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Clément Nouail

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THÈSE PRÉSENTÉE POUR OBTENIR LE GRADE DE

DOCTEUR

DE L'UNIVERSITÉ DE BORDEAUX

ÉCOLE DOCTORALE ENTREPRISE ÉCONOMIE ET SOCIÉTÉ

SPÉCIALITÉ SCIENCES ÉCONOMIQUES (n°42)

Par **Clément Nouail**

La théorie des coûts de transaction et le rôle du trader physique
dans l'organisation de la filière de matière première:
un essai théorique

Transaction costs economics and the role of the commodity trader in the
organization of the industry: a theoretical essay

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Soutenue le 29 mars 2021

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Glossary

Glossary of acronyms

| | |
|------|--|
| API | American Petroleum Institute |
| BDI | Baltic Dry Index |
| CIF | Cost Insurance Fret |
| CTF | Commodity Trading Firms |
| EIA | Energy International Administration |
| FFA | Forward Freight Agreement |
| FOB | Free On Board |
| FTA | Free Trade Agreement |
| GL | Grubel and Lloyd index |
| ICE | Intercontinental Exchange |
| IEA | International Energy Agency |
| IMO | International maritime organization |
| INE | Shanghai International Energy Exchange |
| IOC | International Oil Companies |
| IPE | International Petroleum Exchange |
| IPI | Industrial Production Index |
| IPO | Initial Public Offer |
| LME | London Metal Exchange |
| LNG | Liquefied Natural gas |
| NIST | National Institute of Standards and Technology |
| NOC | National Oil Company |
| OECD | Organisation for Economic Co-operation and Development |
| OHC | Oil Hub Country |

Glossary of acronyms

| | |
|------------|---|
| OPEC | Organization of the Petroleum Exporting Countries |
| SIC | South Improvement Company |
| ULSD | Ultra-Low-Sulphur Diesel |
| WTI | West Texas Intermediate |
| <i>CR</i> | Counterpart risk |
| <i>eac</i> | <i>ex-ante</i> costs |
| OC | Organizational costs |
| | |
| bbbl | barrel |
| b/d | barrel per day |
| mbbl | million barrels |

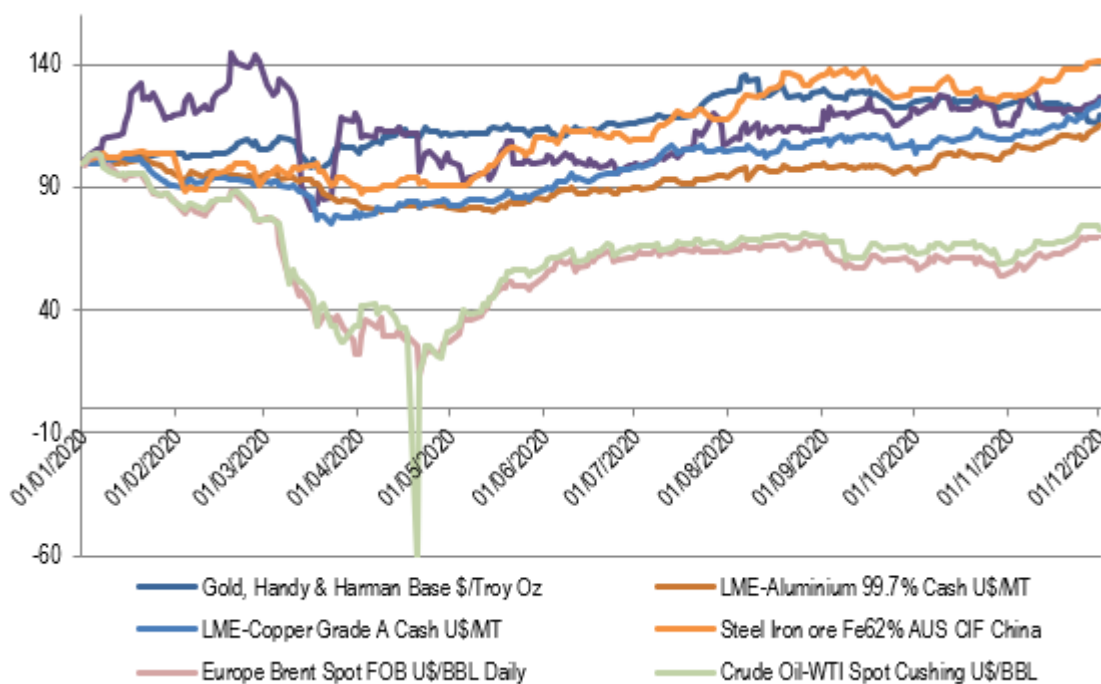
Glossary of model acronyms

| | |
|-----------|---|
| AR | Autoregressive model |
| ARCH | Autoregressive Conditional Heteroskedasticity model |
| ARMA | Autoregressive-moving-average model |
| BEKK | Baba, Engle, Kraft and Kroner model |
| DCC-GARCH | Dynamic Conditional Correlation GARCH model |
| EGARCH | Exponential Generalised Autoregressive Conditional Heteroskedasticity model |
| GARCH | Generalised Autoregressive Conditional Heteroskedasticity model |
| MIDAS | Mixed Data Sampling |
| MST | Minimal Spanning Tree |
| OLS | Ordinary Least Squared |
| PPML | Poisson-Pseudo Maximum Likelihood |
| VECM | Vector Error Correction Model |

General Introduction

The beginning of 2020 was particularly difficult for raw materials and commodity producers, especially those of an extractive nature. As a result of the COVID-19 pandemic that began in China before spreading to the rest of the world and the subsequent containment period, the prices of almost all metals and energy products fell significantly. Between January 1 and March 31, 2020, for example, the price of copper collapsed by nearly 20%, while those of aluminum and nickel fell by 16% and 18% respectively. Platinum, which was also penalized by the structural decline in diesel-powered vehicles, lost 25% of its value during this period. While gold logically grew strongly in a context marked both by very high health and macroeconomic uncertainties and by low interest rates, energy was hit hard by this unprecedented situation. Brent, the world benchmark for crude oil, declined from around \$67/bbl on January 1 to just under \$15/bbl on March 31, 2020. The situation for West Texas Intermediate (WTI) was even more remarkable, with negative prices (\$ -37.63 at the closing price on April 20, 2020) recorded on the May futures contract traded on the Intercontinental Exchange (ICE) (see figure 1).

Figure 1: Changes in commodity prices
(base 100 as of January 1, 2020)



Source: Refinitiv, Thompson Reuters Datastream

With the global economy at a standstill, end-users, whether companies or countries, did not benefit from these particularly low prices, but this was not true for all players in the commodity value chain, especially those in the oil sector. At the end of June, the trading company Trafigura reported a sharp increase in profits for the first half of its 2020 financial year (from 1 October 2019 to 31 March 2020), led by an “exceptionally strong performance in physical oil trading” which was “driven by significant volatility and dislocations in the global market, which make the physical trading and risk management activities of specialist companies such as Trafigura more relevant than ever”. Christophe Salmon, Trafigura’s Group CFO, explains this financial performance in no uncertain terms: *“at times like these, the physical trading and risk management activities of specialist companies such as Trafigura become more relevant than ever. Our core competence lies in understanding the global supply chain in great detail, in having highly skilled trading teams and in managing infrastructure such as oil storage facilities, pipelines and freight capacity. During this period, our market intelligence on the impact of COVID-19 and of the decisions by the Organization of the Petroleum Exporting Countries, the OPEC, and other oil producers on demand and supply, enabled us to act efficiently and effectively. This superior market understanding combined with our physical infrastructure and our capacity to manage the supply chain were key in balancing the oil market during these unprecedented times”*¹.

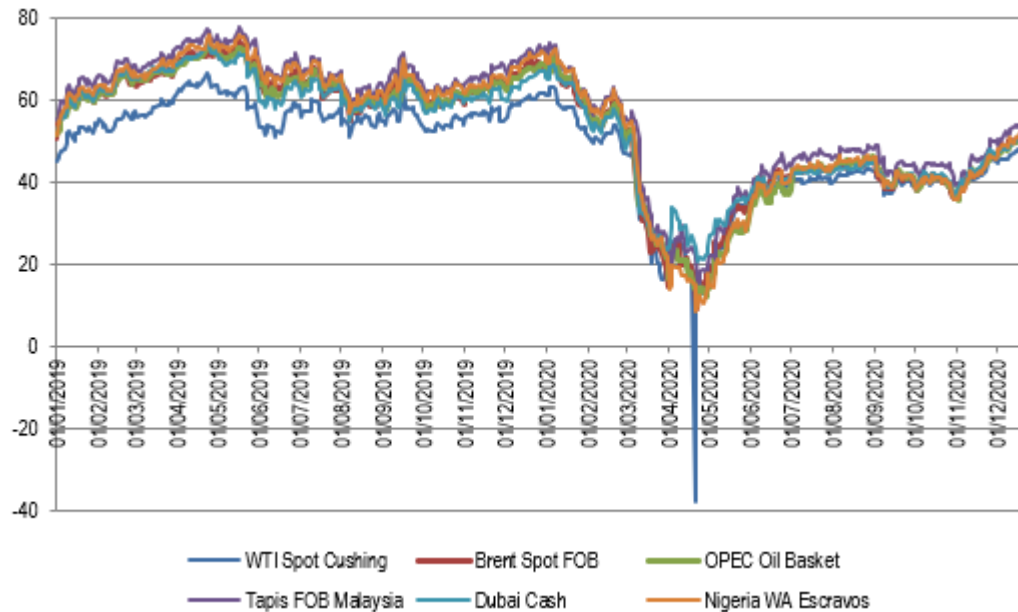
This ability of Trafigura, like probably many physical traders, is actually hardly a surprise. It points to the fact that these traders have an economic role and that this role goes far beyond the mere intermediation function that brokers, for example, perform. As explained by Marquet (1992^[192]), their function is to reconcile, in time and space, sellers (producers/exporters) and buyers (users/importers) on the international physical markets and, in this capacity, to assume a certain number of risks, particularly commercial and price risks. More specifically, *“commodity trading is, in essence, the process of*

¹See Trafigura’s press release dated 11 June 2020, available on the group’s website at the following address: <https://www.trafigura.com/press-releases/trafigura-releases-2020-half-year-results-showing-a-strong-performance>

transforming commodities in space, time, and form. Firms that engage in commodities trading attempt to identify the most valuable transformations, undertake the transactions necessary to make these transformations, and engage in the physical and operational actions necessary to carry them out. The creation of value in commodities trading involves optimizing these transformations” (Pirrong^[228], 2014, p.7). However, the importance of this task is not constant over time. In periods of high prices and constrained supply, or even risks of shortages as it was the case during the so-called “commodity super-cycle” (2002-2012) (see figure 2), the problem for end-users is to secure supplies, which can be achieved through integration strategies upstream of the value chain. Producers, for their part, are in a very-favorable market situation. The profits they make can lead them to consider, in symmetry with the end-users, vertical integration strategies downstream, where there is greater added value resulting from the processing of raw materials. Under such a configuration, the need for physical traders is not essential. This is no longer the case when commodity markets are oversupplied, as it was the case at the beginning of 2020 or from the second half of 2014 to the end of 2016, which, with the slowdown in Chinese economic growth, marked a profound change in the market paradigm.

In this situation of abundance where prices are consequently low, the need for producers is to try to sell at market places where prices are comparatively higher and, for end-users, to take advantage of this situation to get the commodities they need at their lowest prices. Often synonymous with debt strategies on the banking or bond markets during periods of rising prices, vertical integration becomes all the more costly when the declining revenues from activity no longer allow for sufficient financing of interest charges and, for publicly-traded companies, when deleveraging is required by shareholders. This paves the way, in a cyclical dynamic, to a de-integration of value chains with an increased role for the physical trader. It should also be remembered that these low prices may be accompanied, as it is the case since 2018, by a resurgence of protectionist tensions, which also justifies the interest of “market arbitrage” strategies that international physical traders can implement. However, one can only notice that despite the importance

Figure 2: The strong correlation of crude oil prices
(in USD/bbl)



Source: Refinitiv, Thompson Reuters Datastream

of physical traders in commodity value chains and their economic and financial weights, their role remains at best unknown, at worst misunderstood. The fundamental ambition of this thesis is to address this “deficiency” by developing a theoretical approach to model the behavior of this physical trader and its influence on the organization of value chains and, in a complementary way, to implement econometric approaches studying the market conditions in which he intervenes.

An economic definition of commodities

To understand the economic role assumed by physical traders within value chains or industries, it is necessary to specify the very notion of “commodities” beforehand. However, in spite of being the core component of any product, the high variety of commodities does not enable them to benefit from a singular definition. The Habana Charter of 1948, which carries any authoritative weight in this field, defines base products as *any product from agriculture, fishing, forest and any mineral, be it either under its natural shape or its*

*processed format for being sold internationally in large volume*².

This approach, very UN-like, is illustrative of the fact that raw materials are also defined by their economic characteristics. It is yet not sufficient to circumscribe the perimeter of the notion of “commodity”, which – in our view – is very different than that of “raw materials” and, even more so, of “natural resources”. Some raw materials are indeed not widely traded internationally or their price is very dependent on their quality: they cannot be considered as commodities. Some commodities, on the other hand, are already well downstream of the first stage of their production/extraction because they have already undergone a number of industrial transformations and cannot, in this respect, be considered strictly speaking as raw materials. These include, among many other examples, metals (steel in particular, which, like so-called “specialty steels, can be a product with high added value), refined petroleum products, ethanol or even electricity.

Commodities can very logically be identified through “physical” criteria with a segmentation traditionally done between agricultural products, minerals and metals. Are usually categorized as “hard”, resources coming from mining or extracting activities in raw or processed form, like ores and metals, both precious and industrial (ferrous and non-ferrous, also called base metals), as well as non-renewable energy products such as oil, gas or coal and, once again, all the downstream by-products that can be derived from these commodities. In the broad sense, soft commodities can be assimilated to grown commodities like agricultural and “exotic” products. The grain and oilseed markets are the largest in volume terms, but we must also consider the market for dairy products (milk, butter and even cheese which, like Cheddar, can sometimes be recognized as a commodity), meat and, to a lesser extent, fish (salmon can also be considered a stan-

²Implemented by the United Nations Conference on Trade and Employment, the Havana Conference was held in the Cuban capital from november 21, 1947 to March 24, 1948, which concluded with the signing of the Havana charter for an international trade organization, as the first step towards the creation of the multilateral trading system. In Chapter IV on trade policies and barriers to trade, articles 27 & 28 explicitly deal with primary commodities and recognize the right to the existence of commodity price stabilization systems that were experimented in the following decades, with very limited success. The charter can be consulted at the following address: https://www.wto.org/english/docs_e/legal_e/havana_e.pdf

standardized product since an international salmon exchange exists in Bergen, Sweden³) as well as soft commodities, in the narrow sense of the term this time, *i.e.* coffee, cocoa, sugar, as well as rubber, which reminds us that some agricultural commodities may not be food and thus serve an industrial demand (integrated in biofuels, corn can thus be part of the latter category). Agricultural products are involved in a production process that is inherently dependent on the plant growth cycle and results in one or two harvests per year. Consequently, they must deal with a high seasonality and storage services have key role to mitigate price fluctuation during the year. Hard commodities are less exposed to production cyclicity but raises issues about the right timing to extract them rather than keep reserves untapped. Commodities also meet common economic criteria that explain why they form, beyond the differences in products, a coherent set (Marquet, 1993^[192]). Each of these factors explains the specific nature of the role of the physical trader.

First, commodities see their production being highly localized, whereas their demand is global, which means that they are the subject of a vast international trade, as stated in the Habana Charter, in value as well as in volume. The physical reconciliation of supply and demand requires considerable transport infrastructure and logistics, much of which is assumed by physical traders. To be traded on an international market a commodity must be storable. It is the key characteristic to reconcile the time mismatch because of a seasonal supply and/or demand.

