar.

Table 3.4 *An optimized composition of Taiwan's secondary educational stock*

	1979	1984	1989	1994	1998
V	16,53	23,2	29,09	34,47	39,59
G	24,54	26,52	27,91	29,58	28,32
V+G	41,07	49,72	57,00	64,05	67,91
VG	0,674	0,875	1,042	1,165	1,398
CVG	0,674	0,890	1,085	1,266	1,400

V and G – vocational and general secondary educational stocks;

(V+G) – total secondary educational stock;

VG – the ratio of VG education;

CVG – the ratio of VG education, calculated by the author.

⁴⁶Indeed, (3.5) requires the data on V and G education for each year and therefore, the growth rates of V and G education are taken as 7.01%, 4.63%, 3.45%, 3.52% and 1.56%, 1.03%, 1.17%, -1.08% respectively which are stable for each of the periods 1979-1984, 1985-1989, 1990-1994 and 1995-1998.

In other words, during the period of 1979-1998 the real dynamics of VG can be reconstructed totally by CVG which means that Taiwan has apparently succeeded in increasing the average years of education from 3.2 to 8.2 years (Table 3.1) by optimizing the composition of its secondary educational stock.

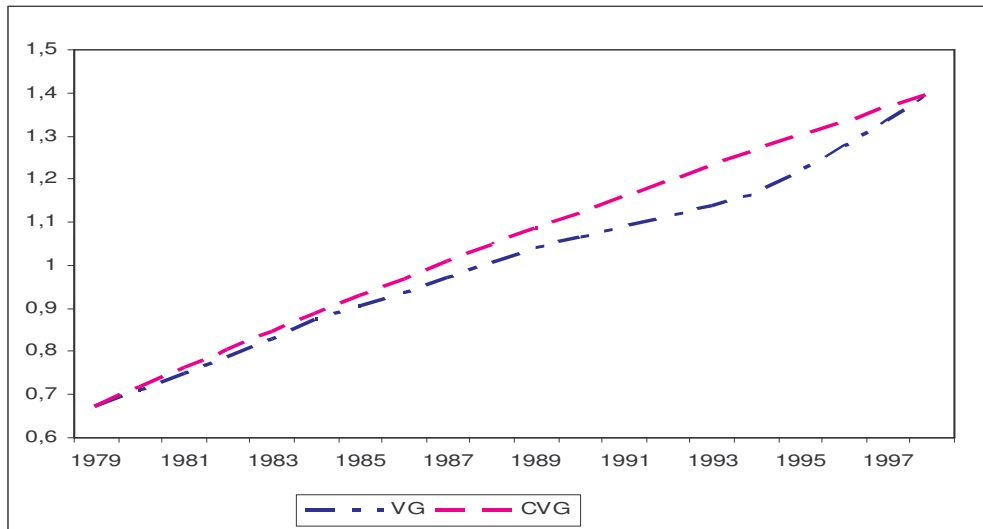


Figure 3.3 *An optimized composition of Taiwan's secondary educational stock*

Analogously, we portray graphically a likely dynamics where G will be dominated relative to V or an optimized trajectory of GV education for a developed country (Figure 3.4).

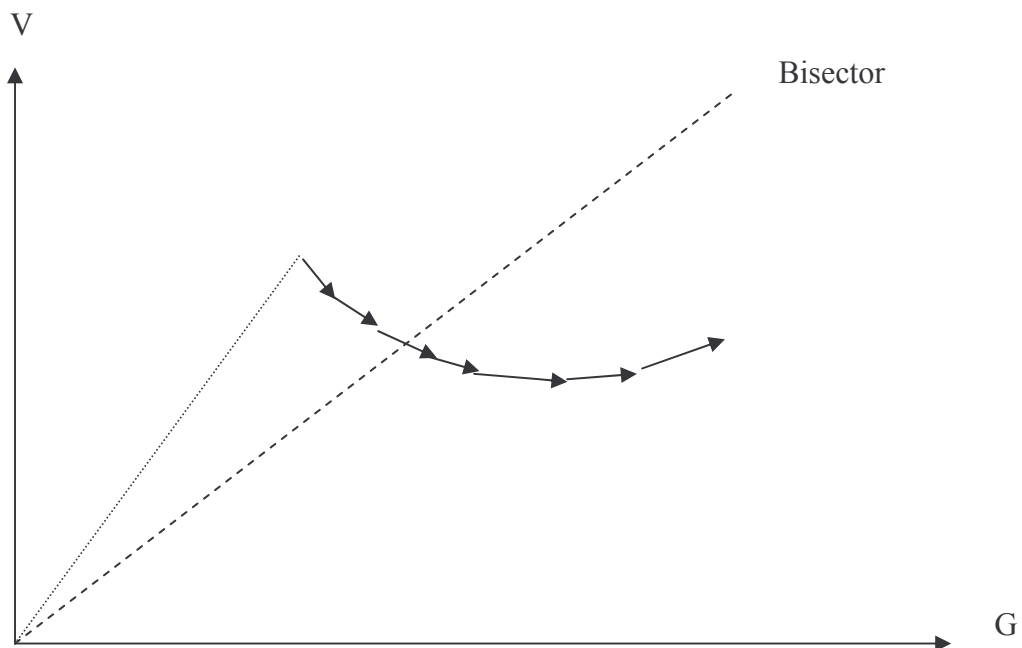


Figure 3.4 *An optimized trajectory of GV education in developed economy*

3.3.1 Empirical evidence in transition

Transition from a command to a market-oriented economy has implied radical changes in the structure of production and employment by restructuring enterprises and reallocating labour sectors (Boeri and Terrell, 2002). Formerly gained skills in transition economies were strictly specific, and therefore, not perfectly tailored to market conditions. By addition, a command economy was characterized by huge industrial and agricultural sectors whilst the size of sector of services was insignificant due to the lack entrepreneurial activities. Thus, since the transition period working population with vocational education has been considerably contracted. Nevertheless, with transition to the market economy the entrepreneurship has considerably increased. In result, the agriculture has been squeezed, and by contrast, services have been sharply widened⁴⁷. The transition to a market-oriented economy imposes on education system increasing the rate of secondary enrolments in accordance with strategy of technological development in transition economy.

During the period of restructuring large enterprises from 1989 to 1998 the CEE countries experienced high unemployment among all categories of population, particularly among women and elderly workers (Bruno, 2006). For instance, in Estonia from 35% to 50% workers changed previous job (Campos and Dabusinkas, 2002). According to Campos and Jolliffe (2004) in Hungary among unemployed persons there was a dominance of former workers of industrial and agricultural sectors. On the contrary, workers employed in services became winners by contributing to small entrepreneurship and commerce.

On the basis of relevant data of 149 countries for 1950-1991 Bertocchi and Spagat (2004) have revealed an U-inverted curve between the ratio of vocational to general enrolments and GDP per capita. Thus, they established that a ratio of vocational to general education reaches its maximum when GDP per capita is equal to \$7310 in constant US\$ 1980. Following the authors we will verify that whether there is a similar relationship between the two indicated variables in transition countries. Using the panel of UNICEF-IRC data for the period of 1989-2004 we came to the conclusion that there exists also a U-inverted curve between GDP per capita and the ratio of vocational to general enrolments (Table 3.4).

⁴⁷Raiser et al. (2004) define the limits of labour reallocating in the main sectors such as manufacture, agriculture and services in most transition economies.

Table 3.5 *Reduced forms regressions of VG enrolment*

	(1)	(2)	(3)
<i>GDP per capita (constant 2000\$)</i>	$7.67*10^{-5}$ (10.1)	0.082789 (15.32)	0.066503 (9.29)
<i>GDP per capita squared</i>	$-5.21*10^{-9}$ (-9.4)	$-5.99*10^{-6}$ (-9.66)	$-4.25*10^{-6}$ (-5.15)
<i>Total Employment</i>			$6.57*10^{-6}$ (3.81)
<i>Number of transition economies</i>	149	10	10
<i>Observations</i>	6258	147	147
<i>Adjusted R squared</i>		0.11	0.19
<i>Maximum of GDP per capita</i>	\$7310	\$6911	\$7824
<i>Maximum of VG</i>	0.62	2.86	2.60

Notation: (1) the estimation of Bertocchi and Spagat (2004) in constant 1980US\$ for 1950-1991

(2)-(3) the author's estimation in constant 2000 US\$ for 1989-2004

Source of data: World Bank and TransMONEE, 2006.

A maximum level of GDP per capita is reached at 6911US\$ with a correspondent ratio which is equal to 2,86. As we see from the table 3.1 adjusted *R* squared is not high. This can be explained by the heterogeneity amongst the transition economies in terms of production structure, labour reallocation etc. In order to smooth the effects of heterogeneity, total employment which is a proxy for the size of economy, has been included. Hence, the re-estimation improves the statistic criteria, notably adjusted *R* squared which became equal to 0.19. The second variant increases a maximum level of GDP per capita, reached at 7824US\$, but a ratio of vocational to general education is slightly decreased till 2.6.

Therefore, in spite of a decline of the ratio of vocational to general education since at the first phase, linked to the reallocation of labour across the sectors, an increase in the ratio of vocational to general enrolments at the second phase seemingly raises the ratio of vocational to general education. Moreover, the ratio of vocational to general education can be specified as an alternative measure of human capital stock which would give scope for re-establishing the relationship between productivity growth and human capital and applying the modern growth theory to transition economy. This hypothesis will be verified by constructing an computable general equilibrium model for a transition economy.

3.4 Conclusion

The impressive economic performance of East Asia economies shows that there can be a positive link between a relative rise of working population with vocational education and the size of secondary education. Seemingly, the scarcity of data on the structure of attained secondary education has been restricting research on unequivocal understanding of how the size of secondary education changes depending on the ratio of vocational to general education. In particular, it is shown that the ratio of vocational over general enrolments is a better proxy only when the ratio of vocational to general education increases, e.g. for developing countries. Hence, the conclusions, made first by [Bennett \(1967\)](#) and later by [Bertocchi and Spagat \(2004\)](#) regarding to less-developed and developed economies, are less strong since the ratio declines. Moreover, it is also shown that the rate of vocational over general enrolments can serve an exact proxy for the ratio of vocational to general education depending on a share of recently entered at universities students in labour force with general education.

The importance of secondary education is strengthened in technology adoption. Like middle income countries transition economies face to technology adoption rather than innovation by rising labour force with vocational education. An emerging trend in the rate of both types of secondary enrolments specifies that the VG dynamics analogously follows an inverted U-shaped link in the CEE transition economies. The initially declined ratio, related to the reallocation of labour in transition, seemingly rises further with technology adoption.

The paper opens up some insights by exploring the main differences stemming from raising productivity and increasing the size of secondary education and the directions in which they work altogether. A convergence (divergence) of the directions of the ratio of vocational to general education and the size of secondary education gives scope for optimizing the composition of secondary educational stock for developing (developed) economy. These results would allow for specifying the ratio of vocational to general education as a measure of human capital stock and hence, applying the modern growth theory to transition economies.

3.5 Appendix

We assume that secondary as well primary education is compulsory in developed and transition economies. Hence, the enrolments rates at the secondary level are higher. Thus, one can say that there is so-called *Substitutability* (*SSB*) effect when an increase in vocational enrolment possibly occurs due to a decrease in general enrolment. In other words, the size of secondary education enrolment remains at the same level independently on a change in its structure. It is likely that *SSB* raises the size of secondary education although vocational and general enrolments can be differed by their duration. Then, it can be seen that the change rates of secondary, vocational and general education will be the same. On the contrary, a growth in the size of secondary education can result of an increase in secondary enrolment rates which, in turn, depend on the rate primary enrolments. Thus, one can say that there is so-called *Complementarity* (*CPB*) effect when an increase in a secondary enrolment is not due to *SSB* effect, but holds owing to raising of the rates secondary enrolments. These effects let analysing the insights in the structure of working population with secondary education. Seemingly, when it concerns developing countries, both effects affect working population with vocational and general education. Under the assumption of a constant growth rate of population and a higher rate of enrolments in secondary education, we will get the following hypothesis.