Second, commodities are homogeneous products in the sense that quality, while being a fundamental determinant of price levels, is not a sufficiently important variable to protect producers from conditions prevailing in international markets. In other words, price competitiveness is fundamental while non-price competitiveness is not. This means that in the commodity markets, reference prices exist, like Brent, WTI or Fateh for oil crude, and other products of the same nature are traded on the basis of price differentials. As we will explain later, it is precisely the existence of these price benchmarks that makes it

³<https://fishpool.eu>

possible, in part, to develop futures contracts, which are essential price risk management tools for traders. This brings us to the third and fourth characteristics common to commodities: their prices are particularly volatile, not because of a form of market illiquidity, but rather because their explanatory variables (economic, meteorological, financial, logistical, regulatory, psychological) are themselves particularly unstable. Finally, commodities are highly financialized, *i.e.* there is a futures market that not only offers opportunities for hedging and speculation, but also provides price references on the basis of which commercial prices are determined. We did state above that a commodity must be traded internationally to be considered as a commodity. Nevertheless, our commodity definition - while fully acknowledging that there is no consensus in the academic literature on the criterion of definition - requires commodity trade flows as twofold, *i.e.* occurring both in physical and financial markets. As long as they can be storable and exhibit a degree of homogeneity high enough to ensure standardized international trade, commodities might be the best physical underlying asset to a financial contract. Actually, there might not be physical markets as much related to financial ones. The real contribution of future contracts is to provide financial instruments to offset price risk, among other risks related to trades within the industry. One could argue that the description of future contracts as hedging instruments only works for financialized commodities. Nevertheless, we stick to our definition of the twofold trade flows by arguing that futures contracts can offset risks of commodities other than the underlying one. Cross-hedging strategies can be set when two commodity prices exhibit high and stable correlation relationships.

The triptych of soaring commercial markets, physical traders and commodity derivatives markets

The essential role of commodity trading began long before private companies entered the intermediate segment of the value chain. Because this particular intermediation function

is one of prerequisites for productive activities, it might even be considered as one of the oldest sources of international relationship. Indeed, whatever the civilization under scrutiny, commodities are always of central concern. First proofs of trading contracts are found, around 4000 BC, with Sumerians using clay tokens, before clay tablets, to describe the relationship that brings to the delivery of a specified amount of goats at predetermined date and location. These characteristics already summarize the basics of modern future contracts. Civilizations and markets kept spreading until the precious metals were used as money and trades. International trade flows multiplied and created first hubs where supplies and demand could meet. As Chalmin (1983^[51]) or Baffes (2018^[18]) remind us, it is probably to the fall of the Roman Empire and the profound modification of the links between East and West that we owe the rise of physical traders based in Genoa, Venice, Amalfi or Bari whose function of commercial intermediation was then based on manufactured products and not commodities. In the Middle Ages, intra-European trade was organized around the famous Champagne fairs before the bypass of Spain by sea offered to those of Antwerp, Geneva, then Lyon a leading role, while the trade route between England, the Netherlands and Baltic countries (Novgorod, was gaining in importance. Anyone who remembers the saga of the “Accursed Kings” by the French author Maurice Druon knows that the history of international trade is intimately linked to the existence of large families, such as the Sienese house of Tolomei among many others (the renowned German Fugger family which dominated the metal trade at the beginning of the 16th century, for example), and then private associative corporations such as the British “regulated companies” (Chalmin, 1983^[51]), whose ramifications extended across the entire European continent. The quality of the relations that these families and corporations had with the authorities, kings and princes, was a determining factor in the development of this international intermediated trade. It must indeed be acknowledged that if “private” dynamics were the driving force of intra-European trade, they would probably not have been sufficient to give it the international scope that it gradually acquired from the 17th century and what Chalmin (1983^[51]) describes as “the era of the Company of the Indies”, eastern (British) and western (French, Dutch, Swedish and Danish) without the involve-

ment of states and the protection that they could give to merchants in the defense of their interests. However, these relations have always been complex and unstable. Because the development of international trade in commodities is an imperative condition for the monopolization of natural resources for hegemonic purposes, States have been keen to grant commercial monopolies to private companies and, thus, to foster their development. At the same time, the orientation, by the public authorities, of trade flows for strategic reasons was for a long time a definite impediment to their expansion. Clearly, as Marquet (1992^[192]) writes: *“On the one hand, trade can only really develop if it is truly international - stateless - and therefore seeks to avoid rules imposed by States. At the same time, it needs access to national markets, and therefore needs to accept the constraints associated with its locations. On the other hand, states will perceive trading as contrary to their own interests, while at the same time they need its services and know that they can benefit economically, but also strategically, from the power of the trading companies established on their territory⁴”, (p. 19)⁵*. The authorities did not always support the physical traders, on the contrary, placing them in the ranks of “simple” speculators or even price manipulators (called “agoteurs” in French without there being, as far as we know, an exact translation into English), sometimes overwhelming them with faults for which they were themselves responsible, at least partially. The economic history of commodities reminds us, among many other examples, with the episode of the “great grain robbery”, nickname given by U.S. Senator Henry M. Jackson to the massive purchases of wheat, corn, barley and soya beans from six multinational grain companies (among which trading ones) organized between July 5 and August 9, 1972 by Moscow, when the market was in severe deficit, a situation that Washington was unaware of at the time.

⁴*“D’une part, le négoce ne peut réellement se développer que s’il est véritablement international – apatriote – et partant cherche à s’abstraire des règles imposées par les États. Simultanément, il a besoin d’accéder aux marchés nationaux, donc d’accepter les contraintes liées à ses implantations. D’autre part, les États vont percevoir le négoce comme contraire à leurs propres intérêts, alors que parallèlement, ils ont besoin de ses services et savent qu’ils peuvent tirer avantage d’un point de vue économique, mais aussi stratégique, de la puissance des sociétés de négoce implantées sur leur territoire”.*

⁵See, for example, Morgan, D. (1979), “The Shadowy World of Grain Trade”, The Washington Post, June 10.

We cannot give an account in the few pages of this general introduction of all the great richness of the history of international commodity trading. Nor can we pretend to identify all the factors that led to the rise of physical traders, but it seems clear to us that there is a common factor that connects the Sumerian ancestral idea of goat contracts to first so-called “future contract” in 1864 on the Chicago Board of Trade (CBOT), *i.e.* a standardized financial contract specifying the trade of a predetermined amount of grain products, for a specific grade, at a particular date and delivery location. Given the obvious fungibility of all commodities, value chain players, particularly physical traders, have historically worked to transcribe this distinctive feature into trading contracts, first commercial and then financial, through standardization and offsetting procedures, in order to limit trading costs, to promote the supervision of operations relating to the transfer of commodities from upstream to downstream and to offer them all the flexibility required by this very special intermediation activity. From this point of view, it is important to emphasize that, contrary to the perception that the general public might have, futures contracts are not necessarily juxtaposed to commercial contracts: they are, in a hedging strategy, the natural extension of them. More precisely, they can be considered as an imperfect but temporary substitute for a commercial transaction that should occur in the near future. In the particular case of trading activity, it is these futures contracts that allow traders to make their trading margins depend solely on their negotiating skills and not on the level of prices or their variations *per se*.

If economic history makes 1864 the year of the launch of the first commodity future, and thus, in a way, the year of the beginning of the era of “modern” financial derivatives markets, the creation of commodity derivatives markets may be older. In 1730, under the shogunate of Tokugawa Yoshimune (1716-1745), the Dojima market (named after the district of Osaka where it was located) was created in Japan. As recalled by Baffes (2018^[18], p. 35), *“key characteristics of the Dōjima market were the central clearing of contracts, contract standardization, mark-to-market accounting rules, and the concept of settlement price (referred to as the “fuse cord price”) which was used as the next session’s opening*

price". Such market made it possible to fix the forward price of rice, a product whose exchange then represented 90% of government revenues. This was not a coincidence: the political intention behind its creation was to encourage the development of trading and speculation in order to offset the low rice prices that prevailed at the time (Moss and Kintgen, 2009^[204]). The growth of these derivatives markets, from their infancy in the 19th century to the central role they play today, is due to many factors, (economic of course, but also political and regulatory thanks to the gradual market liberalization), but there can be little doubt that is the development of liquid financial markets that gave a new dimension to physical traders by enabling them to provide risk management services in addition to logistic services to promote the matching between link supply and demand.

Open continental or international markets have always been a key condition for the emergence of liquid derivative markets. Local commercial markets open to foreign players and their progressive globalization since the liberalization of world trade under the impetus of the General Agreement on Tariffs and Trade (GATT) and then the World Trade Organization (WTO) have not only stimulated the rise of international traders, but also accentuated the international transmission of supply and demand shocks, in a post-Bretton Woods context of the generalization of floating exchange rate regimes, which are themselves volatile. In this regard, while the question of the measurement and drivers of commodity price volatility has been widely debated for decades, there seems little doubt that the gradual exhaustion of producer price systems in which market-dominant producers adjust their supply and inventory levels (in a coordinated or uncoordinated manner) to changes in demand has led to an increase in price risk within value chains and, consequently, to an increase in the hedging needs that the rapid development of derivatives markets has met.

This strong tie between the physical expansion of commercial markets, the growth of traders and the development of futures markets is well illustrated, and Cargill's case in agriculture is probably one of the most representative. The history of Cargill as the first

grain trader is highly linked to the development of railroads in the United States. But its growth must be analyzed in two stages: first the expansion of the transport network, second the growth of the grain futures market to manage price risks. On the one hand, the market expansion is characterized by a subsequent development of the transport network. The end of the Civil War in 1865 favored and accelerated the construction of the railroad connecting the Mississippi Valley with the Pacific coast. It became the first to join Kansas City and quickly expanded to Conover, Iowa. In order to take advantage of the new opportunities offered by the railroad access, William Wallace Cargill, the founder of the Cargill company, settled in Conover and began to acquire grain warehouses in the region, before expanding its network to other strategic locations served by the railroad of by the Mississippi river. This introduced him to more farmers and created relationships with suppliers. In addition, the post-Secession War period was also characterized by major innovations in agricultural technology. John Deer offered to use steel plows for ploughing hard soils, Van brunt created new seeders, both of which led to large productivity gains (Broehl 1992, p19). The increasing volume of wheat bushel led to a subsequent decrease of the price. The price in Conover, representative of the Iowa and South Minnesota price, fell from \$2.50/bushel to \$0.90/bushel between April to September 1867. Thus, Cargill was able to contribute to the deployment of the market by offering its storage and logistics services to support the development of grain trade between the various U.S. regions. On the other hand, the development of the physical trader could only be made possible by the combination by the growth of the grain derivatives market. As the volume of trades increases, exposure to risk, particularly price risk, is rising. There is no real consensus on the origins of Futures markets. Dumbell (1927^[83]) considered these contracts are the result of speculation techniques in cotton trading between New-York and Liverpool in 1857, year of the financial crash. Irwin (1954^[151]), on its side, defended the idea that there are merchants who buy and sell commodities that initiated and encouraged futures market development. Odle (1964^[212]) underlined the development of the grading system in the Great Lakes ports in the standardization of contracts. Standardization made it possible to offer viable underlying assets for futures contracts. Williams (1982^[272]) concluded that

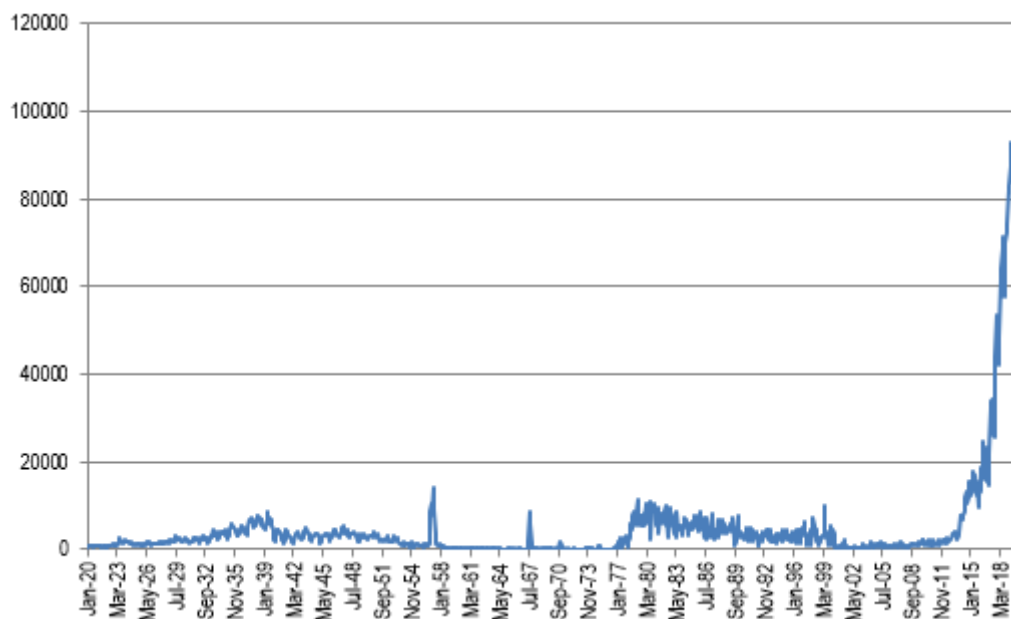
the origin of grain futures market certainly is an addition of these different statements but he also added a final component. He considered the increased price volatility during and after the Civil War has fostered the need for hedging tools.

The oil industry

Although we seek to model the behavior of the physical trader in a comprehensive manner, we have chosen to focus our doctoral work on the oil industry and there are several reasons for this. The first is obvious and is due to the absolutely unavoidable role of oil and refined petroleum products in international trade. This is of course true in a historical perspective that dates back to the 19th century, but also in a much more recent perspective with the disruption in international markets caused by the considerable expansion of unconventional oil production in North America, particularly shale oil, and the exponential growth of American exports (see figure 3). The second reason is just as obvious and is due to the very high volatility of oil prices, to the point of becoming negative in a very exceptional situation such as the one experienced in April in the United States. This volatility is, as mentioned before, specific to all commodities and it is important to emphasize here that this characteristic is not recent and that oil prices have fluctuated sharply since the widespread and international use of these mineral resources at the end of the nineteenth century. Thus, in the context of the “long depression” (1873-1890), the strong increase in Russian production in the Baku region after the end of the Tsar’s territorial monopoly in 1873, but also that of the United States, resulted in a drop in prices, all the more so as Standard Oil had embarked on a strategy of defending its market share and therefore a price war. The depletion of oil fields in Pennsylvania and a cholera epidemic in Baku, on the other hand, led to a price peak in 1895 before a new period of depressed prices until the 1920s. This instability and, more generally, the short-, medium-, and long-term variations in the price of crude oil have not responded to the same variables over the 150 years of its history, and several “eras” can be identified. Thus, after strong

price variations combined with a downward trend over the period 1861-1895, oil prices entered a period marked by an absence of trend and relative volatility that ended in the early 1920s marked by a sharp rise in prices due to rapidly growing demand with the development of the automobile industry. The next period is well known, characterized by low price levels and very limited volatility until the first oil shock in 1973. Although Standard Oil was dismantled on May 15, 1911 (due to its monopoly position ruled contrary to the Sherman Anti-Trust Act of 1890 by the U.S. Supreme Court) and reorganized into 34 smaller companies, producers' control of the market remained effective under the so-called "Achnacarry Pact" which was kept secret until 1952. Sealed on September 17, 1928 and named after the Scottish castle that housed the various protagonists and which was rented by Sir Henri Deterding, the president of Royal Dutch Shell, this pact united five oil companies and aimed to control the world oil market. Together with the later association of two other companies, it led to the famous oligopoly of the "seven sisters" – Chevron, Esso (Standard Oil of New-Jersey), Gulf, Mobil, Texaco, British Petroleum and Royal Dutch-Shell – which set the world price of oil, with two references: that of the Gulf of Mexico, then that of the Persian Gulf after the Second World War (Chalmin, 2007^[52]). This "Texas Era of Price Stability" as McNally called it (2017^[200]) came to an abrupt end in 1973 with the takeover of the Organization of the Petroleum Exporting Countries which tipped the oil world from a problem of excess supply management to one of insufficiency with, as a consequence, prices at a much higher level and volatility than over the past four decades and major macroeconomic consequences on Western economies that no one is ignoring. In this affirmation of the power of the producer countries over the seven sisters, the Libyan strategy of King Idris I and Muammar Qaddafi, after his military coup of September 1969, was victorious and inspired other countries, notably Iran and then Venezuela. With demand for oil rising sharply, OPEC's power of negotiation and then retaliation strengthened and this is what explained the Arab embargo on oil following the Yom Kippur war of October 1973. This price-fixing power hardly lasted, eroding from the beginning of the 1980s and ending at the end of 1985 when OPEC abandoned its previous policy in favor of a market share defense strategy during the oil counter-shock.

Figure 3: U.S. Exports of Crude Oil
(Thousand Barrels)



Source: U.S. Energy Information Agency

The third reason for our focus on the oil industry is related to the central role played by physical traders. We mentioned earlier in this introduction the profits made by Trafigura in the context of the very high price volatility observed in 2020, but its history is also illustrative not only of the physical arbitrage function played by traders, often linked to the exploitation of regulatory differences between countries, but also, admittedly, of the consequent high opacity of some of their operations, an era that now seems to be over. In 2006, as part of the so-called Probo Koala scandal, named after the oil tanker chartered by Trafigura, the trading company was found guilty of having been involved in the dumping of slop chemical waste, a mixture of water, oil and caustic soda from the cleaning of the vessel's tanks. Judged too expensive in Amsterdam, the treatment of this waste was given to a company based in Côte d'Ivoire which, instead of meeting its obligations, illegally dumped it in Abidjan. Much more recently, in 2019, Trafigura and Vitol, the world's largest oil trading company, were cited in a case of corruption allegations involving Brazil's state-owned oil company Petroleo Brasileiro SA (Petrobras) in the years 2012 and 2013. Still focusing on a historical perspective, it is interesting to

note that one of the largest oil companies in the world, known for its oil production and its commercial distribution network, came from a very small company, created in 1833 by Marcus Samuel the Elder, of antiques and curiosities and then exotic shell boxes, at the time particularly fashionable in interior decoration. When he died in 1870, this business, which year after year built up a network of international correspondents, was taken over by his two sons, including Marcus Samuel the Younger, who gave the family business the roots of what was to become in 1897 the Shell Transport and Trading Company, as a tribute to their father's business. The good fortune of the Samuel family can probably be explained by an acute business sense but also by the famous open commercial markets that we mentioned earlier. It was, initially, the end of the monopoly of the East India Company whose charter of 1601 was abrogated by the Charter Act 1833 (also called the Saint Helena Act 1833 or Government of India Act 1833), which opened the way of trade with the East to the merchants. This was followed by the political opening of Japan in the middle of the 19th century, which until then had lived in autarky, and then by the commercial opening of China after the two opium wars which opposed it to the British Empire and which led to the Treaty of Nanking of 1842, the Treaty of Tientsin of 1858 and the Convention of Peking of 1860 with, in the end, the opening to trade of all Chinese ports.

The Samuel brothers' involvement in the oil trade is naturally more recent and dates back to the 1880s, but it immediately came up against a major obstacle: the domination of Standard Oil, the famous oil company founded by John D. Rockefeller, but also of the Nobels, as well as independent Russian and American producer groups, in the refining, transport and marketing segment. Samuel Junior had nevertheless anticipated four key elements of what was to become his success: a strong and unsatisfied demand for the "new light" in the Far East, the "liberalization" of oil exploration in the Caucasus from 1873, the need to drastically reduce transport costs, and a vast distribution network to compete with the dominant players in the sector, including Standard Oil. Joining forces with Fred Lane, the Rothschilds' representative in the marketing of refined products produced by

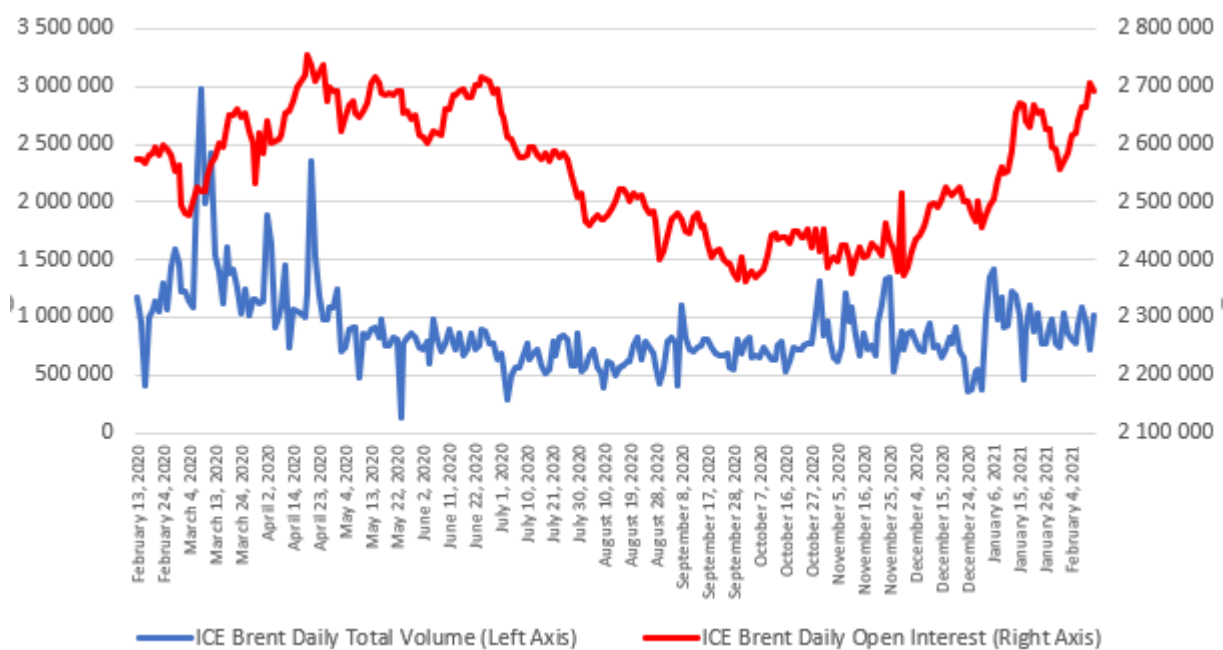
the “Société commerciale et industrielle de Naphte Caspienne et de la Mer noire”, a refinery located in Baku owned by the Rothschilds and universally known as Bnito, Marcus Samuel took the risk, faced with the prospect of a strategic alliance between Standard Oil and the Rotschields, to order from Fortescue Flannery vessels capable of transporting oil in tanks integrated into the ship’s structure (and not in tin cases or in tanks placed on the ship) and meeting modern safety standards (Henriques, 1960). The first of them, the Murex, allowed him to cross the Suez Canal, which had previously been denied to Standard Oil, and to transport oil from Batum to Bangkok in 1892. There was the whole dimension of what underlies physical trading activity: a deep knowledge of market needs combined with a thorough understanding of regulatory constraints, a strategy to rationalize transport costs and the ability to assume significant financial risks. 125 years later, Shell gave the same name to its Liquefied Natural Gas (LNG) tanker that made its first delivery in China. We could not conclude this paragraph on oil trading without mentioning the emblematic and sulphurous Marc Rich, founder of Glencore, whose first oil operations date back to the 1960s when the businessman realized that what was missing in oil-producing countries to free themselves from the domination of the Seven Sisters was not so much political vision as knowledge of oil marketing techniques, the distribution network and contact with refineries: three key elements that he mastered. Thus, during the Six Day War of 1967 and the failure of the first oil embargo which, paradoxically, led to an increase in supply, Rich found the opportunity to trade, outside the system imposed by the seven sisters, oil, which, according to some observers, was the beginning of the spot market that we are now familiar with.

The fourth reason why we have chosen to focus our analysis on oil markets is related to the previous two reasons and to the central role played by oil derivative markets. We fully recognize here that these futures markets are not unique to the oil world but common to all commodity industries, but it seemed to us that the history of oil perfectly illustrates the interactions between the way a value chain is structured and the use of these derivatives. In the oil industry, a first attempt to create a financial market hap-

pened as soon as in 1874, at the very beginning of the oil industry in the U.S., before the market becomes truly internationalized (we point out here that the international oil trade was first based on kerosene, then called lamp oil, for strictly domestic use – except for a demand for lubrication –) and not related to the transport sector. The Oil City Exchange, Pennsylvania, incorporated in 1874 and became in few years on the largest U.S. financial exchange of any kind in America. However, the monopolistic competition, dominated by Standard Oil, put an end to the initiative in 1895. We will have to wait more than a century and, finally, a form of reversal of what the oil market was like after Colonel Francis Drake’s first drilling, i.e. the end of a market ruled either by the seven sisters or by OPEC to logically see the appearance of future oil contracts as we know them today. The WTI Light Sweet Crude Oil futures contract was launched on the New York Mercantile Exchange in 1983, as a consequence of the US governmental decontrol of oil prices on January 28, 1981 and the rise of the spot market. In Europe, the International Petroleum Exchange (IPE) was set up in London in 1980, also to offer hedging solutions in the face of the increasing volatility of crude oil prices, particularly Brent crude oil, the world’s benchmark price for oil, especially low-sulfur (“sweet”) crude oils. However, it was not until June 1988 that a first futures contract on this price reference was launched and became the ICE Brent futures contract after the IPE was bought out by the Intercontinental Exchange (ICE) in June 2001. Although recent in its modern form, the history of oil futures contracts is rich and this introduction is not a sufficient account of it. It should just be noted that it could take a new turn since 2018 with the launch of a Chinese futures contract but open to foreign participants on the Shanghai International Energy Exchange (INE). The latter obviously cannot compete in the short term with its American and European counterparts, but it may prefigure what will be the organization of the world oil market with China as a new price reference, in parallel with historical references.

These four factors which explain the focus of this thesis on the oil industry (the economic importance of oil, the volatility of crude oil prices, the intermediation of physical traders within value chains and the positioning of commodity futures exchanges within

Figure 4: Daily Open interest and volume of the ICE Brent Futures



Source: Intercontinental Exchange (ICE)

the value chain) are all variables whose importance has fluctuated over the one hundred and fifty years (or more) of the international history of oil. In spite of the decrease of the vertical integration of the production process among the major oil producers, the industry remains relatively integrated. Nevertheless, independent commodity traders, as illustrated by Trafigura in 2020, might still be providing the most critical service in the industry. Besides, It should be pointed out that physical traders cannot be considered as a group of homogeneous companies, as some of them also engaged in vertical integration strategies (mostly upstream) during the bull phase of the supercycle, while others remained in their core business of intermediation between supply and demand and management of the related risks. Glencore, for example, has become one of the most important producers and marketers of ores and base metals (copper, bauxite, alumina, zinc, lead and ferrochrome, nickel) or strategic metals, such as cobalt hydroxide, thanks to its subsidiary Kamoto Copper Company (KCC) located in the Democratic Republic of Congo. From 2014, the sharp drop in commodity prices has, like producers, led traders to revise their investment strategy downwards and focus on their core business, but the pragmatism that intrinsically characterizes their business model may have led them, over

the past two years, to reconsider acquisition strategies, such as the sale to Trafigura in November 2020 of the “Usine du Sud” in New Caledonia, operated by the Brazilian mining giant Vale. In other words, there is a form of permanent strategic interplay between, schematically, the three main types of actors within the commodity chains (producers, end users, traders), the outcome of which is very largely dependent on the level of prices and, therefore, on those of supply and demand. To account for this, in a necessarily partial way, is the fundamental objective of this PhD thesis.

The oil industry’s analytical framework

Commodity markets have their own pricing mechanisms. As mentioned earlier, futures markets play a major role in price determination as they offer a public price that instantly aggregates the different positions of market participants. The ability to centralize information allows futures prices to be an essential determinant of prices on the cash market:

$$P_t^{WTI} = \beta F_t^{WTI} + \varepsilon_t \quad (1)$$

The relationship stems from the usual view in the literature that defines the future price F_t^{WTI} as the best predictor of the future spot price $E[P_t^{WTI}]$ (McCallum and Wu, 2005^[199]; Altquist and Kilian 2010^[8]). If we consider that future spot price of crude oil $E[P_t^{WTI}]$ is unpredictable, it appears that the future price is the best predictor of the spot price P_t^{WTI} . Non-predictable variations are then recorded in the error terms ε_t . Alquist *et al.* (2013^[9]) explains that equation (1) is widely used by central bank to forecast oil spot price, even if results of such techniques are limited on the short run (Knettsch 2007^[175]; Altquist and Kilian 2010^[8]).

On the contrary, at the fundings of the commodity economics and finance, Working (1942^[279]) strongly criticized the use of futures prices to predict spot prices. he even characterized as an “error” the assumption that futures prices are more sensitive to an-

ticipations than spot prices⁶.

Up to this point, we have described the price formation of a single crude oil price, namely the WTI. But it remains that we cannot speak of a single price for a commodity. On the contrary, the oil industry offers as many prices as it does references. There are a large number of them, distinguished by their origin, their quality and the supply and demand factors specific to their geographical area.

The validation of the *Law of one price* has an important role in the industry. The price of a commodity should be the same in two countries once they are expressed in the same currency unit and adjustment costs have been taken into account, which has been demonstrated in empirical studies (Baffes, 1991). Therefore, crude oil prices can be determined from a reference price and short-term differences are recorded in the error terms:

$$P_t^{WTI} = \beta P_t^{Brent} + \varepsilon_t \quad (2)$$

The validation of the *Law of one price* is at the basis of commodity arbitrage, without which the same commodity could not be traded between two places at the same price. The law is verified when β equal one. The idea of an integrated crude oil market amounts to considering the latter as "one great pool" (Adelman, 1984^[1]). Numerous empirical works have also validated the integration of the oil market, either by using cointegration models (Hammoudeh, 2008^[125]; Giulietti *et al.*, 2015^[109]) or by mobilizing graph theory (Ji and Fan, 2016^[157]). However, momentary deviations are still possible between crude price, creating opportunities for commodity traders. The analysis of this spreads could be the occasion to highlight the role of commodity traders to maintain the market integrated. Part of the chapter 4 is dedicated to this issue.

Moreover, the oil industry, like any other industry, must consider the entire supply chain in its price discovery mechanism. The price of raw materials at various stages of

⁶Working H., Quotations on Commodity Futures as Price Forecasts, *Econometrica*, Vol. 10, No 1 (Jan., 1942), pp 50.

the production process will necessarily influence each other. Thus, it is also appropriate to present the price of crude oil as dependent on the price of its refined products:

$$P_t^{WTI} = \beta_t^{Gasoline} + \varepsilon_t \quad (3)$$

It should also be noted that the causality also goes naturally from the price of crude to the refined products. The relationship will be all the more important to analyze since oil refining products themselves have their own futures prices, and thus a public price gathering information specific to their own market segment. RBOB (Reformulated Blendstock for Oxygenate Blending) Gasoline, heating oil and gasoil are listed on Nymex, while kerosene is listed on the Tokyo Commodity Exchange. Cointegration relationships are empirically demonstrated in empirical studies since the contribution of Serletis (1994^[246]) on petroleum prices. Recent studies, on the contrary, still tend to conclude that prices are cointegrated, but also highlight that in periods of high volatility, spread can significantly deviate and takes time to go back to equilibrium (Westgaard *et al.*, 2011^[270]).

Finally, the evolution of the price of crude oil is also closely linked to its fundamentals. While supply factors have long been seen as the main drivers of crude oil prices, demand factors have overtaken them as the central determinants since the 2000s (Kilian, 2009^[168]; Baumeister and Kilian, 2016^[29]). The financialization of commodities has made their prices much more sensitive to short-term factors and macroeconomic variables. Empirical studies have made extensive use of Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models to determine the short term components of crude oil prices.

$$P_t^{WTI} = F(\text{Short Term Fundamentals}) + \varepsilon \quad (4)$$

Authors usually conclude on the close link between commodity price volatility and the dollar (Yousefi and Wirjanto, 2004^[286]; Baffes and Etienne, 2016^[19]) or with stock market returns (Creti, 2013^[72]), particularly since the last financial crisis. The second

chapter of this thesis focuses on this issue and aims to identify some of these short-term factors.

The four equations presented here thus allow us to constitute a general framework of analysis to which we will return in the various chapters of this thesis.

Thesis outline

This doctoral work is structured in three main parts of two chapters each. Each of these chapters serves the same purpose, which is to demonstrate that commodity traders change the pattern of trade flows in the industry.