Assumption 3.1. An increase in working population with vocational education is due to an adequate decrease in working population with general education, and vice versa, e.g., $\Delta V_t^s = -\Delta G_t^s$.

In other words, despite of a change in the ratio of vocational to general education a rate of secondary enrolments is constant or $G_t^s + V_t^s = G_{t-1}^s + V_{t-1}^s$. The latter we will rewrite as

$$\frac{1 + \left(\frac{V}{G}\right)_t^s}{1 + \left(\frac{V}{G}\right)_{t-1}^s} = \left(\frac{G_{t-1}}{G_t}\right)^s \quad (\text{A1})$$

On the other hand, due to the equality $S_t = G_t + V_t$ by transforming we will have

$$\log \frac{S_t}{S_{t-1}} = \log \frac{G_t}{G_{t-1}} + \log \frac{1 + \left(\frac{V}{G}\right)_t^s}{1 + \left(\frac{V}{G}\right)_{t-1}^s} \quad (\text{A.2})$$

Then, in view of (A.1) and the left side of (A.2) is equal to zero according to the assumption 3.1, we will receive that $\frac{G_t}{G_{t-1}} = \left(\frac{G_t}{G_{t-1}}\right)^s$.

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CHAPTER 4

REVISITING LUCAS: A PROSPECTIVE ANALYSIS OF THE CATCHING UP IN KAZAKHSTAN WITH A COMPUTATIONAL GENERAL EQUILIBRIUM MODEL⁴⁸

⁴⁸ I am grateful to Associate Professor Stéphane Calipel for sharing his knowledge on constructing a CGE model for Kazakhstan and, especially on its implementation in GAMS. The paper (Tracking Number APPC-49) has been accepted for presentation in the Asia-Pacific Productivity Conference 2008 (APPC2008) in Taipei, July 17-19, 2008.

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Abstract

The concept of Lucas (1988) is revisited to demonstrate that secondary education structurally adjusts to technology adoption. Therefore, the ratio of VG can be used in place of secondary enrolments in the Nelson-Phelps catch-up model of technology diffusion to re-establish the links with productivity growth in empirical studies. The potential of long-run catch-up toward the technology frontier is analyzed with a computable general equilibrium model for Kazakhstan. The pattern of productivity growth, measured in terms of barriers to technology adoption, reveals that the economy converges initially to lower steady state, endogenously determined by the interaction between the barriers to technology adoption and productivity growth.

JEL classification: O41; O52; F43.

Keywords: Computable general equilibrium modelling; Endogenous productivity growth; Kazakhstan.

“The role of human capital is indeed one of facilitating adoption of technology from abroad and creation of appropriate domestic technologies rather than entering on its own as factors of production” (Nelson and Phelps, 1966).

4.1 Introduction

In their influential empirical contribution Benhabib and Spiegel (1994), inspired by the earlier work of Nelson and Phelps (1966), recognize by arguing that the level of human capital, measured by secondary educational attainment is important for technology adoption. Thus, the level of human capital is interpreted as the capacity to absorb new ideas and creatively build on the existing abroad technologies new knowledge stock in generating new own technologies. As a consequence, it matters for improving productivity and hence, for the growth of human capital stock.

However, unlike the standard practice though, the educational attainment can not be directly accepted as a proxy of human capital in transition economies⁴⁹. High educational endowments in transition countries that were generally believed in the earlier stage of transition can not unambiguously led to economic growth. Inefficiency of human capital which arises with the openness to the world economy is seemingly linked to the redistribution of human capital (Galor and Tsidden, 1997). Notably, in early stages of development income earnings become polarized and, as a consequence, educational attainments can deteriorate. Consistently with the theory that openness and education stimulate productivity growth, there is negative impact of this growth on human capital accumulation (Kumar, 2003). On the other hand, the first stage of development is characterized by physical capital accumulation, and at the second stage economy follows a growth path which is mainly characterized by human capital accumulation (Funke and Strulik, 2000).

As Spagat (2006) argues, two paths of human capital evolution which lead to a bad and a good equilibrium, emerge in transition economies. In the bad equilibrium past educational achievements are wasted while in the good equilibrium the level of education allows for taking advantages from technology diffusion. Therefore, policies and economic conditions

⁴⁹ Using the standards measures of human capital stock such as the average years of education and the enrolment rates are empirically found as weaker, in most cases negative in Central and Eastern European (CEE) countries as compared to East Asian economies (Crafts and Kaiser, 2004).

are decisive in determining the equilibrium for the former centrally-planned economies. On the other hand, the finding of a relevant measure of human capital endowments in transition economies will certainly be of help for conducting effective policies on preserving previous higher educational attainments.

The introduction of the ratio of VG education as a proxy of human capital accumulation in transition economies is justified by the following arguments: First, it reflects greater and broader technological skills, imparted through secondary education. Second, the new measure of human capital is consistent with the concept of [Lucas \(1988\)](#), referring to the results of the time allocation between acquiring skills through education process and gaining working experience in production sector. Third, the existence of a link between the ratio of vocational to general education and the per capita GDP is based on the hypothesis of [Bennett \(1967\)](#). Therefore, it can be introduced to measure, in a broad manner, the changes both in secondary education and in demands for skills, linked to technology adoption. Finally, the ratio of VG allows for re-establishing the relationship with productivity growth which is the subjects of many studies on transition economies⁵⁰.

The paper argues that a surprised increase in educational attainments in the East Asia countries ([Collins, Bosworth and Rodrik, 1996](#)) is held mainly by a dramatic augmentation of vocational relative to general education. While lowering barriers to technology adoption increases a massive transfer of new technologies, the growth rate of VG affects a rise of the number knowledgably people by acquiring higher skills. Therefore, the section 2 first indicates not only the directions in which the size of secondary education and the ratio of VG are interlinked, but also a positive growth of these variables. Based on the recent evidence, presented by [Bertocchi and Spagat \(2004\)](#), that the ratio of VG tends to be higher in middle income countries, the concept of Lucas is revisited using the ratio of VG in place of secondary enrolments in the Nelson-Phelps catching-up model of technology diffusion. Next, the ratio of VG is introduced in the barrier function as education-related barrier to technology adoption. A computable general equilibrium model, developed in the Section 3, analyzes the endogenous interaction between technology diffusion and improvements in the efficiency of human capital in Kazakhstan and reveals the economy's convergence to its lower steady state.

⁵⁰ See, for instance, [Kejak et al. \(2004\)](#) and [Ragnitz \(2007\)](#).

4.2 Productivity Dynamics

Our approach of human capital measure is directly related to the concept of Lucas (1988). Allocating one part of time to production of ideas and another part of time to production of goods can be seen as an increasing working population possessing high skills or with secondary education. Thus, the demand for skilled labour force which is formerly educated at secondary schools but currently work, increases with technology adoption. On the other hand, in particular, vocational education and training (VET) is directly related to a country's ability to adopt and implement foreign technology. In addition, we show that an increase of vocational relative to general education is in the line with raising secondary education for developing and transition economies. Therefore, these concepts can jointly be understood as building a catch-up potential by filling up pools by ideas and new knowledge that increases productivity growth. The distinctive feature of both concepts lies in the fact that while a simple allocation of time to production of ideas improves productivity, VET provision is not commonly accepted by policy makers and governments. There is still an uncertainty on whether VET provision should be funded by state or should be left to individuals, enterprises and private sector training institutions without government intervention kept to a minimum.

However, VET provision without government intervention might be indeed a difficult task. Bennell and Segerstrom (1998) have criticized the World Bank for its misleading VET provision policy and argued that “*The high performing Asian economies show that social rates of return to vocational education are higher than for general secondary education*⁵¹. *South Korea and Taiwan deliberately shifted the emphasis of secondary school provision towards specialist vocational education at an early stage in their respective industrialization processes*”. There are many reasons of the importance of VET for economic development. First, skills other than those imparted by basic (primary and secondary) education can not be provided by enterprises and private sector training institutions without very significant government intervention. Second, the development process is becoming increasingly skill-driven, in particular in the traded goods sector, where countries should have comparative advantage. Third, the provision of good quality VET is crucial in order to improve labour productivity in all economic sectors. Fourth, a

⁵¹ VET provision in the majority of Latin American and Asian countries has been relatively successful, but not in sub-Saharan Africa (Bennell and Segerstrom, 1998).

broad based VET strategy targets all activities that are essential to the process of economic restructuring and modernization in both developing and transition economies.

4.2.1 Revisiting Lucas

Recent literature points out the main factors such as investment in human capital and technology diffusion in economic development. For example, [Aghion, Howitt and Violante \(2003\)](#) state that *“skills are not just an input to the production of goods and services but also a factor in the absorption and creation of new technological knowledge”* (page 444). Therefore, the enrolments in secondary education are generally accepted a proxy of skilled workforce and second, the Nelson-Phelps technology constraint is often used as the main technology adoption function. On the other hand, [Acemoglu \(2003\)](#) reemphasizes that *“Nelson and Phelps (1966) postulated that human capital is essential for adoption of new technologies. This view has at least two important implications: First, the demand for skills will increase as new technologies are introduced, and second, economies with high human capital will effectively possess better technologies”* (page 465). More educated and skilled workers are certainly conducive to productivity growth. And inversely, economies exploiting better technologies should possess high human capital.

The use of a broader definition of human capital in the explicit modelling of the process of technology diffusion can be supported by [Lucas \(1993\)](#): *“The theory of human capital focuses on the fact that the way an individual allocates his time over various activities in the current periods affects his productivity or his level in future periods”* (page 17). In other words, an increase in the time allocation to schooling affects the accumulation of human capital. Thus, in the Lucas formalization labour force is assumed to become skilled as the rates of secondary enrolments rise. It means that in each period of time an increased number of graduates from secondary schools enter into production sector by enhancing productivity growth. It is quite consistent with [Bennett \(1967\)](#) who argues that *“industrialization will consistently call for greater and broader technological skills – imparted through secondary education”* (page 107) and *“the ratio between vocational education and general education is highly related to economic development, but not related in the linear fashion”* (page 109).

Thus, the Lucas formalization and the Bennett hypothesis result that labour force with secondary education will dominate as the ratio of vocational to general education will rise. It allows for the existence of the links between secondary education and the ratio of vocational to general education. To shed more light we set up a correspondence of the size of secondary education to the ratio of VG so that:

$$(V_t + G_t) \mapsto \left(\frac{V}{G} \right)_t \quad (1.1)$$

For simplicity, we present a graphical demonstration of the interrelations between the size and the composition of working population with secondary education. Let begin with an initial point L with the coordinates G_t and V_t , under the bisector, transformed into another point E (V_{t+1} , G_{t+1}) which is also below the bisector and the angle of slope belongs to $45^\circ < \alpha < 135^\circ$.

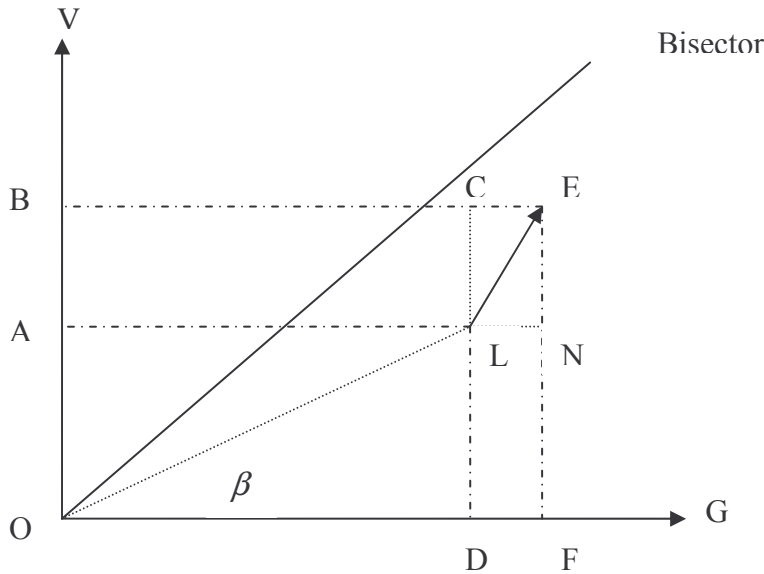


Figure 4.1 *The interrelation between the size and the structure of secondary education*

Then, as we can show from the Figure 4.1 that the perimeter of the rectangle ($OBEF$) which equals to $2 \cdot (V_{t+1} + G_{t+1})$ is larger than the perimeter of the rectangle ($OALD$), equal to $2 \cdot (V_t + G_t)$. Hence, we will get that $\frac{V_{t+1} + G_{t+1}}{V_t + G_t} > 1$.

On the other hand, the areas of two rectangles ($OBCD$) and ($OANF$) can be expressed by $V_{t+1} \cdot G_t$ and $G_{t+1} \cdot V_t$ respectively. However, one can not say unambiguously whether the

ratio of the areas of two rectangles $\frac{V_{t+1} \cdot G_t}{V_t \cdot G_{t+1}} = \frac{\left(\frac{V}{G}\right)_{t+1}}{\left(\frac{V}{G}\right)_t}$ is superior to one. By contrast, if we

assume that the angle of slope, for example, belongs to $90^\circ < \alpha < 135^\circ$ then, we will get that $\frac{V_{t+1} \cdot G_t}{V_t \cdot G_{t+1}} > 1$.

For example, if the initial point L slides to the final point E or $\Delta V_t + \Delta G_t \rightarrow 0$ which occurs only when if $\Delta V_t \rightarrow 0$ and $\Delta G_t \rightarrow 0$ then the perimeters the rectangles ($OBEF$) and ($OALD$), and the areas of the rectangles ($OBCD$) and ($OANF$) will be the same and equal to one. Therefore, we conclude that the size of secondary education and the ratio of VG grow positively depending upon the angle of slope. Below, the important cases are formulated by:

- (P1) *If $45^\circ < \alpha < 90^\circ$ then the growth rate of secondary education is superior to one.*
- (P2) *If $90^\circ < \alpha < 135^\circ$ then the growth rate of the ratio of vocational to general education is superior to one.*
- (P3) *If $\Delta G_t = 0$ or $\alpha = 90^\circ$ then the growth rate of the ratio of vocational to general education is superior to the growth rate of secondary education.*
- (P4) *If $\Delta V_t = \Delta G_t$ or $\alpha = 45^\circ$ then the growth rate of secondary education is superior to the growth rate of the ratio of vocational to general education.*

Briefly, the properties (P1) – (P4) state the directions alongside of which the size of secondary education and the ratio of VG will grow⁵². In particular, (P1) indicates uniquely a direction where growth of the size of secondary education is positive while (P2) – for the ratio of VG. Thus, the property (P3) states that if the difference $\Delta G_t = G_{t+1} - G_t$ in general education tends to zero then the ratio of VG will grow faster than the size of secondary education. By contrast, the property (P4) says that if the difference $\Delta V_t = V_{t+1} - V_t$ in

⁵² The proofs are given in Appendix 4.5.1.

general education tends to zero, but by virtue of $45^0 < \alpha < 135^0$ it converges only to ΔG_t , then the size of secondary education will expand relative to the ratio of VG.

The above presented properties are quite consistent with the strong results of the Essay 2. Namely, the size of secondary education maximizes along the bisector or when $\alpha = 45^0$. By contrast, the ratio of vocational to general education gets its maximum the direction the angle of slope of which composes $\alpha = 225^0 - \beta$, where β - the angle of slope of the initial point L as indicated in the Figure 4.1. Summarizing the above statements, we can conclude that there exists a balanced growth of two variables which can be defined by the angle of slope, equal to $\alpha = (225^0 - \beta) / 2$ and stated by the following proposition.

Proposition 4.1

There exists a balanced growth between the gross enrolment of secondary education and the ratio of vocational to general enrolment.

Next, it is useful to determine whether two variables will grow positively alongside the balanced growth path or their growth rates are superior to one. For that, we use (3.5) in the Chapter 3 and show that first, the ratio of VG grows positively and second, the growth rate of the size of secondary education is superior to one⁵³. Therefore, the following proposition is important in identifying a positive growth of both the size of secondary education and the ratio of VG, which is stated by

Proposition 4.2

Along a balanced growth path both the gross enrolment of secondary education and the ratio of vocational to general enrolment will grow positively.

If the growth rates of V and G education in Taiwan, equal to 7.01%, 4.63%, 3.45%, 3.52% and 1.56%, 1.03%, 1.17%, -1.08% respectively in each five years during 1979-1998, are applied to Kazakhstan during 20 years, then total secondary educational stock will increase from 57.44% in 1997 and 94.73% in 2016 year. Thus, we calculate first the ratio of VG by using the data on V and G enrolments and compare it with the calculated CVG, derived from (3.5) in the Chapter 3. There is a slight difference between both VG and CVG

⁵³ The proofs are presented in Appendix 4.5.2.

dynamics. By contrast, if we take the growth rates of VG and (V+G), they are almost the same (Table 4.2).

Table 4.2 *An optimized composition of Kazakhstan's secondary educational stock*

	1997	2002	2007	2012	2016
V	22,92	32,17	40,34	47,80	54,90
G	34,52	37,30	39,26	41,60	39,83
V+G	57,44	69,47	79,59	89,40	94,73
VG	0,664	0,862	1,028	1,149	1,378
CVG	0,664	0,813	0,941	1,057	1,142
RCVG	1,000	1,224	1,417	1,592	1,720
R(V+G)	1,000	1,210	1,386	1,557	1,649

V and G – vocational and general secondary educational enrolment, % of population, aged 15-18;

(V+G) – gross secondary educational enrolment, % of population, aged 15-18;

VG – the ratio of VG enrolment;

CVG – VG calculated by the author's;

RCVG – the growth rate of CVG;

R(V+G) - the growth rate of (V+G).

Thus, the obtained results confirm that there is a balanced growth between total secondary educational enrolment and the ratio of VG enrolment (Figure 4.2). Secondly, the growth rates of both total secondary educational enrolment and the ratio of VG are superior to one and moreover, are unexpectedly similar which allows for using the ratio of VG in place of secondary educational enrolment.

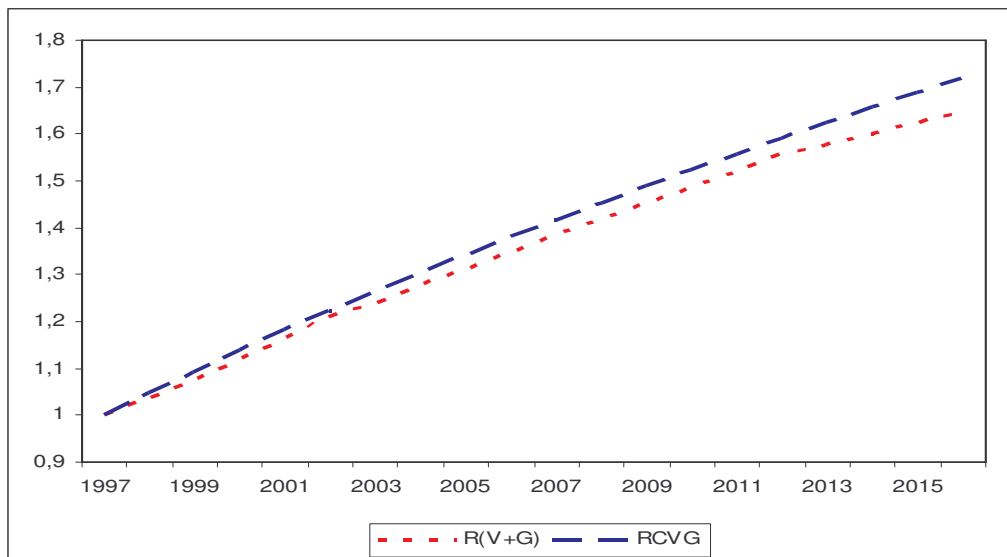


Figure 4.2 *Kazakhstan's total secondary educational enrolment and calculated VG*

In resume, the above developed approach can be useful in evaluating the interpretation of the size of secondary education by the ratio of vocational to general in (1.1). It is particularly important for identifying relevant changes in the composition of secondary education as a proxy of human capital in transition economies. Therefore, using the ratio of VG has many advantages. First, it presents a broader measure than the rates of secondary enrolments. Second, it indicates unambiguously a relative increase in acquiring technical skills for imitation process, which might be conducive to productivity growth. Third, the new measure of human capital can be seemingly applied to both developing and transition economies, where the main occupation is technology adoption. Moreover, it appears to be relevant to the early phase, when imitation is most important than innovation, and therefore, indicates the limits of productivity growth during this period as long as it reaches its maximum.

4.2.2 VG education in the Nelson-Phelps approach

Many transition economies, like middle income countries, currently experience a movement from imitation-oriented early phase to innovation-based growth later on to ensure productivity growth. As it has been commonly agreed, the growth-enhancing properties of human capital depend upon both the composition of labour force with the levels of educational attainment and the distance to technology frontier. Higher education investment has a larger impact on a country's ability to make its own innovations, whereas primary and secondary education is more likely to make a difference by affecting a country's ability to implement existing frontier technologies (Aghion and Howitt, 2005). Moreover, as a country closely approaches to the frontier the main occupations become innovation (Vandenbussche, Aghion and Meghir, 2006). By contrast, a country which is far from technology frontier relies more on absorbing and implementing new technologies and knowledge.

Therefore, our hypothesis is that the growth process in Kazakhstan is based on low technological industries which are not characterized by *R&D*-intensive high skilled production. Assuming that technology adoption will be a source of productivity growth and thereby, the accumulation of human capital will be linked to the ratio of vocational to general education. It is particularly important as the human capital stock is related to the

kinds of employment. For example, industrial technology adoption requires specific skills which can be obtained mostly through vocational education and training. Therefore, the changes in the structure of secondary education, namely an increase in the ratio of vocational to general education improves the country's ability to take advantages through technology adoption and is conducive to productivity growth in middle income countries (Bennett, 1967; Bertocchi and Spagat, 2004). An emerging trend in the rate of both types of secondary enrolments specifies that the VG dynamics analogously follows an inverted U-shaped link between the ratio of vocational to general education and per capita GDP in the CEE transition economies⁵⁴.

Now, we introduce the ratio of vocational to general education (VG_t) as a proxy of human capital in the function of the abundance of barriers (BAB_t) to technology adoption, which will look as follows:

$$BAB_t = b \cdot VG_t^{\gamma_1} \cdot TRADE_t^{\gamma_2} \quad (1.2)$$

where γ_1 - the share parameter of VG_t and γ_2 - the share parameter of $TRADE_t$ which are constant. The interaction with foreign trade is assumed to be fruitful in transferring new technologies to domestic producers, and therefore, a trade share in GDP ($TRADE_t$) is also introduced in (1.2). While a relative backwardness presents a learning potential through imitation, trade will be considered as the main channel for transmitting foreign technology and the ratio of VG will reflect a degree of the exploitation of imported technologies. As a result, there exists a reciprocal link between the trade and the ratio of VG. As it concerns the barrier function (BAB_t) an endogenous interaction with productivity growth will be important for catching up with world technology frontier.