In the first part, we briefly review the history of the oil industry by insisting on the role that transport assets and price systems have played in it when it was governed by vertically integrated oil producers. This first chapter sets the scene for a presentation of the basic contributions of physical traders in the organization of trades. Therefore, chapter two focuses on the close relationship between physical traders and the oil market which simultaneously gained importance starting the 1970s. It shows that their operations are twofold: commodity traders make it possible to reconcile producers and end-users on the physical market and to manage risks associated with international trades on futures market. The second chapter also reports on price volatility and its main determinants. This first empirical contribution shows that risk management depends on the fundamentals of the industry, but also on external factors like the profitability of equity markets.

In the second part, our intention is focused on oil producers' linkages with the international market. Indeed, the majority of studies on the patterns of international trades relies on the gravity equation. However, in our approach, and based on our conclusions from the first part regarding the role of traders in linking producers and end-users around the world, we assume that treating international oil trade flows on a bilateral basis does

not seem to be consistent. The ambition of the chapter is to circumvent this bias by designing a gravity model that would account for the specificity of commodity trading. The next chapter extends the analysis by examining the reasons that allow producers to trade on the international market. A theoretical model demonstrates that physical traders are asked to organize trades when price risks increase for producers. Indeed, without traders, producers would be forced to concentrate on their local market to reduce their risk exposure. Thus, as a proof of producers' connection to the international market, the chapter offers a new attempt to model the oil market integration.

Finally, the last part of this thesis underlines the influence of physical traders in the organization of the industry. Now that we have established that physical traders can manage risks for producers and are integral part of international trades, we argue that the conclusions of the transaction costs theory must be reconsidered to introduce physical traders. The first chapter of this part reviews the literature on the design of commodity contracts. Thus, we show that the organization and the traders share the same objective, which is to facilitate trades while minimizing risks. As a result, physical traders make short-term and price varying contract viable solution, along with long-term contracts and the vertical organization, for trading crude oil within the industry. Furthermore, this comment implies that the organization are sensitive to the price dynamic which can make price risk fluctuate. Therefore, the last chapter proposes to model the organization of the oil industry as a dynamic process. Our results also bring us to conclude that the organization can have a pro-cyclical effect with the price dynamics that can exacerbate price shocks.

Part I

**The relevance of considering the role
of physical traders in the oil industry**

Most academic publications on commodity industries, and more specifically on the oil industry, study the organization of the industry through the argument of competition. This framework seems to correspond to the analysis of oligopolistic organization in an industry dominated by the big producers of the Seven Sisters or to the study of cartel organizations. The integration of producers is usually analysed under the triptych: extraction - refining - distribution. Nevertheless, this analysis underestimates, or even neglects, midstream activities between each of these poles. This is the role played by commodity traders. They provide essential services to producers and participate in the supply chain of the oil industry. They offer temporal and spatial transformation and risk management services to facilitate trade in the market.

Chapter 1

**A partial analysis of the oil industry:
the role of trading infrastructures**

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1.1 Introduction

In the history of the oil industry, transport infrastructure and the management of transport costs have occupied a critical role in the growth of the major businesses. The peculiarity of major oil producers has often manifested itself in their ability to display control over midstream infrastructures, either by using their monopoly or monopsony power to pressure transport companies, like Standard Oil, either by taking advantage of their vertically integrated structures, like the companies forming the “Seven Sisters”.

In this first section, we aim to present the evolution of the oil industry from its premises to its organization as it is known today. We strive to focus on the key role occupied by commodity trading in companies’ vertical organization. Although independent commodity traders could only emerge once with the market openness, we show that transport and price control have always been a central concern of producers. We decompose commodity trading into two components that are transport services on the one hand, and the price management, which is rather a control on the price system in the pre-oil shock period, on the second hand. We explain that the high control of producers over trading activities explains the absence of independent physical traders until the market openness in the 1970s. This event, following the oil peak, has even been a turning point in the industry. The vertical co-ordination of the oil industry within a monopolistic or an oligopolistic competition guarantees advantages to the dominant companies relatively to its rivals. From a theoretical point of view, the analysis of the foreclosure effects appears to be the most suitable framework. There is a large body of literature dealing with the effects of vertical integration to deny the rivals’ access to an asset or a segment of the industry (Rey and Tirole, 2007^[233]). The strategy, known as “raising rivals’ costs”, aims to offer a non-competitive price to non-integrated companies in order to maximize its own profit (Ordover *et al.* 1990^[214]). Actually, we will be able to show that the only pressure of a monopoly and monopsony is enough to raise predatory prices to its rivals (Granitz and Klein, 1958^[114]; Klein, 2011^[172]). With regard to the price risk management, the control

of the price mechanism was also an insurance against a decrease of their revenue which disappear with the end of posted prices.

The post-oil peak period constitutes a shift toward the transaction cost theory as the dominant framework to analyse the industry. The growth of market trades relative to the vertical integration led to consider producers' revenue as the sum of their segmental revenues. Therefore, with new contractual organizations, thanks to the growth of spot and forward markets, producers can focus on the core business and divest in segments that do not justify the cost of integration. We show that, while crude oil is assumed to be homogeneous and standardised in order to be easily traded to any destination, the asset specificity as defined by Williamson still fits with oil trading. The crude oil itself does not have to be specific, but the timing of the transaction and the investment must be able to create a particular relationship between buyers and sellers. We also present that the incomplete contract theory raises contractual gaps that are at the basis of commodity trading risk management. Grossman and Hart (1986^[117]), Hart and Moore (1988^[131]) highlighted the hold-up risk and its consequences on producers. Nevertheless, even if the oil industry seems to fit with the analysis offered in the theory, we can regret that some specificities are omitted, in particular commodity traders' contribution in organizing trades and managing the inherent risks.

The first chapter is presented as follow. First, we focus on the role of transport infrastructures in the growth of Standard Oil's monopoly power and as the first vertically integrated company. Second, we highlight that the Major oil producers, mostly the members of the Seven Sisters, used their control on the price system (posted-prices) to maintain their market share. Finally, in a first step, we show that the market openness transformed the organization of trades to give a more important place to the market. However, this change plunges producers into the uncertainty surrounding a market trade and exposes them to the inherent contract incompleteness.

1.2 Competition focuses on transport infrastructures

An important part of the analysis of the organization of the oil sector lies in its competitive structure. The oil market is characterised by its market imperfections inherent to the geographical mismatch between a supply restricted to few areas and a worldwide demand. Moreover, since the resource is limited, it gives a high bargaining power to the producers in relation to the consumers. These two facts are usually seen as sufficient to justify that the industry is composed of large producers for whom the size is directly related to their market power. The big oil producers are seen so large and visible that the full integration appears to be only organization since the beginning of the development of the industry. However, in reality, the full integration of their supply chain, from extraction to distribution, has never been linear. Actually, considers that vertical integration may rely more on the perception of oil companies than the actual organization of trades (Barrera-Rey, 1995^[26]). Most of the major integration moves occurred in the pre-oil shock period.

The traditional analysis of the vertical integration, identifies three characteristics that drive the organization: technological economies, transactional economic and market imperfection Perry (1989^[219]). The later argument, may be more, than the two others, centralize a lot of the analysis, especially during the pre-oil shock area. Nevertheless, there is a common thread in the organization of the industry that is not given as much prominence as it should be. It is the role of commodity trading in the organization of the industry. Even through no independent oil trader had yet emerged before the 1970s, transport infrastructure, but also the management of the price risks were at the heart of defining the market power of the major producers. Therefore, the two main components of commodity trading must be at the core of the analysis.

1.2.1 The predominant role of crude oil transport

The standard Oil company laid the foundations for the development of the oil industry but also for the oil market structure. The company is usually depicted as one of the first

modern vertically integrated organization. While it may seem expected and obvious that the companies that make up the industry at the beginning of its expansion are vertically integrated because the added value of the industry is not high enough to ensure benefit to separated segmental activity (Stigler, 1951^[257]). Nevertheless, at the very beginning of the industry until 1870 and the rise of the Standard Oil company, the crude oil market was composed of small producers, mostly landowners sending crude oil to refineries through railroad companies.

Standard Oil imposed a new paradigm with a global trend toward the vertical integration of the industry. Levin (1981^[183]) analysed the period starting in 1870 and ending in 1911, with the divestiture of Standard Oil, as one of the only two periods exhibiting a solid movement toward vertical integration at his time.¹ The company pioneered in integrating crude oil production with its refining activities. However, the integration is criticised because it is accused to have created market failure which forced the United States to create antitrust acts with the aim of restoring market competition.

The Standard Oil company as the first vertically integrated company

Founded by Rockefeller, the company appears to be the first company to be integrated on multiple stages of the production process. To simplify, we can assume there are three segments in the oil industry: extraction, refining and transport. While their market power is often reflected in their share in the crude extraction and the refining, their real leadership has been perhaps even more significant with respect to their midstream assets. At the moment, the oil industry was mainly composed of small producers exploiting their deposits in varying states of the United-States. Consequently, the transport of the crude oil to refining units is the main concern to supply crude to refining plants. It gave a critical role to the few railroad companies that organized crude oil transport to the main refining regions: in New York, Ohio and Pennsylvania.

¹Levin define a second period showing a strong trend toward vertical integration during the two world wars (1981^[183]).

Nevertheless, the organization of trade was not optimised yet. Because of the small producers composing the market, the transported quantities are not high large enough to offer low transaction costs. Moreover, there is no delivery standards yet. Standard Oil demarked by stepping out of its initial role as a refiner to acquire midstream assets like pipelines, railroads tanks and terminal facilities and even barrel factories. Its new involvement in the midstream segment of the industry profoundly changed the organization of crude oil trades. First, it gave more flexibilities to the companies which benefited from lower transaction costs. Second, because it was a major player in the sector, the acquisition of barrels manufacturing plants set up oil trading standards, which contributed to reducing transport costs too. It was the first refining company to own these factories, but also innovated in the barrel making by replacing oak with steel. This imposed the barrel unit for oi trading (Rosenthal, 1903^[237]). Nevertheless, the vertical integration of these midstream stages of the industry is not enough to account for the market power of the company on the oil transport.

Horizontal integration strategy asserted Standard Oil's market dominance.

Standard Oil's dominant position is also reflected into their central position in the refining, but also extraction, segments of the oil industry which enabled it to extend upstream as well as downstream. Thus, the company initiated horizontal integration strategies diversifying their regional activities. In 1900, they acquired the Pacific Coast Oil Co., a growing oil producer operating in California. From 1879 to 1911, the company accounted for around 90% of the US supply of refined oil and 82% of the US refining capacities (Granitz and Klein, 1958^[114]). Of course, with no real competitor, the U.S. policymakers, as well as the academic research, could focus on the analysis of market imperfection in the oil industry. Standard Oil became a textbook case of the monopolistic competition. In the *Theory of Monopolistic Competition* (1949^[53]), Chamberlain refers to Standard Oil as the perfect example of a quantitative monopoly in opposition to the seller benefiting

from an monopolistic power because they are the only counterpart for group of buyer in a restricted area². Standard Oil is even openly referred to as one of the reasons why the Sherman Act is signed in 1890 as a first attempt to offer an antitrust law in the U.S. territory. Until 1911 and its split, the company could purchase crude oil at a monopsony price and sell refined products with a monopoly premium, maximizing its benefit and ensuring its rank as the top one major oil company. It also took benefit from midstream assets. The latter enable the firm to be charged at low rates relatively to its competing refiners who could not supply volume as high as Standard did. Nevertheless, the U.S. Supreme Court concluded in 1911 that Standard Oil had violated the Sherman antitrust (1890) act making the company an illegal monopoly. Consequently, one of the most powerful company of the world had to divest its activity to comply with antitrust laws.

1.2.2 Pressure on transport infrastructures creates market distortions

Standard Oil's influence on railroads appeared even before the firm really integrated transport activities. The purpose of the Sherman Act mentioned above was to prevent companies to take advantage of discriminatory discounts because of their critical position in the market. The U.S. government, in particular, focused on the preferential railroad rebates received by the company.

The case of Standard Oil echoed in the foreclosure theory

In a market dominated by a vertically integrated monopoly and monopsony, the foreclosure theory appears to be the dominant framework to analyse the industry. Foreclosure

²Chamberlain use the footnote 4 at page 5 to respond to Hotelling in *Stability in Competition* (1949^[53]), who criticized economic theories on the monopoly concept. Hotelling, like Sraffa before him, explained that the market is not binary and only characterised by a perfect competition or a monopolistic competition. On the contrary, there are many other intermediate market conditions. Hotelling developed the case of a seller who trade with small circles of customers within a limited class and region. Chamberlain explained that this is another form of market imperfection related to a small number of entrepreneurs. The case of Standard Oil is finally quantitatively different but does not significantly differs on the mechanisms

occurs when a firm extends its activity by integrating new companies on complementary and strategic segments producing a bottleneck good (Rey and Tirole, 2007^[233]). The firm can then restrict output to the competing firms on the prior or forward segments. In fact, Standard Oil did not actually merge with railroad companies which can be seen as the critical segment of the industry. Nevertheless, the close relationship and the collaboration between the producer and the railroad did have an influence and foreclosed rivals (Granitz and Klein, ^[114]). The dominant firm, Standard Oil, reduced competitors' access to a key good on the prior or forward segments of the supply chain – known as the bottleneck good, which raises its monopoly power on this segment – known as the bottleneck segment. The firm can then restrict output to the competing firms on the prior or forward segments. Rey and Tirole (2007^[233]) distinguished two foreclosures depending on the situation.

- **Vertical foreclosure** comes from the control of the bottleneck good serving as a critical input in the supply chain of the industry. Thus, the access to the bottleneck good or segment can be denied to rivals.
- **Horizontal foreclosure** is the situation in which the dominant company control the bottleneck good and the competitive good that is sold to customers downstream. Thanks to this position, the dominant is able to rise or maintain costs high on the bottleneck segment of the industry. Depicted as a “predatory” behavior, the firm accept to lower its own profit in order to force the exit of its competitors. In the case of Standard Oil, the control of transport facilities and the collaboration with railroad companies created a threat for independent refiners to suffer from higher and disadvantageous rail rates. Of course, the company might have conducted both vertical and horizontal foreclosure.

Foreclosure effects have been widely discussed in the economic literature. Salinger (1988^[241]) explained that an unintegrated downstream producer is foreclosed when a merger leads to an increase in the input price, which is likely to occur when if the integrated company no longer sells the product to the independent downstream producer because of the lower upstream competition. Ordover *et al.* (1990^[214]) demonstrated in simple models

with duopolies, on both upstream and downstream segments, that vertical integration can lead to anticompetitive foreclosure of downstream firms. As a critique to authors considering there is no reason for the integrated company to raise prices and stop selling input to unintegrated companies (Bork 1978^[37]), Ordover *et al.* showed that foreclosure is a successful strategy as long as the integrated upstream firm's gain is higher than the downstream firm's losses. Rubinfeld and Singer (2001^[239]) provided empirical evidences of the foreclosure effects of the merger of Aol and Time Warner, media and entertainment conglomerate corporations, in 2001. They highlighted that the merger was likely to discriminate rival platform distribution of content downstream.

Standard Oil raised rivals costs

Standard Oil is suspected of having taken advantage of the South Improvement Company (SIC) in 1871 to negotiate preferential railroad tariffs. The SIC was a corporation created by the three main railroads companies – the Pennsylvania, the New York Central and the Erie railroads – to put an end to the rate war (DiLorenzo, 1985^[82]). It designated "evening refiners" in each major refining district to serve as a reference for contract with the railroad companies. Therefore, the Standard Oil has been chosen as one of the four members of the SIC because it is main refiner in Ohio. All together, the four refiners represented 95% of the SIC's stock and Standard Oil emerged as the main stockholder (Klein, 2011^[172]).

Market distortions appeared when the three main railroads companies had agreed on a new, and increased, tariff schedule but they decided it would not apply to the "evening refiners" of the SIC. Thus, Standard Oil benefited from special rebates on railroad tariff compared to its rivals. However, the Supreme Court asked for the dismantling of the company as soon as 1872 because its main shareholder was Standard Oil. Yet, the SIC laid the foundations for the company's market power on transport assets. Standard Oil launched horizontal integration strategies to acquire the three other former members of

the SIC. The new Standard Oil Trust became the main player of the market, being a major crude oil producer and the first refiner. The company evolves as a both monopoly and, more importantly, a monopsony for the railroads company. It maintained low rail rates which lowered the company's production costs of refined product relatively to its competitors. Apart from Standard Oil, tariffs remained high in the 1870s.

Vertical integration of upstream and downstream segments pressured transport companies

Standard Oil's market power would only really have been revealed once its vertical integration strategy had been implemented. In their analysis of the pattern of the competition in the oil industry, Granitz and Klein (1996^[114]) concluded that the company's monopoly power was derived from its infrastructures, and more precisely from their influence on railroads. This pseudo-control, cumulated with the ownership of several refineries, allowed the company to put pressure on railroads. Standard Oil established as a policer of monopoly railroad rates. The authors explained that the merge of Standard Oil with the main refiners in Pittsburg and Philadelphia – the other former “evening refiners” of the SIC – in 1874 put pressure on the Pennsylvania Railroad. Indeed, it would have threatened the Railroad of moving its crude shipments from its facilities in Pittsburg and Philadelphia, decreasing its activity. The Empire Transportation Company, subsidiary of the Pennsylvania Railroad, tried to replicate by acquiring refining facilities on Long Island in the State of New-York. But, Standard Oil replicated the shutdown of Standard Oil's refineries in Pittsburgh decreased by 65% the Pennsylvania Railroad activity in March 1877 (Hawke 1980^[134]). Thus, the railroad company had so choice but to accept to merge by the end of the same year. Because of the new integrated segment, Standard Oil could benefit from transportation rate more attractive than any of its rivals. In 1878, the rate for crude shipments to New York was \$1.06 for Standard Oil against \$1.70 for independent refiners who did not integrated railroads. The implied refining merging³ was then

³The refining merging is the refined product price minus the crude oil price and the transportation costs

\$0.49 for Standard against a loss of \$0.15 for the independents (Williamson and Daum, 1963^[278]).

1.2.3 The control of the oil price mechanism

Now that we have discussed Standard Oil dominance on crude oil transport, we offer to look at its influence on the second major component of oil trading: the price risk management. However, on this point, it would be more appropriate to talk about its control over the price mechanism. Indeed, the firm's market power was the authority on the market. Standard Oil's dominant position discarded the market. It can be considered that the company prevented the formation of an organized market.

Standard Oil used vertical integration to pressure the market system

While the growth of the oil organized market is usually dated in the 1970s-decade, a first one was established starting 1874. Oil City, Pennsylvania was the main trading place and offered spot, forward and even first oil futures contracts. The most traded contract depicted a 1,000 barrels pipeline certificate to be delivered within 10 days, which can be seen as a futures contract on the short term (Weiner, 1992^[268]). In addition to provide tools to manage the price risk exposure, the organized market also contributed to the price mechanism system. By centralising information on the market, Oil Exchange price served as reference to set price in producers trades. However, the organized market only last until 1895 when the Seep Agency, a tanker shipping Standard Oil's barrels, decided to use posted prices for trades with producers. The new "posted price" mechanism led Standard Oil to "post" the price they are willing to pay to crude producers, which created major market distortion considering the monopsony market driven by the company.

Vertical integration has played a major role in the establishment of the new price system. The control of transport assets is critical in the industry for the establishment of

the payment system because it is the segment of the industry that organize trade. If the dominant company bypass the market system, then there is no more liquidity and the organized market is likely to collapse. That is what happened with Standard's trades. They started to pay its upstream producers in cash, out of the Exchange, and without issuing pipeline certificates (Tennent, 1915^[258]; Brown and Partridge, 1998^[40]). Consequently, the formers were no more traded which drastically decreased the liquidity of the Oil Exchange and sealed its collapse. Standard Oil's vertical integration strategy during the period 1875-1995 contributed to reduce the amount of oil barrels traded on the exchange market. Its production was estimate to account for 25 to 30% of the U.S. crude oil (Brown and Patridge, 1998^[40]), while many individual producers still remained on the market, hence a relatively atomistic market out of Standard. Besides, we can notice the company started to divest upstream right after 1895, in order to focus on their core activity in refining and distribution. It shows that vertical integration strategy was set to put an end to the organized market.

The benefits of establishing itslef as the market policer instead of the organized market

The willingness to end the organized market can be explained by the negative impact of futures markets on monopolies or monopsonists' profit. Because of their weight in the U.S. crude and refined production, Standard Oil already had control over the oil supply, so the main remaining uncertainty on their profit was the price volatility. On the contrary, the posted-price mechanism offered a definite advantage since it reduced the price volatility.

Brown and Patridge (1998^[40]) argued that this is not the reason why Standard oil removed organized market. Once again, they concluded that their purpose was to en-

sure and even raise their market power. In 1983, Newberry provided theoretical models analysing the behavior of a dominant company in a market with futures contracts^[207]. He showed that futures markets limit the power of commodity cartels, especially in the oil industry using the example of the OPEC. He provided a linear model with a non-storable commodity and demonstrated that a dominant producer or a cartel organization would favour suppressing futures markets. Indeed, futures markets offer to reduce risk for competitors who are likely to raise their production capacity to maximize their profit on their volume, which puts downward pressure on prices. He found that hedging instruments raise the supply elasticity. On the contrary, company exhibiting a high market power is looking for high prices while it is controlling the supply. However, Newberry's paper is limited by the no-storage assumption which is highlighted by Philips and Thisse (1984^[222]). He developed a new model including Philips' critics that dominant firm's stocks impact futures prices in 1990^[208]. Newberry also introduced hedger's storage capacities and reach to the same conclusion that futures market reduce risk, increase supplies and lower prices at the benefit of the consumers. But, this result decreases dominant firms' market power. As a consequence, a company like Standard Oil enhances its position in a cash payment system.

The analysis of the influence of futures markets on the market power of monopolies and monopsones counterbalances the analysis usually proposed stating that futures markets open the way to market manipulation. It is the role of regulators to ensure that such manipulation is eliminated. The most well-known operation is the corner, which is defined by the Commodity Exchange Act (CEA) as the exercise of market power in a commodity futures market before the contracts expire. In 2004^[226], Pirrong offered to demonstrate that Ferruzzi's corner in the 1989 soybean market⁴ led to a major disruption

⁴Ferruzzi's corner on the soybean is the biggest corner recorded since the 1980s. It was undertaken by the Italian grain trading company, a major player in the Italian market and having held a strategy of rapid establishment in the United States. The episode was made famous by the inability of the market authorities, namely the Commodity Futures Trading Commission (CFTC) and the Chicago Board of Trade (CBOT), to intervene to regulate the trader's situation. Despite the concern of the two regulators, the trader justified the number of soybean contracts purchased for delivery in May 1989 and even obtained an exemption from delivery when the contracts expired. By June 1989, the trader held the equivalent of 23.6 million bushels in contracts and 41% of open positions on the CBOT, driving up the price of soybean (according to Eric N. Breg, *Curb on Soybean Trading Puts Market in Turmoil*, in the

in price and quantity traded. The analysis highlights failures in the regulatory framework for identifying market manipulation.

Brown and Partridge (1998^[40]), using the Buying Power Index methodology (Blair and Harrison, 1993^[35]), provided empirical evidence of the impact of Standard Oil on the U.S. crude oil price. They showed that the company's backward integration strategy had a positive impact on crude oil prices and that the futures market raises supply and demand elasticities. They concluded that in order to balance Standard Oil's monopsony power, crude producers had to collaborate to raise prices, which means that should have turn to a monopolistic competition. This statement confirms Standard's incentive to integrate backward and to suppress the Oil Exchange. They also argue that, if one can see the end of financial hedging instrument as an increase of transaction costs, the company offset this cost by the decreasing number of competitors.

We must notice that posted prices remained the norm on the market even after Standard's dismantling in 1911. The system has been used until the oil market openness in the 1970s. Major oil producers kept using posted prices for crude oil produced by national companies in many places. It still enhanced monopsony power of producers.

1.3 The rise of the Seven sisters kept the competition argument at the center of concerns

Untrusted laws put an end to the Standard Oil's dominant position in 1911. Nevertheless, the collapse has not been the event leading to the rise of independent commodity traders as we know today. Indeed, the monopoly gave way to an oligopoly composed of major oil producers which kept a fully, or close to be fully, vertically integrated structure. Despite

New York Times, 07/13/1989). The CBOT had to implement a holding limit of 600 contracts expiring in the same month and forced the liquidation of Ferruzzi's positions in 5 days, immediately driving down the price (Pirrong, 2004).

antitrust laws, oil producers were still seeking to expand their market power. They use horizontal integration to increase their size and their production capacities. Nevertheless, commodity trading remain a key feature of the industry. Producers exercise their market power by maintaining internal market and posted price system the norm. Nevertheless, the period that last until the oil shock and the competition that was established during laid the foundation for the market openness and the growth of market trades.

1.3.1 The Seven Sisters oligopoly succedes to Standard Oil's monopoly

The dismantling of Standard Oil gave way to regional companies managing oil businesses in the United States. Furthermore, the collapse of Standard coincided with the openness of new international oil markets and the discovery of oil exploration fields, mainly in Middle East. It led to the growth of international oil companies (IOC) which established in the beginning of the 20th century and still exist nowadays for most of them.

The rise of the Seven Sisters or the companies whose transport infrastructure are developed enough to trade on the international market

While the historical descendant of Standard Oil already have transport infrastructures and the distribution network to affirm as the main oil producers, the other members of the Seven Sisters also demarked thanks to their skills to transport oil from where it is extracted to where it will be refined or consumed.

The divestment of Standard Oil created new regional players. On the East Coast, the Standard Oil of New-Jersey will fund the premise of Exxon, Mobil is derived from the Standard Oil of New-York. On the West Coast, the Standard Oil of California became an individual company again, which will emerge as Chevron. Other regional market formely managed by the monopoly has been dismantled, like the Standard Oil of Indiana that will

become Amoco, but none reach to the three formers' level. The three producers could largely benefit from the distribution network already established on the U.S. territory.

Four other IOC emerged at the same period. They took advantage of new exploration site, both in the United States and abroad. We account:

Gulf Oil and Texaco, two integrated player which took advantage of the discovery of oil reserves in Texas, mainly in Spindeltop Field at the very beginning of the 1900s. Concerning Texan oilfields, the producers did not initially have the same infrastructure as the three companies mentioned above. It is because of their size and volume of oil production that they have become major players. Crude oil production in Texas became so important that the oil price from the Mexican Gulf quickly imposed as the international reference.

The companies exploiting the international deposits already benefited from developed distribution network and transport infrastructures.

First, the Persian Oil Company, founded in 1909 explored and refined oil from the Persian Gulf. The turning point in the company's growth occurred when the British government sold British Petroleum to Anglo Persian Oil in 1917 in order to fuel the energy demand during the war. The newly founded company acquired a large distribution network in the UK and entered to the European market at the end of the war. The control of the asset on multiple staged has been critical to enable the company to grow.

Second, the Royal Dutch Shell Group is formed in 1907 by the merger of Shell Transport and Trading Company and the Royal Dutch. The integration of midstream activities made the company a serious competitor to Standard Oil. The Shell Transport and Trading Company demarked thanks to the innovation in the transport of oil they offered by using tankers such as the Murex, to ship oil. Bulk transport reduced transport costs because of the large volume it enables to carry. The second advantage of the trading company relies on its origin. The company has been founded in 1833 to trade antiques and oriental seashells from Far East to Europe. Consequently, they benefited from ex-

port and import infrastructures already founded that eased and accelerated trade when the company turned to oil trading in the 1880s. They merged with Royal Dutch, an oil producer in the Dutch East Indies to extend their network because of the decrease in oil supply in Texas. Once again, that is the control of midstream assets that enabled the group to be part of the Seven Sisters.

1.3.2 Toward a cartel organization

The group of major oil producers, known as the Seven Sisters, is now formed and composed of: BP, Chevron, Exxon, Gulf Oil, Mobil, Royal Dutch Shell and Texaco. All of these actors were already fully vertically integrated and the organization of the industry has been driven by a battle between them to control exploration sites in multiple strategic regions. The 1952 Federal Trade Commission's report highlighted the control this group had on the industry through their involvement in every segment that are exploration, extraction, refining, transportation and marketing. They competed through horizontal integration strategies and extension of their oil supply. They all benefited from the mechanization trend and the development of mass-produced cars (Keating 2006). Moreover, the World Wars made oil a strategic asset to fuel war equipment. The expanding demand and the oligopolistic competition led to strong competition on regional markets. In the first half of the nineteenth century, marginal costs are still low and systematically lower than marginal revenue (Stevens 2008). Producers exhibited excess capacities and chronic overproduction that feeds the price competition between them.

The As-in Agreement

The run to horizontal integration led to a fierce competition between producers but at the expense of their margin. In order to avoid any move to be counterproductive, the Seven Sisters favored collaboration. Because a price war would have decreased market

shares of one of them, Exxon, BP and Shell, agreed on the Achnacarry Agreement, or the “As-in Agreement”, in 1928 in Scotland. Producers agreed not to compete on prices and to maintain existing market shares. Convinced by the collaboration system, the others joined the agreement in the following years (Stevens, 2013^[256]). The 1952 Federal Trade Commission report depicts the crude oil market as an oligopolistic in which Sisters controlled quantities, but do not enter into direct collusion. It induced, that none of them would take advantage on foreclosure to increase its market power. The Majors tune oil supply to the world demand for petroleum goods in order to maintain pressure on the demand side and raise prices.

Nevertheless, the agreement presented several limits. In spite of the so-called cartel of the Seven Sisters, producers never stopped competing and continued horizontal integration strategies. There has been a race to control exploration site in every strategic region in order to lower their costs to trade in European or Asian markets. The discovery of oil reserves in Middle East and Asia attracted many producers. However, most of them controlled assets through joint ventures. The Kuwait Oil Company emerged as a joint-venture created by British Petroleum and Gulf Oil in 1934. The Standard Oil of California has been the first company to purchase concessions in Saudi Arabia in 1933 to the company that will become Aramco. Texaco bought half of Aramco concession in 1936 and others will follow the trend. Producing countries were granted through royalties, but the formers remained low relatively to producers’ revenue.

Posted prices maintained producers’ control on prices

Their market power was assessed by the use of posted prices in joint partnerships with state-owned companies, especially in Middle East. The system contributed to maximize their revenues in their vertically integrated organization. The horizontal integration diversified supplying sites and contributed to ease trades to various demand markets. By 1950, the “Seven Sisters” were estimated to control 70% of the world oil refining capaci-

ties out of the countries from the Communist block, the United States and Canada. On the transport segment, they also owned almost all of the pipeline networks and 60% of privately-owned tanker fleet (Stern, 2020^[255]). They had the capacity to tune oil supply to the world demand for petroleum goods in order to maintain pressure on the demand side and raise prices.

1.3.3 The end of the crude oil price system decreased Seven Sisters' influence

In spite of the agreement and the price system that gave high market power to producers and calibrated the supply on the demand to maintain pressure on the demand side, the crude oil market started to exhibit peaks. The excess supply The Sisters' high revenue created opportunities to the introduction of new independent players which raised the output to maximize their own revenue. Conoco, Phillips and Marathon quickly emerged. Contrary to the Seven Sisters, these producers were not necessarily fully integrated, at least in every market. But, the new independent oil companies could focus their investment on the upstream segment. They raised production capacities to extract oil from reserves rather than leaving it in soil reserves. High volume ensured their revenue and could cover the large investment cost. Non-major oil producers obtained concessions in many producing countries, especially in Venezuela where they supplied 15% of the countries' production by 1965 (Parra, 2004^[93]). Libya also granted concession to newcomers. From 1965 to 1968, their production doubled, from 580 thousand b/d to 1.1 million b/d (Parra, 2004^[93]). Moreover, producers from the Soviet Block supplied large volume of crude that they exported to newcomers. As an example, the Italian producer ENI could import Russian oil at low costs starting 1959. Russian oil exports have multiplied by 7 from 1956 to 1961, from 100 thousand b/d to 700 thousand b/d. It led the market to

oversupply, especially once the US government imposed import quotas to protect local oil producers. In order to defend their market shares, the Seven Sisters had to pressured their refining margins to remain competitive. The cost of maintaining the company vertically integrated became more and more costly.