Similarly to the Nelson-Phelps formalization of catch-up process, the growth of labour-augmenting technical progress (AX_t) is assumed to be endogenously determined by the economy's relative position to the world technology frontier and its ability to absorb and take advantages from technology diffusion. Therefore, in virtue of the above-formulated statements, AX_t is measured in terms of barriers to technology adoption and the distance to technology frontier (GAP_t)

⁵⁴ The estimation is taken from the Chapter 3.

$$\frac{\Delta AX_t}{AX_t} = BAB_t \cdot (GAP_t - GAP_t^2) \quad (1.3)$$

But, productivity growth do not vary always positively with the distance between the technology frontier and current level of productivity and in cutting down of the technology gap there exists a multiplicity with two steady states. Therefore, we define first technology gap as follows:

$$GAP_t = \frac{AX_t}{TFR_t} \quad (1.4)$$

where productivity at technology frontier TFR_t grows with a constant rate or $TFR_{t+1} = TFR_t \cdot (1 + \eta)$. In turn, the dynamics of the ratio of VG in contrast with the rates of secondary enrolments is endogenously defined from

$$VG_t = b_0 + b_1 \cdot \frac{GDP_t}{POP_t} - b_2 \cdot \left(\frac{GDP_t}{POP_t} \right)^2 \quad (1.5)$$

where, GDP_t is gross domestic product in US dollars by the exchange rate of the local currency against USD and POP_t is the size of population. The coefficients (b_1) and (b_2) are positives and estimated by using the panel of data on the enrolment rates of vocational and general education in the CEE. We introduce a constant (b_0) to keep the estimated coefficients and adapt the expression (1.5) to the case of study.

4.2.3 Calibration strategy

As usual, we assume that data are obtained from an economy in equilibrium and the economy is evolving along a balanced growth path. Hence, the 1998 Kazakhstan SAM is regarded as it is derived from its base run state. First above, we need to calibrate the elasticities of productivity growth with respect to the ratio of VG and total trade share of GDP. As it implies from (1.3) technical progress will be growing with the growth rate of technology frontier due to that the growth rate of technology gap becomes zero. In other

words, at the steady states technology gap becomes constant (GAP_{ss}). Thus, let calibrate at the steady state the parameter γ_1 from (1.3) which takes the following form

$$TRADE_t^{\gamma_2} = \frac{\eta}{b(GAP - GAP^2)} \cdot VG_t^{-\gamma_1} \quad (1.6)$$

After its transformation it will look as $\log TRADE_t = c_0 - c_1 \cdot \log VG_t$ where $c_1 = \frac{\gamma_1}{\gamma_2}$. For

simplicity we put that $\gamma_2 = 1$ then the value of the share parameter of VG_t can be estimated from (1.6). Using the panel of data on trade share of GDP from the World Bank and the structure of secondary education of the CEE economies for the period of 1991 to 2004 from TransMONEE 2006 we estimate that

$$\log TRADE_t = 4.60 - 0.14 \cdot \log VG_t \quad (1.7)$$

(123.27) (-3.34)

According to this result, one percent change in the ratio of VG implies that the productivity will increase by 14 percent⁵⁵.

The domestic productivity level is consistent with the production function. We assume that a steady state technology gap, for instance is equal to 0.6 so that $\frac{AX_{ss}}{TFR_{ss}} = 0.6$. Hence, it

gives the value of technology frontier in the calibration of $TFR_{ss} = \frac{AX_{ss}}{0.6}$. In the

simulations technology gap grows exogenously according to the rate, given exogenously. Then, by starting out with a lower value of technical progress an endogenous catching-up can be simulated when $\frac{AX_t}{TFR_t} < 0.6$. Finally, the parameter in (1.3) can be calibrated by

using the values of the growth of technical progress, the ratio of VG and the trade share of GDP for the base year⁵⁶ or by simply putting initial technology gap as known. For example, following Aglietta et al. (2007) technology gap with frontier has been shown as equal to 0.4 by the end of last century in Russia.

⁵⁵ In Stokke (2004), the share parameter of the rates of secondary enrolments is equal to 0.33.

⁵⁶ See Appendix 4.5.3.

4.3 The Computable General Equilibrium Model

Originally, the computable general equilibrium model for Kazakhstan with 3 sectors such as agriculture, industry and services has been developed by Stéphane Calipel and Jean-Michel Marchat from the CERDI, Université d'Auvergne, within a TACIS Programme of technical assistance to Kazakhstan in 1999-2001 (EDKZ9602). The productivity growth of each sector was assumed to be constant. Taking as a basis of our study, we introduce the Nelson-Phelps adoption function in the logistic from (1.3) and the relevant variables of the catch-up process in the model. Due to the unavailability of data on vocational and general education across the sectors we construct one-sector CGE model for the purpose of prospective analysis of the catching up in Kazakhstan.

4.3.1 Production function

One-sector small open economy is assumed to be populated by the continuum of homogenous agents and to have a potential to produce goods employing two primary inputs such as labour (L) and capital (K). Labour and capital are immobile internationally. The output of goods (X) can be traded on world markets. Furthermore, we assume that output X is produced a large number of identical firms according to the Cobb-Douglass production function⁵⁷

$$X_t = (AX_t \cdot L_t)^\alpha K_t^{1-\alpha}, \text{ where } 0 < \alpha < 1 \quad (1.8)$$

where L_t is a labour used in production and AX_t – a labour-augmenting measure of productivity. It is assumed that labour is homogenous, and each unit of labour becomes qualified with a relative increase in vocational education. The labour-augmenting technical progress is endogenously determined by the economy's relative position to the world technology frontier and the barriers to technology adoption, channelled by its ability to take advantages from technology diffusion and its foreign trade. At the steady states technical progress equals the exogenous growth rate of technology frontier. The steady states are defined by the exogenous growth rates of technical progress and the labour supply.

⁵⁷ The full documentation of the computable general equilibrium model is given in Appendix 4.5.5.

As earlier demonstrated, allocating the time either to acquiring skills at secondary schools or to producing goods necessarily implies a change in the structure of working population with secondary education. A direct effect of the ratio of VG is referred to that labour force which is formerly educated at secondary vocational schools becomes essential in adopting and implementing new technologies. Following [Lucas \(1988\)](#) an indirect effect of increased investment in education is a reduced labour supply which influences the wage through the labour market equilibrium. However, showing a relative increase of investment in secondary vocational education the ratio of VG allows for retaining labour, fully engaged in production but definitively changed in each time in favour to secondary education. Therefore, it is assumed that working population with secondary education structurally adjusts to technology adoption which is conducive to productivity growth and enters in (1.8) as a simple factor of production.

4.3.2 Growth path analysis

The CGE model is calibrated to reproduce the growth perspectives for Kazakhstan since 1998 year, driven by, let's say, a technological catch-up, taking into account the education levels and the degree of openness and the technology gap. The main subject of our study is to analyze the dynamics of the variables, such as technology gap, the barrier function and the ratio of VG. As it has been underlined, the ratio of VG will be endogenously determined by a U-inverted curve (1.5) or exogenously introduced by calculated VG as presented in Table 4.2⁵⁸.

As it concerns the initial technology gap we follow [Aglietta et al. \(2007\)](#) where the productivity level is estimated in Russia to about 40 percent of the level in the United States in 1998, corresponding to a technology gap of 0.4. Therefore, we assume an initial technology to the frontier of 0.35 in Kazakhstan for the base year, so that the economy starts with a productivity growth rate of 2.9 percent. However, in most cases we optionally take 3.7 percent as initial productivity growth to compare dynamics.

The relationship between the growth rate of productivity and technology gap is given by (1.3). Even though the economy is far from the frontier, the absorptive capacity, measured

⁵⁸ We assume that the composition of secondary educational stock in Kazakhstan is optimized.

by the skill levels of workers and degree of trade openness, is assumed to equal 0.664, the initial value of the ratio of VG in Kazakhstan for the base year. Given the calibration, an increasing advantage of technology adoption during the whole period of study implies that the improvements in the efficiency of the education system and the openness of trade will generate continuous shifts in the technology gap from 0.35 to 0.42. As we see from Figure 4.3 the economy approaches the frontier more rapidly when the dynamics of VG is defined exogenously as compared to that it is determined endogenously. However, the outcomes are similar as they decline by the end of period of 1997-2019⁵⁹ when the growth of productivity converges to its local steady state.

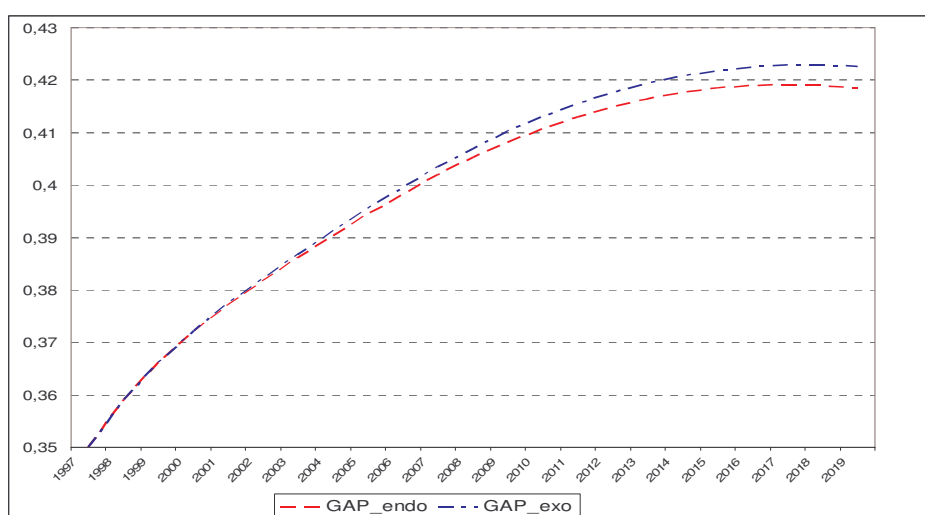


Figure 4.3 Technology gap under endogenous and exogenous VG, when $AX=3.7\%$

The dynamics of technology gap, as compared to other variables is most influenced by the growth rate of technical progress. Whereas the productivity at the frontier is assumed to grow with a constant rate of 1.1 percent two scenarios of initial technical progress are compared. A higher initial productivity implies that the economy closes the gap with the frontier whereas a lower initial technical progress keeps the gap below 0.4 (Figure 4.4).

Often, countries can not reach the higher level of efficiency of technology diffusion because of the difference in the amount of sizeable and persistent constraints on technology adoption (Parente and Prescott, 2004). Different types of barriers can be categorized as international barriers, including tariffs, quotas and regulatory barriers to foreign producers,

⁵⁹ The time period is determined by the CGE model for Kazakhstan.

and domestic barriers, including entry barriers, inefficient financial systems and subsidized state-owned enterprises. Cole et al. (2005) argue that large changes in the size of barriers to competition are systemically followed by large productivity changes. Following the authors Latin America has erected huge competitive barriers that far exceeds those in East Asia and therefore, gets in low productivity growth.