The increasing pression on the dominant producers of the oil industry kept increasing until it cut their margins. To balance the decreasing revenue, Exxon, followed by the other Seven Sisters, lowered posted prices as low as 14 cents per barrels in 1959. The decision actually brought to the end of the price system. The new independent producers traded oil with countries from the Soviet block at higher prices than the posted-ones managed by the historical oil companies and many oil-producing countries ask for renegotiation of prices and concessions.

The formation of the OPEC

The final point that pressured Majors is the growth of national oil companies (NOC) in countries that nationalized and/or developed their own sites. Until the second part of the twentieth century, integration strategies, horizontal as well as vertical, dominates the industry. Horizontal integration enabled Seven Sisters to share most of concessions which created an implicit oligopoly. While, vertical integration brought IOC to deal with internal prices instead of market ones, observable by, at least some, actors of the industries. This organization enabled them to maximize profit and limit tax liabilities on intermediary stages of the production process (Penrose, 1971^[218]).

The preferable position of the independent producers raises conflicts with oil-producing countries which aim to take back the sovereignty of their oil reserves and production. They are no more satisfied with the return they receive from IOC and want to obtain a higher part of the added value of the industry, coherent with their position as a provider of resources. At this period, IOC lost control on the oil supply mainly against the organization

of the Petroleum Exporting Countries (OPEC) which reduced the status of contractors of IOC in their territories (Sampson, 1975^[242]). The OPEC, formed in 1960 by Iran, Iraq, Kuwait, Saudi Arabia and Venezuela, collaborated to compete with the Seven Sisters and Soviet Union producers. More than a new competitor, the Declaratory Statement of Petroleum Policy signed in 1965 by the OPEC members established the inalienable right of all countries to exercise permanent sovereignty over their natural resources. Joint ventures became the only organization enabling IOC to explore OPEC reserves. organizational structure of the industry had to become more flexible and led to major adjustments in order to ensure market shares. By 1973, OPEC provided 53 per cent of the world oil supply out of the Soviet Union.

The trend that brought IOC to set nothing but more integration, vertically or horizontally, slowed down or even stopped. On the contrary, they are looking for flexibility to deal with a market in which demand is no more growing as fast as it used to in the years following the World War II. The oil peaks in 1973 and 1978, sharply increased their margins on the short run, but finally set that IOC do not control oil supply any more. Strategies are now oriented to control costs and supply. On the theoretical view, the use of basic foreclosure theory stopped being the dominant paradigm to explain organization changes in oil industries. The industry is more and more sensitive to transaction costs management.

1.4 The market openness revealed the boundaries of the oil companies

The increasing competition has led to major changes in the industry. The main concern is no longer to ensure outlets, but rather to rationalise their production process. The market has become a viable solution to trade crude and refined oil. The full-integration of the industry, from extraction to refining to distribution, is obsolete. Each segment of the in-

dustry is now considered as an independent stage with its own individual profit function, rights and costs. This means that instead of dealing with an overall profit function that has to cover global costs, each segment has to cover its own costs of capital (Dale *et al.*, 2014^[75]).

1.4.1 The market openness allowed producers to divest

Oil is now sold on an open market gathering multiple operators from the different stages of the production process. It is the birth of the crude oil spot market for specific crude oil that is the Brent for the North Sea, and the West Texas Intermediate (WTI) for the United States, and the birth of the forward and future markets for these crudes. These elements opened producers to disintegration strategies. They are now all the elements – higher number of counterparts on the selling and buying sides and liquid markets – that allow to dissociate upstream from downstream assets. The degree of upstream integration froze or even decreased for many oil producers. Rationalisation pass through costs reduction and disintegration strategies. They no longer have to refine crude they extract themselves, they can source from external sources (Stevens, 2003). Shell pioneered de-integration strategies by freeing its refining site to purchase oil solely from upstream units of the group. They had the opportunity to purchase the lowest price crude oil and sell their crude oil at the highest price with no distinction if the partner is a Shell company or not (Dale *et al.* 2014^[75]). Dale *et al.* also show this trend by citing 1998 British Petroleum Annual Report:

A significant feature of the oil industry in recent years has been the trend towards deintegration, or separation of upstream crude production from downstream refining and marketing. Each part of the oil business then stands on its own so allowing it performance to be measured against the value of its products in the international market

Producer's vertical disintegration reveals the boundaries of oil companies

The issue of vertical disintegration falls within Stigler's framework developed in its seminal paper "The Division of Labor Is Limited by the Extend of the Market" (1951^[257]) for long. Stigler describes disintegration as a natural response to market evolution. New markets are usually small and firms integrate their production to secure profits. But growing markets creates opportunities and enable companies' specialisation to ensure benefits thanks to economies of scale. Hence a disintegration trend. This framework became particularly useful to identify some drivers of disintegration processes. Holmes (1998^[140]) provide empirical evidence of Stigler's theory by showing a positive correlation between vertical disintegration and localisation of the company. Indeed, localisation is useful because a high concentration of companies directly impacts the scale of the industry. However, if this framework has been popular among industrial economists, applications to commodity industries remain weak. The first characteristic of commodity industries is that the geographical constraint on the input production. Hence, it appears that vertical disintegration in commodity industry seems to rely on the boundary of the firms as originally defined by Coase (1937^[63]). The focus of the theory of the firm and the transaction cost theory is to compare internal costs from a transaction within the same firm and the cost of a transaction on the market.

The theory of the firm has gained a particularly strong interest to analyze the evolutions of the oil industry sector. Nevertheless, due to its variables of interest and especially the degree of asset specialisation, we can regret that there are so few applications to commodity industries. Yet, the theory proposes to confront the market with the firm to choose the optimal organization, which coincides perfectly with the dynamics of oil producers in the 1970s. What is more, the theory incorporates uncertainty as a key variable in trade organization. The theory deals with producers of the supply chain, but does not really focus on the role of midstream agents which do not physically transform the asset but offer transport services. Nevertheless, the discussion on the contractual organization in the

supply chain only focus on producers' trades. The analysis deal with two central points in the activities of physical traders that are the optimisation of trades in the industry to link crude producers and refiners and the risk management.

1.4.2 The transaction costs theory is in line with producers' new dynamic

Transaction costs theory offers another framework to explain vertical integration strategies that fits particularly well with IOC's objective to be profitable on intermediary segments starting the second part of the twentieth century. It defines the market and the firm as two alternative governance structures to trade. Of course, there are multiple other organizations available to producers, like joint venture that became popular organization between IOC and OPEC members, but the firm and the market are the two extreme solutions which offers a clear arbitrage. In the oil industry, drilling companies can sell barrels on the market to independent refiners who transform it, on downstream segments of the industry. When trades occur within the same firm, barrels are internally transferred to downstream segments remaining under the same authority. The premise of the theory relies on Coase's seminal contribution *The Nature of the firm* (1937^[63]). He highlights that a firm chooses to proceed on the market or internally by comparing transaction costs. If this framework can be similar to the study of the industry as production-function-firms whose entire activity depends on its production costs, as presented below (Marshall, 1920^[193]). The question is more where do these transaction costs come from rather than their actual amount. The approach is also fundamentally different because rather than dealing with the good as an asset traded from a firm to another one, trades are defined as property rights transfers. By doing so, Coase is able to describe the boundaries of the firm and demonstrate that the trade organization is similar to the issue of optimally distribute property rights. Just like production, trade is costly. It is well known that, on the market, transaction costs are high because of information costs, costs of negotiation,

of enforcing agreement and so on. Consequently, vertical integration can seem like the final step of the champion firms in a mature industry. However, Coase argues that many trades take place outside the boundaries of the firm because the cost of the vertical integration is not sustainable. Management of complex transaction as well as perceptual and cognitive limitations of managers who are not able to drive efficiently trades on multiple segments (Huber and Power, 1985^[148]), can lead to costly internal transaction. Consequently, frequency of trade became a key driver of vertical integration. Coase shows that the costs of re-contracting outside the firm, on the market, can be higher than the cost of trading the asset within the same structure. That is to say, the cost of investing in long-term contract with employees that manage the internal trade.

The critical role of transaction costs

In the oil industry, as in any other industry, transaction costs are diverse and start even before any contract is signed. In the market, between the multiple business segments, there are systematically costs of searching for a business partner and information costs. Every producer has to look for the counterparty that will fit with the asset it is selling. In the case of an oligopolistic competition, the choice of a partner may seem limited due to the limited number of players in the industry. But there are always costs involved in finding the right intermediary agent to ship oil barrels, for example.

The oil industry is familiar with regional events such as a pipeline incident in a region that prevents the export of crude oil. This results in major imbalances in which the oil product is locked up in a small area, creating an oversupplied regional market, while the rest of the world is undersupplied due to reduced supply on the international market. The resulting tight market increases the cost of finding a trading partner. In addition, producers are also exposed to non-sector-specific events. In the midst of the oil crisis of 2020, the search for the most consistent trading partner to guarantee payments and trade flows may prove complex. The global economic slowdown has sharply reduced the complex demand for oil products, while the oversupply of oil has finally led to a further

reduction in production decided by OPEC. China, which ended its quarantine while many Western countries had started theirs, was one of the only places to maintain its oil imports from Saudi Arabia. It imported 2.3 mbbbl/d in April - the highest peak since Bloomberg began recording shipments in 2017 - and 2.1 mbbbl/d in May. While exports to other destinations fell by a third in May - 6.6 mbbbl/d compared to 9.3 mbbbl/d in April. This is expected to result in a significant increase in pre-sales costs. Another common cost is the cost of information for contracting on the market. Counterparties need to know price information - actual and forecast prices - in different locations to allocate their sales and purchases effectively.

Oliver Williamson has provided the best-known framework, or at least laid its foundations, for studying transaction costs and defining those we have described here as ex ante costs. That are, costs that arise before the transaction takes place, as opposed to ex-post costs that arise when a transaction is not as described in the original contract. In *Markets and Hierarchies* (1975^[273]) and *The Economic Institutions of Capitalism* (1985^[274]), the 2009 Nobel Prize winner, identify some of the main drivers of transaction costs. He followed Commons (1934^[65], Institutional economics) which advises analytical organization for each transaction of an asset transferred from one technological surface to another. Next to the production cost function, there is a transaction cost function with its own parameters.

The key role of the asset specificity

Williamson described a basic transaction cost model in which the asset specificity occupies a central role. Specificity creates a bilateral monopoly between a buyer and a seller whose investments are dedicated to the particular transaction relying them (Perry, 1989^[219]). Thus, the transaction is said to be specific when one of the parties has invested in assets that cannot be redeployed to another transaction without loss of value (Diez-Vial, 2007^[81]). The nature of the asset specificity can be divided between: specific physical

capital, specific human capital, site-specific capital, dedicated capital and brand name capital specificity. Therefore, asset specificity led to investment from one of the parties that can be mutually beneficial. There is rent to capture from specific investment. Klein, Crawford and Alchian (1978^[173]) introduced the idea of an appropriable quasi-rent. It is estimated by taking the difference between the amount a renter can value an asset and its salvage value which is the value in its next best use to another renter. In energy economics, the role of asset specificity is acute in natural gas industries. Investment in gas liquefaction facilities create a particular network for LNG importing and exporting countries (Geng, Ji, Fan, 2014^[103]) whose benefits are lost if countries trade natural gas through traditional pipeline technology.

Consequently, asset specificity gives rise to opportunism. Once a firm has invested in a relationship specific transaction, it faces the risk that its partner act opportunistically to appropriate the rent. Indeed, the investing firm is locked-in the trade will the partner did not invest, or not as much. Therefore, it creates a leverage effect to renegotiate the transaction at a better price under the threat of a breach of contract in which the opportunist has less to lose (Williamson, 1992^[276]).

As the degree of asset specificity rises for a firm, non-market trades are expected to be the optimal solution. Since the asset is not traded on the market, the firm bearing the cost of the specific investment keep the control on the asset in multiple stages of the industry which guaranty a sharing of the rent in adequacy with its investment (Hobbs, 1996^[139]). Vertical co-ordination like long-term contracts and integration tie sellers and buyers over a long period. The integration also has the advantage of reducing ex-ante and ex-post costs since negotiation costs and the control of the quality are now all integrated under the same authority. There is no explicit measures of asset specificity, but Levy (1985^[184]) used the intensity of research and development expenditures to identify the determinant of vertical integration in a multi-industry analysis. Lieberman (1991^[186]) referred to the total fixed investment cost of downstream plant of integrated companies as proxy of the asset specificity.

The role of the uncertainty

The asset specificity creates a strong interdependence between a seller and a buyer, which is exacerbated by the uncertainty that underlies any trade. Koopman (1957^[176]) and Simon (1972^[252]) latter, among others, described the effect of uncertainty on the trade relationships and showed that the lack of communication and the lack of trust between counterparts makes trading more complex. It can bring to increased ex-ante costs because of negotiation on contractual clauses to ensure trade under uncertain market. Uncertainty, by nature, makes long-term contracts imperfect because of the time mismatch between the moment a contract is signed and the actual transactions. The inherent incompleteness of contracts comes from the fact that no contract can state on every possible contingency. Information asymmetries exist between counterparts just like in a principal-agent model and the agency theory. Jensen and Meckling (1976^[154]) explained that agency costs arose when a principal needs to align its interest with those of an agent to ensure the good behaves of a task. In a long-term contract, it can be prohibitive expensive to write a contract that would specify obligations in the event of unforeseen circumstances. Because of these costs, the contract may fail to efficiently allocate the surplus between the parties in certain states of the market. Indeed, at the moment the transaction is effective, there may be major changes in quality, quantity or prices. The latter might be the best-known risk derived from market trades because of oil price volatility. Uncertainty, therefore, creates an opportunistic behavior when one of the party benefits from the new state of the world at the expense of the other. Opportunism can appear from uncertainty too, exposing to the hold-up risk (Goldberg, 1976^[110]).

Like the asset specificity, vertical integration strategies arise with uncertainty because it makes contract unable to state on all possible contingencies. The measure of the uncertainty can take multiple forms, but in the case of commodity industries changes and volatility of supplies and prices are the most eloquent.

The asset specificity in commodity transport

The oil industry is no exception to the specific asset analysis. It is easily visible for mid-stream activities where commodity traders can dedicate department and human resources to particular producers, or even creating new shipping lines to link producers on different segments of the industry. Even by going back to the premise of the industry, the construction of pipeline linking crude producers to refining plants created specific relationships. This is even more noticeable in the case of the railroad development. Because of the high cost of financing them, their construction was likely to closely link sellers to the refiners located along the railroad terminals, especially considering the low network development at this time. In this particular case, it is not the asset specificity that is the key component of the trade relationship but the specific investment underlying its trade. However, the oligopolistic competition and the vertically integrated structure did not allow for the transaction cost theory to emerge as the main framework.

1.4.3 The particular role of long-term contracts in the oil industry

The boundary of the firm and the arbitrage between internal trade and the market opens the door to a vast research field around contracts. Their analysis can profoundly change according to their duration and the level of vertical co-ordination. As stated in the transaction cost theory, contracts are incomplete and the asset specificity exposes parties to hold up risk.

The analysis of the incomplete contract theory finds an attractive material in energy industries because of the critical played by infrastructure investments in these. The complexity of such a design relies on the irreversibility of investments which creates the risk that opportunism shows up from the buyer of the seller side. Creti and Villeneuve (2004^[71]) showed this problem in the natural gas industry in which sellers, upstream, need

to invest in natural gas wells while buyers, downstream, may have to invest in pipeline connections. These investments being expensive, producers agree on long-term bilateral contracts. Of course, perfect contracts do not exist and many events can impact and deteriorate the depletion of the agreement. In case the buyer cannot take the delivery, the seller has lost its investment until he is able to find another party able to replace the initial buyer. However, it cannot happen without a loss of value, at least storage costs until the trade can actually occur but mainly investment costs if the structure is tailored for the partner. Similar costs are assumed by a buyer if the seller cannot take the delivery, or if the quantity or quality is not as stated in the contract. This problem defines the basis of the incomplete contract theory with specific investments.