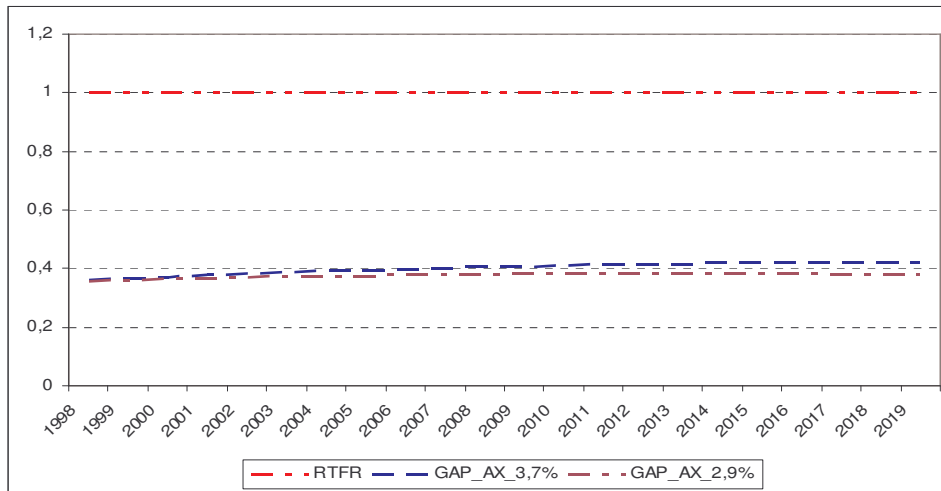


Figure 4.4 Total factor productivity under the different initial technical progress

The expression of the productivity growth (1.3) takes into account the persistence of barriers to technology adoption. Since the ratio of VG and the share of trade are endogenous in the model, the abundance of barriers (1.2) is also endogenously determined.

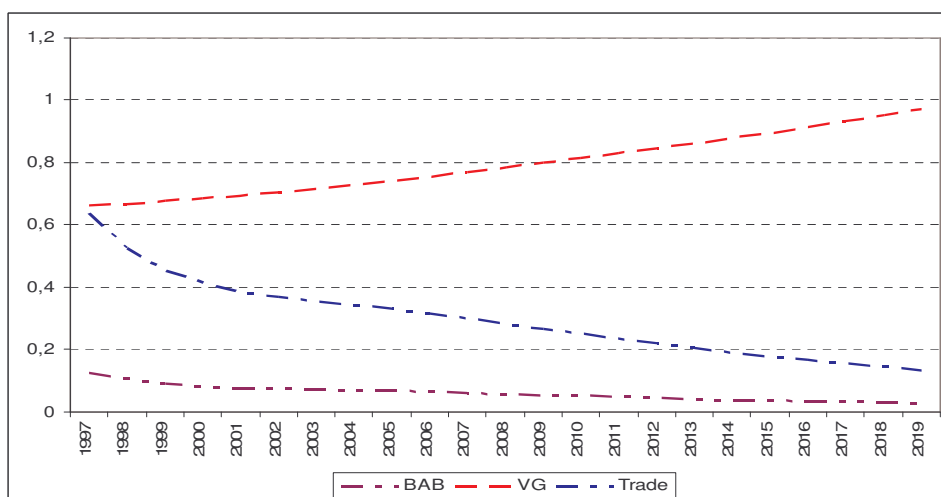


Figure 4.5 The determinants of the barrier function: endogenous VG and trade

As a result, the barrier function decreases because the share of trade diminishes⁶⁰. In other words, the economy faces with a sharply increased magnitude of barriers at the beginning of the period when it begins the convergence towards technology frontier (Figure 4.5). However, the barriers to technology adoption are further relaxed with increasing the efficiency of human capital.

The pattern of productivity (1.3) describes a situation when the economy, which initially grows faster, converges to the local steady state or so-called ‘an underdevelopment trap’, for example, due to the inconsistency between lower skills of labour and new technologies. The existence of underdevelopment trap is demonstrated by [Azariadis and Drazen \(1990\)](#) arguing that “*Rapid growth can not occur without relatively overqualified labour, that is, without a high level of human investment relative to per capita income*” (page 504). The growth rate of technical progress decreases from its 3.7% and in 2018 year falls below the rate of frontier (Figure 4.6). Consequently, during the period of 1997-2018 the technology gap with the frontier approaches to the technology frontier due to the higher growth of technical progress. However, after this period the technology gap begins to stabilize and hence, the productivity finds it lowest level by the end 2019 year.

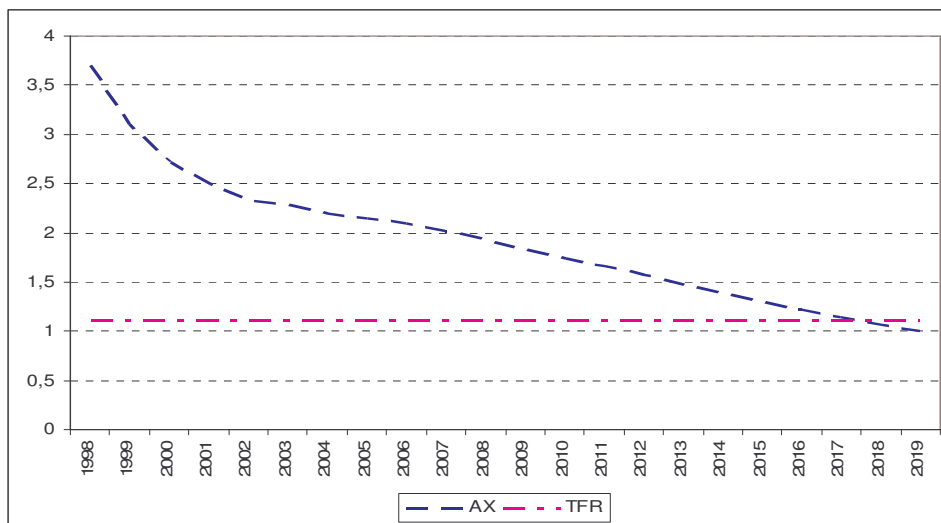


Figure 4.6 The evolution in the technical progress and the productivity growth at frontier

⁶⁰ It is assumed that both world price of import good PWM_i and world price of export good PWE_i grow with a constant rate. Certainly, we may provide different simulations depending on diverse exogenous growth rates of export and import prices but this might not change considerably the conclusions.

Very importantly, the resistance of the barriers to technology adoption is different depending upon on how the ratio of VG is introduced. In particular, the endogenous VG corresponds to more resistant barriers than the exogenous VG (Figure 4.7). Certainly, there

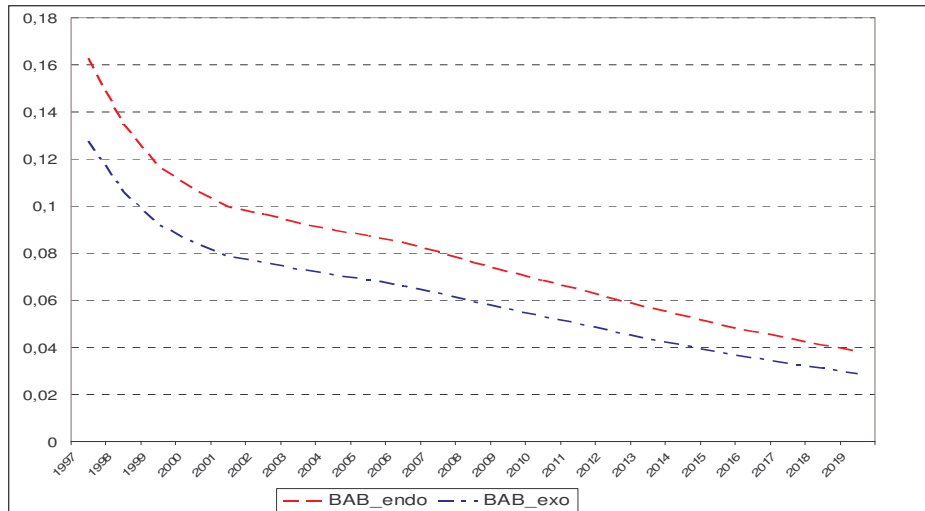


Figure 4.7 Barrier functions under endogenous and exogenous VG

is a link between the growth rate of technical progress and the barrier function as they similarly tend to decline by the end of the period. The dynamics of productivity growth is predetermined by the barrier function and vice versa, the magnitude of the barriers defines

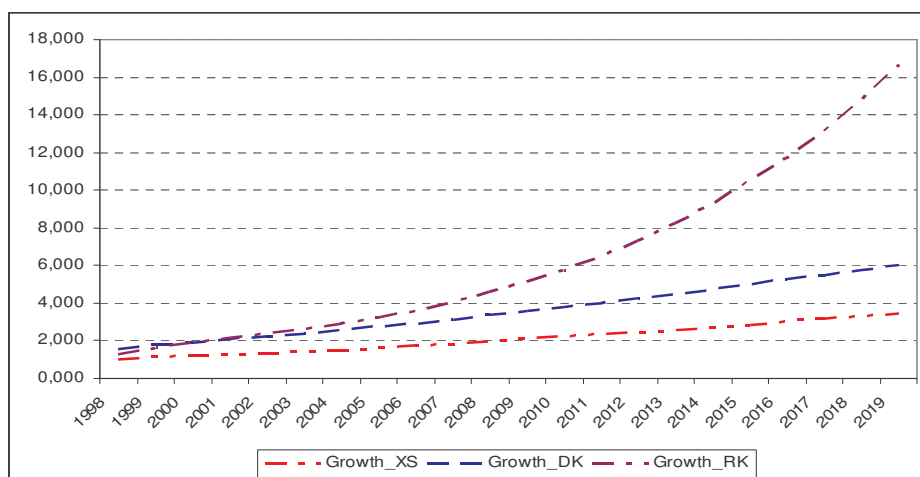


Figure 4.8 The growth of production, total investment and capital income

the growth rate of technical progress. Seemingly, a higher initial growth rate of technical progress serves as a powerful tool for weakening the magnitude of the barriers to

technology adoption. On the contrary, a high depth of barriers that occurs at the beginning of the period firmly lowers the productivity growth.

Nevertheless, the growth rate of technical progress remains as the main factor of catch-up process. We observe a growing marginal return to investment since the beginning of the period with consequent high investment growth and capital accumulation. Certainly, high productivity makes investments more profitable and therefore, capital income will grow. There is the interplay between productivity growth and high investments, together with a gradually improved efficiency of human capital in adopting foreign technologies. Higher investments in education, resulted a relative increase in working population with vocational education, has the positive effects on the productivity growth and therefore, the growth of production. The model shows that the production of goods increases although capital income rises more rapidly than investment and production (Figure 4.8).

4.4 Conclusion

The paper develops a computable general equilibrium model by incorporating the Nelson-Phelps approach that presents an analytical tool in evaluating the long-term catch-up potential of a transition economy. The catching-up function of technology diffusion which is newly specified by the ratio of VG, is introduced for the purpose of policy analysis in Kazakhstan.

The concept of [Lucas \(1988\)](#) is revisited to demonstrate that there exists a balanced growth path of the size of secondary education and the ratio of VG. Moreover, it is shown that alongside the balance growth path both secondary education and the ratio of VG grow positively. Allocating the time either to acquiring skills at secondary schools or to producing goods necessarily implies a change in the structure of working population with secondary education. Therefore, it is assumed that working population with secondary education structurally adjusts to technology adoption which might be conducive to productivity growth and can be entered in the production function as a simple factor of production. The present underpinning allows for using the ratio of VG in place of secondary enrolments rates and thereby, re-establishing the relationship with productivity growth in empirical studies.

The ratio of VG presents a broader measure of human capital accumulation as it reflects greater technological skills, imparted through secondary education. Thus, it can be applied to both developing and transition economies where the main occupation of technology adoption is imitation process. The growth path in Kazakhstan is seen as it will be based on low technological industries which are not characterized by *R&D*-intensive high skilled production. By analyzing the endogenous interaction between technology diffusion and improvements in the efficiency of human capital in Kazakhstan the model reveals the economy's convergence to its lower steady state in 22 years. The policy implications are related to improving the country's absorptive capacity through significant investment in the education system and lowering barriers to technology adoption, aimed at taking great advantages from technology diffusion.