The inherent contract incompleteness and the principal of informativity

The incomplete contract theory is an entire section of the literature on vertical integration devoted to the study of long-term contracts. The latter cannot be a complete contract, due to the inherent incompleteness of the contracts. But, rather than looking for the optimal organization between the market and the firm, this theory aims to identify the optimal contract. The idea of optimal contracting finds its premise in Homlström (1979^[141]) who tried to determine the contract that would solve the principal agent problem.

Early studies focused on the manager's problem whose utility does not fit with the company's profit function. Information asymmetries create an incentive for the manager not to invest enough effort for the benefit of the company. Homlström asserted that the contract must benefit the principle of informativity which must be able to remunerate the agent under the condition of observable signals. Nevertheless, it can easily be argued that the identification of the agent's actual contribution to the company's performance depends on factors much more variable than the agent's effort. Business cycles, exchange rates in terms of international trade and input prices are other key exogenous variables (Schmidt, 2017^[243]). Moreover, the contribution to the impact of the producer of a standard good, such as a barrel of oil, traded on an international market is limited by the

ability to find another producer offering a good with similar characteristics. But some application can be found to intermediate operations. Holmström recommends the use of performance evaluation (1982^[142]), *i.e.* to look at the advantage of the company in relation to its competitors. This methodology could imply that a manager could be "punished" if it is considered that the good performance of the enterprise does not depend on him, but it can also be an insurance against hazards over which he has no control. Contracts derived from the principle of informativity are very complex because they must deal with all the observable signals concerning the agent's effort. Schmidt (2017^[243]) explains that the clause depends on the probability distributions of the signals, whereas in the real world, contracts are not so complicated. Wages are based more on a linear function of output.

Further research on the principal agent problem completes the analysis. Holmström and Milgrom (1987^[143]) used a two-stage dynamic model that allows the agent to adjust his effort in response to past experiences. They concluded that the optimal contract in the continuous model remunerates the manager with a linear function in total profits, which is a simple solution compared to a complete contract. Indeed, it induces a linear pressure on the manager instead of bonus/malus payments scaled on performance thresholds. A manager who has reached his annual sales targets in advance has no incentive to continue working until the end of the year, for example. They proposed extensions (1991^[144] and 1994^[145]) with a multi-task model and the introduction of incentive instruments. They showed that increasing asset ownership significantly increases workers' performance, which has been demonstrated in other theoretical and empirical literature (Gibbons 1998^[105], Lazear 1999^[179], Ichniowski and Shaw, 2003^[149]).

Market uncertainty and opportunism can jeopardise trades

Research on hold-up risk and the inter-company transaction finds its roots in Grossman and Hart. They make this risk the key element of the incomplete contract theory. Even

if one of the counterparties meets its commitments in a long-term bilateral contract, in the event of a breach of contract a court will always have difficulties to determine compensation costs. In *The costs and benefits of ownership: A theory of vertical and lateral integration* (1986^[117]), Grossman and Hart argued that third parties could never observe and verify all the market and industry information. Therefore, they assume that a long-term conditional contract - which would be a complete contract - is not practicable.

To show the effect of the risk of hold-up, they described trades as commitments giving rights to both parties but with a twofold definition of contractual rights. There are specific rights whose definition is stated in the contract. And there are residual rights that are not specified in the contracts and from where opportunistic behaviors emerge. Thus, the purpose of a contract is to determine the effective distribution of residual rights between the parties. Unlike Holmström's models and its extension by contemporary economists, Grossman and Hart's model deals with a vertical relationship between two companies. Residual rights are determined by the asset over which they exercise control and by the ownership of that asset. It is a two-period model. The first details the contract and the investments specific to the relationship in which the companies are engaged, while the second presents the advantages of each party. The latter is based on their specific investment and on the behavior of the counterparty's manager, which is derived from maximizing ex-ante net profits or manager surplus B_i for both managers $i = 1, 2$:

$$B_i a_i, \phi_i(q_1, q_2) \tag{1.1}$$

The main advantage of this presentation is that manager's benefit depends on the right of control over the partner's asset, q_2 for the first manager. The right is not supposed to be contractible ex-ante, but can be ex-post. Ex-ante investments a_i are also assumed not to be contractible as well because they are too complex or not observable. They are determined simultaneously and uncooperatively. Because of the dependence of each party's profits on efforts of the other, they might be induced to specify a long list of rights based their mutual behavior. But such a contract, which would tend towards a

complete contract, may be too costly. Optimality can be found when one party purchases all residual rights of control; That is to say when the party takes the asset ownership or launches vertical integration process. In doing so, the maximization program does not depend only on the manager's asset, but we rather consider both managers:

$$B_1 a_1, \phi_1(q_1, q_2) + B_2 a_2, \phi_2(q_1, q_2) \quad (1.2)$$

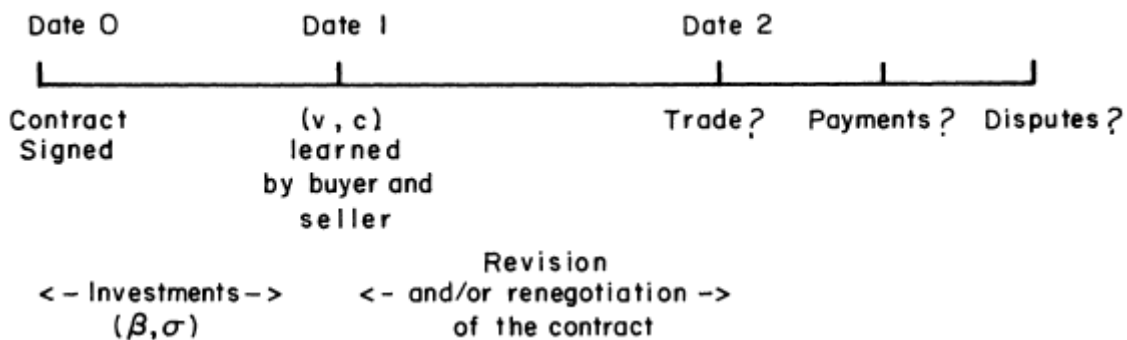
Because the optimal contract ensures to maximize one manager's benefit while the second benefit from his reservation utility, integration cancel any uncertainty on partner's specific investments. Coordination through integration is the first-best solution for the industry.

The uncertainty also endangers investment

The asset specificity is closely related to the companies' specific investments whose costs can modify the surplus distribution between counterparts. Grossman and Hart provided strong arguments on their role and impact of long-term contracts on vertical integration strategies. The contractual incompleteness of long-term contract leads to a distortion between ex-ante investment and ex-post return. The share of the surplus coming to each of them depends on their residual rights ownership. Consequently, the author warned that vertical integration is optimal only if there is a mismatch between the relative importance of each firm's investment decision. But when the investment is important for both firms, the market is desirable and surplus is divided equally. Nonetheless, a contract could deal with unexpected if it can be renegotiated with high profitability once the state of the world is fully realised. Hart and Moore's paper *Incomplete contract and renegotiation*^[130] offered an alternative approach that does not deal with property rights, but rather focuses on mutually beneficial investments and the benefits of ex-post renegotiation. It can be heard that, in case of a crude oil trade between upstream and downstream operators, investments in human capital and logistic capacities to coordinate with the counterpart are mutually beneficial and critical to the transaction.

On this basis, it is important to make a clear distinction between contracts incompleteness and asymmetries of information. In Hart and Moore's model, the first arises because it is too costly to use and process all the set of information in the contract, but both of the parties can have the same information. While the seconds arise when contingent statements are impossible because the state of the world is not observed by all of the parties. In both cases, parties need to make expectations on these many contingencies. They state that they have the option to revise or renegotiate the contract when the state of the world ω is known. They also use a multi-period model whose time period can be summarised in the following scheme:

Figure 1.1: Hart and Moore's lifetime of a contract (1988^[130])



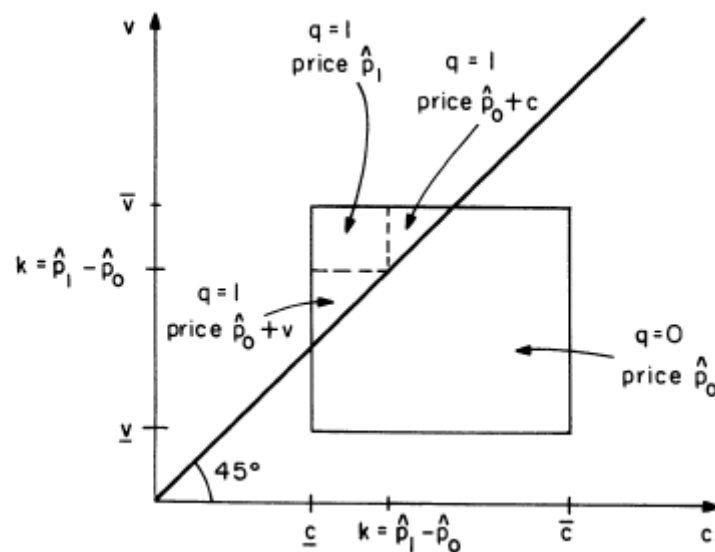
Source: Hart and Moore 1988, p 758.

The buyer and the seller enter into a relationship for the sale of a homogenous good in date 0. They sign a long-term incomplete contract which locks them in until date 2. They also decide on their specific investment strategy β and σ . However, there is no insurance that the trade will actually occur. The buyer values the good by v while the cost is established to be c for the buyer. Value and costs are known at date 1, before the transaction and results from β and σ which make investments mutually beneficial. Of course, one could take advantage of the other investment and decide to underinvest.

They assume a court can observe if the trade occurs, the amount the buyer must pay

if there is trade p_1 and if there is not p_0 , and, potentially, messages and information m exchanged between parties once the state of the world is revealed, between dates 1 and 2. As a consequence, prices $p_1(m)$ and $p_0(m)$ relies on information to share. They show that at the date 1, multiple scenarios are possible, depicting why the trade may not happen and what are the renegotiation possibilities. Scenarios are represented in the following figure:

Figure 1.2: Hart and Moore's trade case scenari (1988^[130])



Source: Hart and Moore 1988, p 758.

The figure allows them to demonstrate that a trade can happen only and only if the buyer value the asset more than the seller's production cost, that is to say $v > c$. Thus, all couple (v, c) below the 45 degree line are not realistic and the buyer pay \hat{p}_0 . Furthermore, without renegotiation, parties must verify that parties must verify that $v \geq \hat{p}_1 - \hat{p}_0 \geq c$. Indeed, in this case, the buyer values more the asset than what he need to pay to achieve transaction k . So does the seller whose payment coming from a successful trade exceeds its costs c . Then renegotiation is needed for the transaction to occur when:

- When $v \geq c > \hat{p}_1 - \hat{p}_0$, the seller values more the asset than buyer. To compensate the spread, renegotiation leads the buyer to pay $\hat{p}_0 + c$ as a compensation.

- When $\hat{p}_1 - \hat{p}_0 \geq v \geq c$, the seller values more the asset than buyer. To compensate the spread, renegotiation leads the buyer to pay $\hat{p}_0 + v$ as a compensation.

In the case where messages can be exchanged between the date 1 and the date 2. Then, prices p_1 and p_0 can be updated. First, investments, when they are specific and mutually beneficial, impact costs and valuations. They state that the decrease of the buyer's choice of investment β reduces his expected valuation v and the buyer's costs c , so does a decrease in the seller's investments α . Consequently, there is a change in the condition for the trade to happen. The difference between p_1 and p_0 must decrease as well. Both the buyer and seller's expected surplus is thus affected. Because investment depends on the expected surplus but parties cannot control each other investment decision, the market would lead to under-investment. Each party does not take into account the other's surplus. These conclusions are similar to the ones stated by Williamson (1985^[275]) and Klein, Crawford and Alchian (1978^[173]).

The other component of the prices that is given in Hart and Moore's model is the role of the state of the world ω on p_1 and p_0 . It does not necessarily lead to opportunistic behaviors because there are no information asymmetries but it is a component that parties must deal with. A look at commodity economics is enough to see the effect of the state of the world. Moreover, the state of the world can be particularly unstable, and a look back to the timeline in Hart and Moore's model (figure 1.1), introduces the risk that the state of the world at the moment producers agree on a contract and set their investment profile might be totally different from the one when the transaction occurs. Price volatility occupy a critical role, especially in the oil industry as it is a highly-traded commodity. Therefore, if producers agree on prices that are no more relevant at the date of transaction, the probability that the transaction fails increases. Because of the uncertainty, parties may agree on a wrong price system. If they expect the market to be highly volatile, they could have an incentive for more flexible trade organization, and market solution might be more efficient.

1.4.4 Contractual design in commodity industries

Long-term contracts are largely used to trade oil barrels because they are strategic assets whose supply needs to be ensured on the long-run and because of the price risk management. However, long-term contract exposes to opportunistic behaviors because one party can have an incentive to appropriate rents when the other party involves capital that does not have a lot of value for another transaction. No long-term contract can avoid it. In its simplistic form, a long-term contract offers multiple benefits to ensure trade like fixed quantity, quality and price for a trade. But in reality, specific clauses can allow flexibility in order to manage demand and/or supply fluctuations. Rather than rigid and fixed price, parties can agree on price escalators which can be done by predetermining price increase or decreasing rate per year or, more likely, by anchoring the price to an index (Creti and Villeneuve, 2004^[71]).

Commodity economics, and more precisely, energy economics are a largely used in the literature to test the validity of the transaction costs theory and the role of long-term contracts in the industry. Joskow's research on the organization of the coal industry (1985^[161] and 1987^[162]) is one of the main empirical evidence of the asset specificity's impact on organization. He focused on the impact of transaction-specific investments, as described by Williamson (1985^[275]), on the duration of contracts in the coal industry. He estimated, for U.S. coal suppliers and investor-owned electric utilities, the relationships between the duration of contractual commitments and the annual quantity of coal contracted. Regional dummy-variables are introduced to control for the site specificity of coal supply relationship. The effect of the "physical asset specificity" are captured by the fractions of a plant's coal requirement and the total coal requirement of the utility in his model. Indeed, a buying plant operator might favour a specific supplier trading a particular type of coal⁵. The physical asset specificity can also be measured by the location of the selling miner because quality relies on the site. Thirdly, the author tests the dedicated assets

⁵Type of coal can be distinguished by their quality in terms of Btu, sulphur, ash and chemical composition, or by the source of coal and the timing and conditions of the transaction (Joskow, 1987^[162]).

characteristic which can be seen as a specific investment or an investment that would not have been made for a transaction with another party. He makes a distinction for the sample of contracts that are dedicated to a single plant. He concluded that important specific investments create an incentive for the parties to reach longer-term contracts specifying clauses to prepare for repeated transactions. Although clauses are costly and results from potentially equally costly negotiations, Joskow recommended them in order to limit the hold-up risk exposure and post-transaction bargaining and renegotiation that would be even more costly.

Contractual flexibility must reduce contract incompleteness

Long-term bilateral contracts can introduce specific clauses to specify the price for the delivery of the asset as well as the quantity to be delivery. These clauses, known as take-or-pay provisions, are popular in energy markets and more precisely for gas trades. They link buyers and sellers for long periods – 20 to 30 years – with strict requirements for the parties (Creti and Villeneuve 2004^[71]). The most-known clause, from which the contract takes its name, is the obligation for the buyer to pay the seller a predetermined amount whether the gas delivery is made or not, while the seller must be able to supply a predetermined volume of gas on his side. The use of these contracts is also discussed for coal (Joskow, 1985^[161]) and petroleum coke (Goldbger and Erickson, 1987^[111]) trading. Take-or-pay provisions are, therefore, defined as risk-sharing instruments because an event on one side of the industry will also be managed by the other side (Crocker and Masten 1985^[196] and 1996^[197]).

solution to reduce exposure to opportunism A simple solution to reduce hold-up risk in the oil industry might be the use of spot markets. Al-Najjar (1995^[4]) recommends that producers use spot contracts or increase renegotiation mechanisms based on the information available ex-post. Such a design could reduce uncertainty and restore flexibility

in case of high price volatility. This differs from classical conclusion of the transaction costs theory and empirical results finding that, on the contrary, high uncertainty brings to increased vertical integration. Fan (2000^[97]) found that oil price shocks in the 1970s initiated a wave of mergers and restructuring in the US petrochemical industry. However, on the global market, it is clear that the higher use of spot and forward market clearly offered an alternative to internal transactions. The main contributions from the transaction cost theory and the incomplete contract theory beginning to find applications to the oil industry starting this period to the present day. IOC can no more be depicted as rigid fully integrated companies but need to adapt their organization to cost and profit function on each segmental activity. Moreover, this trend has been reinforced by what Baaij *at al.* (2011^[15]) name the “efficiency focus regime” which echoes the spread of the shareholder value philosophies in the mid-1980s. Producers release assets that are not profitable, which created new opportunities for NOC looking for higher downstream integration in this period.