Further research can be devoted to modelling technological catching-up with the ratio of VG for a developing country.

4.5 Appendices

4.5.1 Proof of the properties

As it is indicated in Figure A.1, if we assume that $V_t < V_{t+1} < G_{t+1} < G_t$ or the angle of slope, for example, belongs to $90^\circ < \alpha < 135^\circ$ and we multiply the above inequalities by G_{t+1} and V_{t+1} correspondingly then they will look as follows $V_t \cdot G_{t+1} < V_{t+1} \cdot G_{t+1} < G_t \cdot G_{t+1}$ and $V_{t+1} \cdot G_t > G_{t+1} \cdot V_{t+1}$. Hence, we will get that $V_{t+1} \cdot G_t > G_{t+1} \cdot V_t$ or $\frac{V_{t+1} \cdot G_t}{V_t \cdot G_{t+1}} > 1$ which proves the property (P.2).

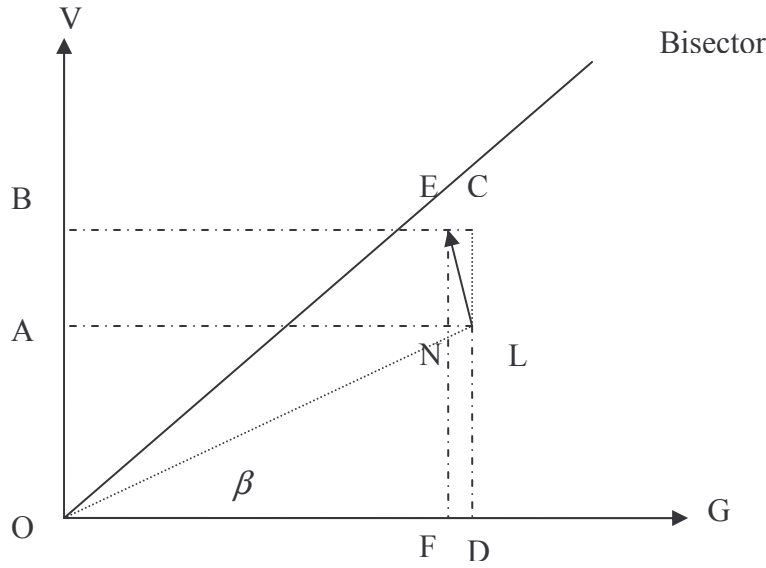


Figure A.1 The ratio of VG grows positively

For example, if the initial point L slides to the final point E or $\Delta V_t + \Delta G_t \rightarrow 0$ which

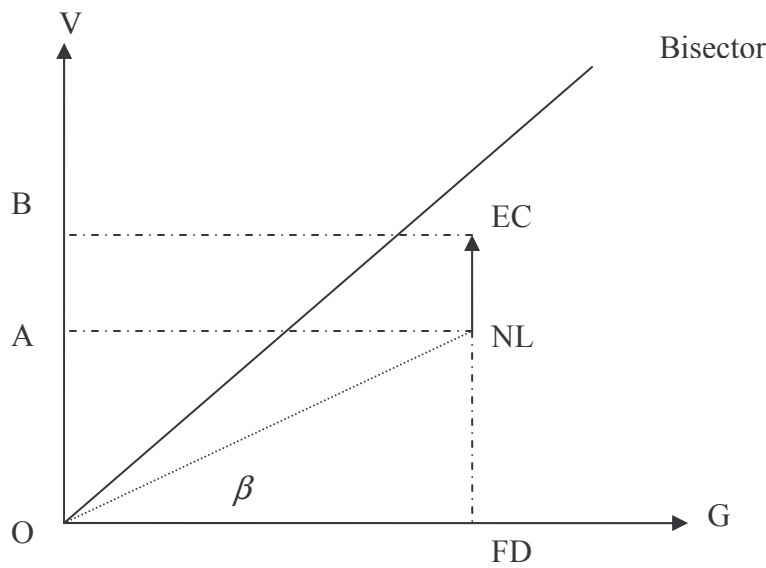


Figure A.2 $\Delta G_t = 0$ or $\alpha = 90^\circ$

occurs only when if $\Delta V_t \rightarrow 0$ and $\Delta G_t \rightarrow 0$ then the perimeters the rectangles ($OBEF$) and ($OALD$), and the areas of the rectangles ($OBCD$) and ($OANF$) will be the same and equal to one. Figure A.2 shows that the difference in general education converges to zero or $\Delta G_t \rightarrow 0$ which is equivalent to $\alpha = 90^\circ$ and $V_{t+1} > V_t$. Hence, we multiply the inequality by G_t and add $V_{t+1} \cdot V_t$ to its both sides, and then it will look as follows $V_{t+1} \cdot V_t + V_{t+1} \cdot G_t > V_t \cdot G_t + V_{t+1} \cdot V_t$. Multiplying again both sides of the inequality by G_t or/and G_{t+1} which are the same we will get after its transformation that $\frac{V_{t+1} + G_{t+1}}{V_t + G_t} < \frac{V_{t+1} \cdot G_t}{V_t \cdot G_{t+1}}$ which proves the property (P.3).

Now, the difference tends to zero or $\Delta V_t \rightarrow 0$ is shown in Figure A.3. It means that the initial point of the vector slides on the vertical line. However, by virtue of that the angle of slope can get its maximum at 45° , then $\Delta V_t \rightarrow \Delta G_t$.

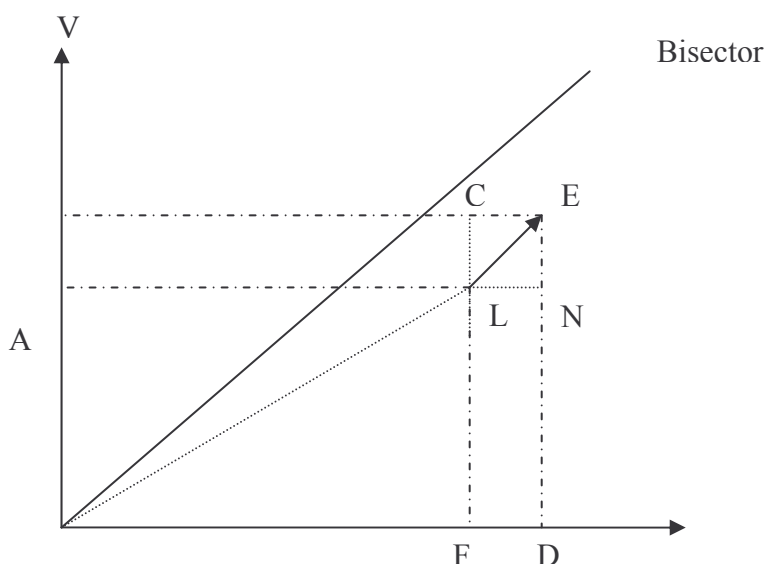


Figure A.3 $\Delta V_t = \Delta G_t$ or $\alpha = 45^\circ$

The latter is the same as when the sum of vocational and general education maximizes. Thus, the growth of secondary enrolments will be superior to that of the ratio of VG which proves the property (P.4).

4.5.2 Alongside of the balanced growth path

First above, following the property (P2), when the angles of slope equals 90^0 and more until it gets $\alpha = \frac{225^0 - \beta}{2}$, where $\beta < 45^0$ the growth rate of the ratio of VG will be superior to

one. Now, we need to show that it will be equally relevant to secondary education. For that, let express $V_{t+1} + G_{t+1} = \omega_t \cdot (V_t + G_t)$, where $V_{t+1} = V_t + \sin \alpha$ and $G_{t+1} = G_t + \cos \alpha$. Thus, taking into account that $\sin \frac{225^0 - \beta}{2} = \cos \frac{45^0 - \beta}{2}$ and $\cos \frac{225^0 - \beta}{2} = -\sin \frac{45^0 - \beta}{2}$ we

will get that $\omega_t = 1 + \frac{\cos \frac{45^0 - \beta}{2} - \sin \frac{45^0 - \beta}{2}}{V_t + G_t}$ which is superior to one.

4.5.3 Calibration of the parameter in the productivity pattern

Now, it remains to calibrate the parameter (b) in the pattern of productivity dynamics (1.3). For that, we use a method which consists in searching the initial value of technical progress (AXO) from the function of production. Thus, putting arbitrarily the targeted value of the technology gap $GAP^*=0.6$ we will find approximately the initial value of the technology frontier by

$$TFRO = \frac{AXO \cdot (1 + RAXO)^{TF}}{GAP^* \cdot (1 + \eta)^{TF}} \quad (D.1)$$

where TF is the final time period and $RAXO$ - the initial growth rate of technical progress, which is arbitrarily chosen. However, the growth rate of technical progress is endogenous. Using the initial values of the ratio of vocational to general education (VGO) and trade share of GDP ($TRADEO$) the calibration of the parameter in productivity growth is defined as⁶¹:

$$b = \frac{RAXO}{VGO^\eta \cdot TRADEO^\eta (GAPO - GAPO^2)} \quad (D.2)$$

where the initial value of the technology gap ($GAPO$) is certainly determined from (1.3) because the technical progress AXO and the technology frontier $TFRO$ are initially known.

⁶¹ It can be calibrated in a different way as $b = \frac{\eta}{VG_{SS}^{\gamma_1} \cdot TRADE_{SS}^{\gamma_2} (GAP_{SS} - GAP_{SS}^2)}$, but the steady state values of the variables initially remain unknown.

4.5.4 The equations of the CGE Model

The following equations represent the detailed description of the computable general equilibrium model. The numerical model is solved by the GAMS.

1. Production and labour market

A small open economy has a potential to produce goods using endowments of labour (L) and capital (K). The output of goods (X) can be traded on world markets. It is assumed that there is a constant return to scale Cobb-Douglass production function for the economy.

$$XS_t = (AX_t \cdot LD_t)^\alpha K_t^{1-\alpha} \quad (E.1)$$

The first order conditions yield:

$$W_t = \frac{\alpha \cdot PVA_t X_t}{LD_t} \quad (E.2)$$

$$R_t = \frac{(1-\alpha) \cdot PVA_t XS_t}{K_t} \quad (E.3)$$

$$PVA_t = PX_t \cdot (1 - TX_t) - \sum_{j=1} a_{ij} \cdot PQ_j \quad (E.4)$$

where, the profit rate (R_t) is the ratio of gained profits (RK_t) over the stock of capital (K_t). The labour supply in the urban sector (L_U^S) and in the rural sector (L_R^S) equals the sum of labour demand of the economy and from the State (LG_t) plus unemployment ($CHOM_t$). As the nominal wage is nominally rigid, there is a quantity adjustment on labour market.

$$L_U^S + L_R^S = LD_t + LG_t + CHOM_t \quad (E.5)$$

There is no unemployment in the rural area. The urban unemployment equilibrates the labour market. The nominal wages for the urban sector are assumed to be rigid and there is a quantity adjustment on the labour market. By contrast; the wage in the rural area is remunerated by the marginal labour productivity.

The following equations define the evolution of the ratio of VG and barrier function.

$$VG_t = vga + vgb \cdot \frac{PIBT_t}{POP_t \cdot E_t} - vgc \cdot \left(\frac{PIBT_t}{POP_t \cdot E_t} \right)^2 \quad (E.6)$$

$$BAB_t = ba \cdot VG_t^{\gamma_1} \cdot \left(\frac{EX_t + M_t}{PIBT_t} \right)^{\gamma_2} \quad (E.7)$$

There are three economic agents in the domestic economy and these are namely households (consumers), enterprises (producers) and the government. This is in addition to the Rest-of-World (ROW) with whom the domestic economy trades in goods and services (exports and imports). Each of these economic agents has a different behaviour which will be described in details below.

2. Foreign trade

2.1 Exports

Domestic enterprises supply goods to the domestic market and to foreign countries. It is assumed that this division is governed by a constant elasticity of transformation (CET) production function. The enterprises maximize revenues from the domestic and foreign markets. The price of exports is the world price of exports in foreign currency multiplied by the exchange rate of the local currency. The price of exports is net of any export tax.

$$PE_i \cdot (1 + TE_i) = E \cdot PWE_i \quad (E.8)$$

The domestic price of exports (PE_i) increased from export taxes (TE_i) equals the world price of the same good in domestic currency (i.e. the world price PWE_i multiplied by the nominal exchange rate E).

$$XS_i = AE_i \cdot \left[(ae_i \cdot EX_i^{\rho_{e_i}}) + ((1 - ae_i) \cdot DD_i^{\rho_{e_i}}) \right]^{\frac{1}{\rho_{e_i}}} \quad (E.9)$$

The repartition of production between the export market and the domestic market is done through the CET that depends on exports (EX_i) and on domestic demand (DD_i). AE_i is scale parameter. $0 < ae_i < 1$ is a sectorial proportion parameter. ρ_{e_i} is a parameter used to compute the elasticity of transformation.

$$EX_i \cdot (ae_i \cdot PD_i^{\sigma_{e_i}}) = DD_i \cdot ((1 - ae_i) \cdot PE_i^{\sigma_{e_i}}) \quad (E.10)$$

This expression, derived from the first order conditions, defines the relative share of exports versus domestic demand.

$$PX_i \cdot XS_i = PE_i \cdot EX_i + PD_i \cdot DD_i \quad (E.11)$$

The domestic production in value at current prices ($PX_i \cdot XS_i$) equals the current value of exports ($PE_i \cdot EX_i$) plus the current value of domestic sales ($PD_i \cdot DD_i$).

2.2 Imports

It is assumed that domestic and foreign goods are imperfect substitutes and therefore, there is a composite good. Therefore, enterprises combine the good imported with the domestically produced output good into a composite good that will be provided to the domestic market. The enterprises minimize the costs of combining the imported goods and the domestic product using a constant elasticity of substitution (CES) production function. The price of imports is the world price of imports in foreign currency, multiplied by the exchange rate of the local currency. The price of imports includes any import tariffs.

$$PM_i = E \cdot PWM_i \cdot (1 + TM_i) \quad (E.12)$$

The domestic price of imports (PM_i) equal the world price of the same good in domestic currency (i.e. the world price PWM_i multiplied by the nominal exchange rate E) increased from import taxes (TM_i).

$$Q_i = AM_i \cdot \left[(am_i \cdot M_i^{-\rho m_i}) + ((1 - am_i) \cdot DD_i^{-\rho m_i}) \right]^{\frac{1}{\rho m_i}} \quad (E.13)$$

An Armington function that considers the demand for a composite goods is a CES function of imports (M_i) and of domestic demand (DD_i). We consider here that a possibility of imperfect substitutability between imported and domestic goods exists, i.e. there is some product differentiation. AM_i is a scale parameter. $0 < am_i < 1$ is a sectorial proportion parameter. ρm_i is a parameter used to compute the elasticity of substitution.

$$DD_i \cdot (am_i \cdot PD_i^{\sigma m_i}) = M_i \cdot ((1 - am_i) \cdot PM_i^{\sigma m_i}) \quad (E.14)$$

This expression, derived from the first order conditions, defines the relative share of imports versus domestically produced goods.

$$PQ_i \cdot Q_i = PM_i \cdot M_i + PD_i \cdot DD_i \quad (E.15)$$

The domestic demand for composite good in value at current prices ($PQ_i \cdot Q_i$) equals the current value imports ($PM_i \cdot M_i$) plus the current value of domestic sales ($PD_i \cdot DD_i$).

3. Income and savings

The public sector income is the sum of all taxes collected. They are:

$$\text{The production tax} \quad TAXX_i = TX_i \cdot PX_i \cdot XS_i \quad (E.16)$$

$$\text{Taxes on imports} \quad TAXM_i = TM_i \cdot PWM_i \cdot E \cdot M_i \quad (E.17)$$

$$\text{Taxes on exports} \quad TAXE_i = TE_i \cdot PE_i \cdot X_i \quad (E.18)$$

$$\text{Value added tax} \quad TAXVA_i = TVA_i \cdot PQ_i \cdot C_i \quad (E.19)$$

$$\text{Tax on households income} \quad TAXYM = TYM \cdot YM \quad (E.20)$$

$$\text{Tax on enterprise income on public sector revenues} \quad TAXYE = TYE \cdot YE \quad (E.21)$$

$$YG = TAXYM + TAXYE + \sum_{i=1} (TAXX_i + TAXM_i + TAXE_i + TAXVA_i) \quad (E.22)$$

The public sector saving is the difference between the revenues (YG), the wage bill ($WG \cdot LG$) and the consumption of goods (CG).

$$SG = YG - WG \cdot LG - CG \quad (E.23)$$

Households derive the following as capital income:

$$RKM = (1 - \delta) \cdot \sum_{j=1} RK_i \quad (E.24)$$

The capital income distributed to households RKM is the sum of sectorial profit adjusted for the share that goes directly to companies (δ).

$$YM = RKM + \sum_{i=1} W_i \cdot LD_i + WG \cdot LG \quad (E.25)$$

The total gross income of households (YM) is derived from capital (RKM) and labour employment in the different sectors.

$$YDM = YM \cdot (1 + TYM) \quad (E.26)$$

Household's disposable income (YDM) is their total gross income (YM) less the tax on household's income (TYM).

$$SM = pms \cdot YDM \quad (E.25)$$

Household's saving (SM) equals a constant marginal propensity to consume (pms) multiplied by the Household's disposable income (YDM).

$$CM = YDM - SM \quad (E.26)$$

Household's consumption is the difference between the disposable income and their saving. For enterprises, the income is:

$$YE = \delta \cdot \sum_{i=1} RK_i \quad (E.27)$$

Enterprises income (YE) is the sum of sectorial profits adjusted for the share that goes directly to companies (δ).

$$SE = YE - TAXYE \quad (E.28)$$

Enterprises saving are equal to enterprises income minus the tax on enterprise income.

4. Prices

$$PC_i = PQ_i \cdot (1 + TVA_i) \quad (E.29)$$

Consumption prices are the prices of composite goods increased from VAT.

$$PK_i = \sum_{i=1} \beta_{ij} \cdot RQ_i \quad (E.30)$$

$$PINDEX = \sum_{i=1} \beta_{ci} \cdot RC_i \quad (E.31)$$

The consumer price index (*PINDEX*) is the weighted average of consumption prices.

5. Demand for final and intermediate goods

5.1 Investments

$$DKT = SM + SG + SE - BC \quad (E.32)$$

Total investment is the sum of domestic saving minus the trade balance account.

$$PK_j \cdot DK_j = DKT \cdot \alpha_{kj} \cdot \left[\frac{\alpha_{kj} \left(\frac{R_j}{PK_j} \right)^{\alpha_{kj}-1}}{\sum_{i=1} \left(\frac{R_i}{PK_i} \right)^{\alpha_{ki}-1}} \right] \quad (E.33)$$

$$INV_i = \sum_{j=1} \beta_{ij} \cdot DK_j \quad (E.34)$$

5.2 Intermediate inputs

$$C_{ij} = \alpha_{ij} \cdot XS_j \quad (E.35)$$

Quantities of intermediate inputs are a function of a technical coefficient (α_{ij}) and of the production (XS_i).

$$PC_i \cdot C_i = PC_i \cdot cm_i + pmc_i \cdot \left(CM - \sum_{j=1} PC_j \cdot cm_j \right) \quad (E.36)$$

Linear Expenditure System (LES) for consumption.

$$G_i = \beta_{gi} \cdot \left(\frac{CG}{PQ_i} \right) \quad (E.37)$$

Sectorial volume of Government Consumption.

5.3 Balance of payments

$$BC = -FKW \cdot E \quad (E.38)$$

5.4 Equilibrium in goods market

$$Q_i = C_i + G_i + INV_i + \sum_{j=1} C_j \quad (E.39)$$

5.5 Money

The equilibrium in the money market is attained if the demand for money is equal to its supply.

$$MM \cdot vm = \sum_{i=1} (PC_i \cdot C_i + PQ_i \cdot (G_i + INV_i)) \quad (E.40)$$

5.6 Accounting relations

$$PIBM = \sum_{i=1} PVA_i \cdot XS_i \quad (E.41)$$

$$PIBT = PIBM + WG \cdot LG + \sum_{i=1} PQ_i \cdot G_i \quad (E.42)$$

5.7 Walras Law

$$\sum_i PWE_i \cdot E_i + FKW = \sum_{i=1} PME_i \cdot M_i \quad (E.43)$$

6. Dynamic equations

The growth rate of labour force is given by the following equations, where the growth rates are exogenous.

$$L_{ut}^S = L_{ut-1}^S \cdot (1 + TXLS_t) \quad (E.44)$$

$$L_{rt}^S = L_{rt-1}^S \cdot (1 + TXLS_t) \quad (E.45)$$

The evolution of capital stock

$$K_t = (1 + d_{it}) \cdot K_{t-1} + DK_{t-1} \quad (E.46)$$

$$POP_t = POP_{t-1} \cdot (1 + TXPOP_t) \quad (E.47)$$

$$AX_t = AX_{t-1} \cdot (BAB_{t-1} (GAP_{t-1} + GAP_{t-1}^2) + 1) \quad (E.48)$$

where, VG_t – the ratio of vocational to general education. The rate of labour-augmenting technical progress growth (AX_t) is specified in terms of barriers and distance to technology frontier, which is defined as

$$GAP_t = \frac{AX_t}{TFR_t} \quad (E.49)$$

Productivity at technology frontier grows with a constant rate.

$$TFR_t = TFR_{t-1} \cdot (1 + \eta) \quad (E.50)$$

7. Variable definitions

Parameters

α	Share parameter in production function
a_{ij}	Technical coefficients
αe_i	Dimension parameter in CET function
σe_i	Proportion parameter in CET production function
ρe_i	Substitution parameter in CET production function
αm_i	Dimension parameter in CES function
σm_i	Proportion parameter in CES production function
ρm_i	Substitution parameter in CES production function
βc_i	Key for household's consumption
βg_i	Key for public consumption
β_{ij}	Key for investment repartition
αk_i	Repartition parameter of the CESK function
σk_i	Substitution elasticity in investment demand function
ρk_i	Exponent of the CESK function
CM_i	Minimum consumption of good i
pmc_i	Propensity to consume good i
ε_i	Elasticity of expenditure with respect to income
Fr	Frish parameter, a proxy of the ratio of income over minimum expenditure
δ	Share of capital income that goes to firms
pms	Propensity to save
vm	Money velocity
d_{it}	capital depreciation rate in each sector
ba	coefficient in technology adoption function
γ_1	elasticity of the VG in technology adoption function
γ_2	elasticity of trade share in technology adoption function

Exogenous variables

AX_i	Labour-augmenting technical progress
GAP	Technology gap
TFR	Technology frontier
POP	Size of population
GM	General government consumption
FKW	Capital financial flows in foreign currency

K_i	Sectoral quantity of capital stock
MM	Monetary base
LG	Labour demand of the public sector
L_R^S	Rural labour supply
L_U^S	Urban labour supply
PWM_i	World price of import good
PWE_i	World price of export good
TE_i	Tax rate on exports
TM_i	Tax rate on imports
TX_i	Tax rate on production goods
TVA_i	Value added tax rate
TYM	Tax rate on household's income
TYE	Tax rate on enterprises income
W	Average wage
WG	Average wage in civil service
η	Growth rate of technology frontier

Endogenous variables

BAB	Abundance of barriers
VG	Ratio of vocational to general education
BC	Current account balance in local currency, KZT
C_i	Consumption (quantity)
G_i	Government consumption (quantity)
CIJ_i	Sectoral input consumption (quantity)
$CHOM$	Unemployment
CM	Total consumption of households in value
DD_i	Domestically consumed goods (quantity)
DK_i	Sectoral investment (quantity)
DKT	Value of total investment
E	Exchange rate (in terms of KZT per US Dollar)
EX_i	Exports (quantity)
INV_i	Sectoral allocation of investment (quantity)
LD_i	Sectoral labour demand
M_i	Imports (quantity)
PC_i	Domestic price of consumption goods
PD_i	Price of domestically produced good
PE_i	Price of export good
PK_i	Price of capital
PQ_i	Net of tax price of composite goods
$PIBM$	GDP at market prices
$PIBT$	Total GDP at factor costs
$PINDEX$	Overall price level

PM_i	Price of import good
PVA_i	Price at value added
PX_i	Production price
Q_i	Demand for composite goods (quantity)
RK_i	Capital income
RKM	Capital income redistributed to households
R_i	Sectoral capital income
SE	Enterprises saving
SG	Public saving
SM	Households saving
$TAXYM$	Tax on household's income
$TAXYE$	Tax on enterprises income
$TAXX_i$	Tax on production
$TAXM_i$	Import taxes
$TAXE_i$	Export taxes
$TAXVA_i$	Value added tax
W_i	Average wage rate in the rural sector
XS_i	Supply of goods (quantity)
YDM	Household's disposable income
YE	Enterprises income
YG	State revenue
YM	Household's income

4.5.5 Social Accounting Matrix for Kazakhstan

Table F.1 A theoretical SAM

	Labour	Capital	HH	ENT	RoW	GOV	ACC	PROD	DOM	FOM	
Labour	RL	RKM	RK-RKM	TAXYM	TAXYE	WB.LG	SG	WB.L	TAXX	TAXVA+TAXM	RL
Capital											RK
HH											YM
ENT											YE
RoW											M
GOV											YG
ACC											S
PROD											PX.X
DOM											PQ.Q+TAXVA
FOM											PWE.E
	RL	RK	YM	YE	PWE.E-BC	YG	I	PX.X	PQ.Q+TAXVA	PWE.E	

Note: HH – household, ENT – enterprises, RoW – rest of world, GOV – government, ACC – accumulation, PROD – production account, DOM – domestic market, and FOM – foreign market.

Table F.2 Kazakhstan SAM 1997, in mln. Tenge

	Labour	Capital	HH	ENT	RoW	GOV	ACC	PROD	DOM	FOM							
Labour	741 072	855 672				122 346		618 727			741 072						
Capital								1 016 216			1 016 216						
HH											1 596 745						
ENT							160 544				160 544						
RoW											543 765	543 765					
GOV							41 804	40 131				63 775	75 890	0	221 600		
ACC							112 013	120 412			29 290	-62 731			198 985		
PROD														2 743 170	514 474	3 257 645	
DOM								1 442 928					161 986	198 985	1 558 927		3 362 825
FOM												514 474					514 474
	741 072	1 016 216	1 596 745	160 544	543 765	221 600	198 985	3 257 645	3 362 825	514 474							

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CHAPTER 5

SUMMARY OF THE ESSAYS

5.1 Summary of the Essays

Chapter 2 Technological Absorptive Capacity and the Distance to Frontier as Relative Barriers to Technology Adoption

This essay develops the Nelson-Phelps catch-up function by specifying the distance to frontier as a ratio of absorptive capacity to the abundance of barriers to technology adoption. The present generalization gives a broader view of catch-up in terms of persistent barriers and therefore, technology adoption is assumed to succeed with weakening the magnitude of barriers in laggard country. The convergence to technology frontier is likely to occur with lowering reverse effects of barriers on technological gap and can be quantitatively described by a logistic model of technology diffusion which is, in turn, derived from the new presentation of the distance to frontier. Hence, the present specification in terms of barriers to technology adoption can be used in evaluating the ‘*potentiality*’ to catching-up with technology frontier.

Moreover, it opens up a large room for further research aimed at classifying the main barriers which are most persistent to technology diffusion and therefore, searching relevant methods to assess their weights. Certainly, the barriers can be identified and assessed with the availability of relevant data. A calibration strategy aims at determining the elasticity of each barrier with respect to productivity growth. Depending upon the value of the barrier abundance function the diverse types of productivity trap: a single steady state, the cyclical attractors or chaos can be detected.

Chapter 3 Optimizing the Composition of Secondary Educational Stock

The composition of labour force with secondary education regains a new interest with the current studies on transition economies. It is known that secondary educational stock favours the process of technology adoption. Seemingly, [Bennett \(1967\)](#) was first to explicitly find the effects of the ratio of vocational to general education on GDP per capita. Very recently, [Bertocchi and Spagat \(2004\)](#) have confirmed the hypothesis of Bennett with a broader sample of countries and longer periods but using secondary educational enrolments because of the lack of regular data on the structure of labour force in the light of

vocational and general education⁶². Moreover, [Krueger and Kumar \(2003\)](#) present a model of household's optimal choice between the two streams of secondary education and show that at early periods favouring vocational education as compared to general education is effective on productivity growth but ineffective at later periods when new technologies are introduced with a more rapid pace.

The present essay offers a model which links VG education and with VG enrolments. It is shown that VG education and VG enrolments are interacted in the diverse directions depending on the level of economic development. Notably, only developing countries have the similar directions of the interaction between VG education and VG enrolments whereas less developed and developed economies have not. Therefore, the existence of a U-inverted curve between the ratio of VG and GDP per capita can be justified by using the rates of secondary enrolments in developing countries. The model shows also that the ratio of VG enrolment can be an exact proxy of the ratio of VG education depending on the share of recently entered at universities students in labour force with general education. Moreover, policies, aiming at increasing the ratio of VG, will certainly result in raising the size of secondary education. Therefore, there exists an optimized trajectory of VG education for developing and transition economy. Apparently, Taiwan has succeeded in rapidly increasing the average years of education by optimizing the composition of secondary educational stock. Respectively, we are able to build an optimized trajectory of GV for developed country. Further research can be linked to finding a trade-off between the different levels of education and the contribution of each of them to economic growth.

Chapter 4 Revisiting Lucas: A Prospective Analysis of the Catching Up in Kazakhstan with a Computational General Equilibrium Model

In accordance with the modern growth theory human capital increases productivity growth by facilitating the adoption of new technologies and enters as a simple factor to production function. Secondary educational enrolments are usually used as a relevant proxy for human capital as applied to developing countries not to transition economies. Therefore, based on the results of the previous essay the concept of [Lucas \(1988\)](#) has been revisited.

⁶² Few data can be collected only by non-regular surveys of labour force by national bodies.

This essay shows that the allocation of time either to education or to production implies that the number of working people with secondary education importantly increases in technology adoption. On the other hand, labour force with vocational education relative to general education tends to be higher in middle income countries. As it has been demonstrated, there exists a balanced growth path of growth rates of the total enrolment of secondary educational and the ratio of VG enrolment. Moreover, alongside of the balanced growth path the total enrolment of secondary educational and the ratio of VG enrolment grow positively.

A prospective analysis of the catching-up in Kazakhstan has been provided by a computational general equilibrium model in which the barriers to technology adoption and productivity growth endogenously interact. VG education is assumed to be taken as a proxy of the efficiency of human capital in the transition economy. The main variables such as technology gap and barrier function are compared with two different dynamics of VG education by endogenously determining with a U-inverted curve and exogenously introducing with calculated VG. The elasticity of VG is econometrically estimated by using the data of the World Bank and TransMONEE 2006 on trade and education for the CEE countries. Thus, the results of simulation shows that the technology gap is stabilized around 0.4 as regard to the world frontier of technology. Finally, a new policy will be needed to overcome the productivity trap and thereby, to ensure the convergence to the higher steady state.

In the conclusion we summarize that:

1. an appropriate function of technology diffusion is derived from the Nelson-Phelps approach by specifying newly the distance with technology frontier;
2. barriers to technology adoption are introduced as a proxy of technological absorptive capacity;
3. the ratio of VG education is found as a relevant measure of human capital accumulation in transition economy;
4. a CGE model is constructed for Kazakhstan to evaluate the long term potential of technological catching-up.

Résumé

Une nouvelle spécification de la distance à la frontière est proposée en termes de barrières à l'adoption dans la diffusion technologique de Nelson-Phelps. Des coûts élevés liés à l'adoption technologique limitent le processus de rattrapage de la frontière mondiale. La nouvelle forme de la productivité, renforcée par l'évidence empirique, permet de modéliser les régimes multiples de convergence vers les points stationnaires. La performance impressionnante de l'Asie du sud montre qu'il existe un lien fort entre une augmentation de la force de travail avec une éducation professionnelle (V) par rapport à celle avec une éducation générale (G) et leur somme (taille de l'éducation secondaire). La littérature récente présente une évidence empirique mentionnant la tendance à la hausse du ratio de l'éducation professionnelle à l'éducation générale aux pays avec les revenus moyens. Cela renforce considérablement l'importance de l'éducation secondaire dans l'adoption technologique et permettrait d'appliquer la théorie de la croissance moderne aux pays en transition. Un modèle est proposé en vue d'analyser les interrelations entre le ratio (V/G) et la taille de l'éducation secondaire et les directions dans lesquelles ils interagissent. Finalement, le concept de Lucas est revisité pour montrer que l'éducation secondaire s'ajuste à l'adoption technologique. Par conséquent, le ratio V/G pourrait être utilisé à la place du taux de scolarisation secondaire dans le modèle de Nelson-Phelps afin de rétablir les liens avec la productivité dans les recherches empiriques. Un potentiel de rattrapage à long terme est analysé avec un modèle d'équilibre général pour le Kazakhstan. Ainsi, la croissance du progrès technique, mesuré en termes des barrières à l'adoption technologique, montre que l'économie, tout d'abord, converge vers le premier point stationnaire, déterminé de façon endogène par l'interaction entre les barrières à l'adoption technologique avec la productivité.

Abstract

A new specification of the distance to technology frontier as relative barriers to technology adoption generalizes the Nelson-Phelps catching-up model of technology diffusion. Higher costs of technology adoption constrain the catch-up process with the world technology frontier. Therefore, the new pattern of productivity gives scope for modelling the multiple regimes of convergence to the steady states. Supported by empirical evidence it allows for interpreting a catching-up in terms of barriers to technology adoption. Next, East Asia's impressive economic performance shows that there is a strong link between a relative increase in vocational education and the size of secondary education. Recent literature presents empirical evidence that the ratio of vocational (V) to general (G) education tends to be higher in middle income countries. Thus, it substantially strengthens that secondary education is important in technology adoption and thereby, seemingly allows for applying the modern growth theory in transition economy. The insights are explored with a model in which the main differences between stemming from raising productivity and increasing the size of secondary education, and the directions in which they work altogether are analyzed. Finally, the concept of Lucas is revisited to demonstrate that secondary education structurally adjusts to technology adoption. Therefore, the ratio of VG can be used in place of gross secondary enrolments in the Nelson-Phelps catch-up model of technology diffusion to re-establish the links with productivity growth in empirical studies. The potential of long-run catch-up toward the technology frontier is analyzed with a computable general equilibrium model for Kazakhstan. The pattern of productivity growth, measured in terms of barriers to technology adoption, reveals that the economy converges initially to lower steady state, endogenously determined by the interaction between the barriers to technology adoption and productivity growth.