One particular critic that can be made on the transaction cost theory relatively to its application to commodity industries relies on its conclusion on the superiority of the firm relatively to the market when the asset specificity is high because of opportunism. On the contrary, spot and forward contract are backed by the specific relationship that link producers because of the timing specificity of the trade. Pirrong (1993^[225]) demonstrated that spot contract are not uneconomic in bulk shipping markets by showing that spatial and time specificities constrain agents to deal together once the contract is signed.

1.4.5 Recent organization changes

Based on our analysis, the development of an open spot and forward market for oil producers made the market a profitable way to trade oil assets. We cannot state whether the market or the internal trade is best suited for the oil industry. However, it is the state of the world, that we can define as the price dynamic and the supply – demand balance for

producers—that defined the organization that fit the most. Consequently, there is now an arbitrage between these two extreme but valuable solutions that draws the major trends of the industry’s organizations. It comes that organization changes became volatile. If it needed around 80 years to come from the full integration of the production process to independent inter-segmental trades, the last decades exhibit more volatility.

The final years of the twentieth century marked a relative return of global vertical integration processes. State of the world has been fundamentally affected by the rising demand from emerging countries which boosted prices. What is more, the fall of spare capacity for both crude oil production and refining capacities starting the 1990s (Purvin and Gertz, 2008^[232]) helped to feed upstream profits but also downstream ones. Even downstream entities exhibited higher refinery margins which made them attractive assets for vertical integration. The later was supported by sky-high prices and the market feeling that this demand dynamic and these prices were there to stay. It is worthy to notice here that both IOC and NOC benefited from this state of the world, which brought them to exhibit similar organization features. However, this framework knew a first pitfall with the exploration of new sources of hydrocarbons raised the oil supply and with the economic slowdown from the 2008 financial crisis. Many IOC restructured their businesses and rationalised their portfolio of segmental activities. There has been a consequent increase of divides between upstream and downstream units. In its annual report from 2012, Exxon announced they have divested or restructured their downstream assets in “19 refineries, 6,000 miles of pipeline, 191 product terminals, 37 lube oil bland plants and more than 22,000 retail service stations”. Exxon had the objective to focus on its upstream assets, especially located in the United States. These measures led to a significant increase of their return on capital employed, by nearly 4 percentage points.

The price decrease did not last long since oil prices quickly reached new records between 2010 and 2014. Oil prices have been taken within the so-called commodity price super-cycle. During this period, prices did not have a major role in the industry’s or-

ganization, companies remained globally vertically integrated but some exceptions are observed. Crude oil prices are so high that it affected refining margins. Again, the investor's philosophy dominated and companies divested in non-performant segments. In summer 2014, the huge price dropped that marked the end of the commodity super-cycle brought producers to restructure their activities and drastically reduce their investment strategies (see chapter 5). It brought to a new and more significant wave of disintegration strategies. Consequently, it seems that, from a rigid organization structure, the oil industry exhibited integration dynamic whose structure seems to respond to market changes.

1.5 Conclusion

This first chapter aims to analyze the main stages in the construction of the oil market from its first emoluments to the last few years. We have thus been able to show three main periods. The first concerns the domination of Standard Oil within the framework of a monopolistic competition that brought antitrust laws to the American territory. The second major period marked the advent of the producers making up the Seven Sisters. Oligopolistic competition was inherited from the fall of Standard Oil and it was a cartel organization that characterized the period. Nevertheless, we cannot deny that competition remained increased between producers.

Each of these two first period make competition the main issue of organization strategies. Producers are mostly leading vertical integration strategies, which can be explained mainly in line with the theory of foreclosure. Integration seems to be the only possible organization for producers to face competition and to ensure supplies and outlets. It is the collapse of the posted-prices system that put an end to the dominance of this organization because of the exchanges allowed on the physical market between independent firms located in different segments of the supply chain.

The last period we present here concerns the most recent decades since the 1970s. The possibility of trading on the market opens up new possibilities for producers for whom vertical integration is becoming less rigid. Thus, the transaction costs theory has become the dominant framework for analyzing the industry. The degree of vertical integration can thus vary from one period to another and producers can therefore focus on minimizing transaction costs and risks.

Through this chapter, we have been able to reveal a common thread in the determinants of the organization of the oil industry. This is the role played by transport and price risk management assets. Indeed, the primary source of Standard Oil has been its influence on the railroad networks and its ability to create its own system of producer prices (posted-prices) instead of trying to create a futures market to determine the price of a barrel of crude. It is this momentum that justifies the implementation of Standard Oil's first vertical integration strategy. Therefore, Standard Oil thus had full control over the transport infrastructure and the pricing system. This legacy was passed on to the Seven Sisters who inherited the pricing system and whose vertical integration allowed them to control trading networks on a global scale. It is only with the emergence of a liquid physical market and the determination of the barrel price by the interplay of supply and demand that producers were able to abandon the full vertical integration of the supply chain. The management of transport networks and price risks is thus relegated to the intermediate segments of producers but also to the physical traders that have emerged simultaneously.

Chapter 2

The economic functions of the commodity trader

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2.1 Introduction

Despite the abundance of scientific works in the field of agricultural and energy economics, little seems to have been written on the particular role played by physical traders in commodity industries. They are usually depicted as midstream agents providing logistic services within the commodity supply chain in exchange for commissions. However, their role goes far beyond this. They actually have a key economic duty. The one to reconcile, in time and space, buyers and end-users of raw materials. It is therefore hardly appropriate to model the various commodity chains without taking them into account.

Originally, trading activities were not orchestrated by independent agents even if it has always been a major feature of the oil industry. Trades used to be run by producers which owned transport infrastructure to move commodities to refining plants and distribution networks. This even constituted the market advantage of major oil producers. We underlined in the first chapter that the basis of the Shell's business relied in its logistic capacities. Nevertheless, the development of commodity trading firms (CTF) as independent actors of the oil industry finds its roots with the divestment wave observed in the 1970s. Major oil producers like the Seven Sisters progressively concentrated on upstream operations and partially sold downstream assets to national oil companies or to new-comers. Producers of the industry do not necessarily have to meet and schedule their extraction to their refining capacities anymore. As a consequence, the rise of market trades finally led to the appearance of open oil markets, spot and forward, and the market price replaced the posted-price system. This has extended the role of the midstream segment, as commodity trading is no longer simply a matter of transport. Commodity trading helps to reconcile any mismatch between buyers and sellers. By organizing trades, they also manage risks associated with international trades. Thus, they are in charge of a wide range of risks as large as execution risks, financial risks and price risks, on which we focus in the second part of this chapter.

Therefore, physical traders have been an integral part of commodity industries for almost 50 years, yet the analysis of their role in organizing and managing trade does not seem to correspond with their importance. A preponderant role is always allocated to upstream and downstream producers. Indeed, an important section of the literature deals with the influence of producers on prices. Once again, imperfect competition is at the heart of the analysis and the OPEC still centralizes a lot of attention. As soon as 1976^[70], Cremer and Weitzman highlights that the cartel organization acts as a monopole on the oil market and drove prices up. Kaufmann and *et al.* (2004^[166]) shows a granger causality between real oil prices and OPEC capacity utilization, excess production, oil stocks and quotas. More recently, Loutia *et al.* (2016^[187]) shows a positive relationship between OPEC announcement and oil price volatility with a deeper influence when prices are low. Kilian demonstrates the dominance of supply shocks on oil prices until the 1990s decade and the higher role devoted to demand shocks since (2009^[168]). However, this is not where the analysis must stop. On the contrary, that is exactly where the study of commodity traders starts. They are the actors who deal with price fluctuation and offer solution to still enable trade to occur.

Furthermore, the process of relative vertical disintegration described before and the emergence of segment-specialized producers created the need for an agent managing temporal and spatial distance. Unlike producers whose role is to sell products which expose them to price movement, commodity traders can take this exposure through their storage capacity. The agent can then resell raw materials at the right time to the most suitable trading partner. This is why commodity traders are frequently located in major international ports, to be ready to meet any demand both upstream and downstream, whatever the destination.

In this chapter we aim to present the role of commodity traders in the oil industry and their contribution to the supply chain. Then, we focus on price risk hedging services they offer to producers. This leads us to discuss the close link between physical traders and

derivatives markets. The two go hand in hand since derivative products provide risk management instruments while physical traders provide liquidity to these markets. In a third section, we develop exponential generalised autoregressive conditional heteroskedasticity (EGARCH) models and mixed-frequency GARCH models to highlight the high sensitivity of commodity price volatility to both macroeconomic and financial factors on the one hand and sector-specific factors on the other hand. We find that energy price volatilities tend to be more sensitive to equity market return since the 2008 financial crisis and that energy supply and demand proxies influence the long-term component of energy price volatilities.

2.2 Commodity trading firms in commodity processing

Now that we have stated that upstream and downstream assets are disassembled and not necessarily located in the same place, the need for independent midstream agents became critical to ease trades. Consumption centres can be far away from production sites. Therefore, CTFs are critical to connect segments of commodity industries but also to reach distribution networks.

2.2.1 The growth of independent oil traders to connect markets

We have discussed in the first chapter that the oil peaks and end of the posted price system in the 1970s led to a profound change of paradigm in the industry. The divestment process gave a higher role to market trades instead of internal trades in vertically integrated firms. It is therefore not surprising that the rise of oil traders coincides with this period. Two of them centralise our attention because of their size and their longevity until today.

- Vitol, the Dutch company created in 1966, which was initially known for carrying oil products through the Rhine quickly arose as the main actor in Europe. Vitol's

trading desk clearly benefited from being located in Rotterdam, the biggest European port and the opening gate to the European market. Because the city is a trading hub, the company could benefit from the trading infrastructure to organize commodity trades.

- Glencore is another key actor of crude oil trading that appeared in the same period, in 1974. Founded by Marc Rich, the company is known as the first modern commodity trader. Glencore developed its core activity in the exporting Middle East crude oil and emerged by taking advantage of the OPEC 1973 embargo¹. The organization had declared an embargo against countries supporting Israel in the Yom Kippur War. By targeting the United States, the United Kingdom, Canada or Netherland, among others, it cut off big oil companies' access to Middle-East crude oil. The decision jeopardised long-term contract with OPEC members' concessions, but Marc Rich found a way to circumvent the embargo and bought Iranian and Iraqi crude oil through spot contract in their oversupplied market to resell it in the undersupplied US market. The trader ensured a high price spread as remuneration².

Other oil traders later emerged:

- Trafigura is a split off from Glencore in 1993 founded in 1993. The company used to focus on South American and African markets.
- Gunvor has been created in 1997, it initially specialized in exporting Russian oil barrels thanks to its storage facilities and logistics assets in Russia and in Estonia. This last trader may seem relatively recent but it is also the result of a market extension, the opening up of the Russian market.

These four companies seem to support the idea that independent commodity trading firms (CTF hereafter) emerged as a result of an extension of market, first the divestment

¹Glencore also trades ferrous and non-ferrous metals and minerals trading activities

²Glencore is known for its controversial trading activities in the area. The company also bypassed the Iranian embargo in 1979. Moreover, it is also accused of abusing of the United Nations Oil-for-Food Program in Iraq between 1996 and 2003. During these episodes, the company could buy cheap crude oil barrels, below the international price, and sell them at the international reference price which guaranteed huge profits.

process, then the access to the Russian market. Hence a key role to link oil supplying countries to end-using countries. It follows an interdependence between the market and traders. International oil trades expose producers to multiple risks that subsequently increase transaction costs. The strategic position of traders in the supply chain is to offer new transformation of the commodity.

2.2.2 Commodity traders in the supply chain

Although upstream and downstream segment of the oil industry dominate the analysis, midstream segments are critical to link every stage of the production process. Most of the time, commodity traders, through their skills and infrastructures are able to provide key services to enable the market to prosper and can buffer market imbalances in time and space³.

Resolve discrepancies between commodity sellers and buyers

Producers' decision to sell and end-users' decision to buy commodities differs. Indeed, they do not face the same constraints. By following Marquet (1992^[192]) typology, we see that:

- The producer is condemned to sell which leads him to search for contractual relationships. He must ensure that he is able to supply a sufficient volume and to comply with quality criteria. Moreover, the selling decision also depends on producer's expectations on future prices to determine the right timing to sell. If he expects prices to increase in the following months, he has an incentive to store the commodity and sell it in the future to benefit from more attractive prices.

³This vision of physical traders as pure trading intermediaries has undergone profound changes in recent years. Many of the main physical traders have acquired physical asset in order to participate in the physical transformation of the commodities. The trend is particularly strong in the mining, where Glencore has become the world's leading copper producer since its merger with Xstrata in 2013. Glencore is also a major producer of zinc, lead and coal. Trafigura has many joint venture and minor investments in iron ore, copper, lead and zinc, among other metals. The dynamic is not as prominent in the oil industry. Nevertheless, Glencore owns several exploration and refining units in Bermuda and South Africa, and, more significant, has invested 25% in the Russian oil producer, the second largest in Russia, Russneft through a consortium with the Qatar Investment Authority in 2016.

He prefers offering commodities under the conditions that are most favorable to him. Therefore, the seller will always prefer designing a contract specifying a Free on Board (FOB) sell, meaning that the buyer take the control of the asset once commodities are shipped. The buyer is in charge of transport risks. A FOB sell reduces seller's trading costs.

- The end-user, on the contrary, wants to buy commodities that meet its needs. He therefore has its own requirements in terms of quality and must ensure the supply to feed its production process. Just like the producer, he makes price expectations. If he expects prices to increase, the buyer prefers buying the commodity as soon as possible.

Furthermore, to decrease its transport costs, the end-user searches for a Cost Insurance Freight (CIF) purchase in which the seller covers these costs while the commodity is in transit.

We see from these point that its decision to buy and sell usually are negatively correlated, which creates the need for intermediaries to reconcile these timings. Commodity trading firms provide two key services:

- He provides a technical-commercial transformation, meaning that the commodity he buys is not resold under the same exact condition.

He can buy in one place and resell it in another market, which will be analyzed hereafter as a transformation in space (Pirrong, 2014^[228]). He has the storage capacities to buy the commodity when the price is favorable for the producer and sell it in the future to meet end user's requirements, it is the transformation in time. He can also blend and refine a commodity to ease the meeting of supply and demand, it is the transformation in form.

What is more, as the trader is an intermediary, he can buy the commodity FOB to producers, and resell it CIF to end user. It becomes the agent that manage transport costs and risks.

- He provide risk management services:

- Execution risks to control that contractual clauses are compatible between sellers and buyers.
- Financial risks like the access to credit in order to finance physical trades
- Price risks which involve a large set of variables such as the commodity price, the exchange rate to which we can add the freight price. These risks can be managed thanks to trader’s access to derivative financial markets. In this chapter we will focus on the commodity price risk.

Commodity traders provide spatial transformation

The commodity spatial transformation is a basic service that involves logistic skills and shipping management. Traders transport commodities from regions where they are produced to the ones where they are consumed. Overseas transportation covers most part of commodities international trades that link major ports. It is worthy to notice that infrastructures are one of the most valuable assets of CTFs. Coordinating international trade brings them to have facilities in major ports to load and offload products. They also own warehouses in order to be reactive to any shock that would lead them to deliver or receive large volume of commodities. Operating directly in port facilities offers them strategic location of these ports. Dutch ports, where Rotterdam and Amsterdam count among the biggest European ports, are commonly depicted as the opening gate the European market. Singapore exhibits the same characteristics for Asian Southeast markets for example.

On the contrary, vessels ownership is not as central as traders can rent it by using “time charters⁴” or use a voyage charter⁵. Of course, CTFs own vessels but their volume of transaction exceeds their shipping capacities. Owning ships is not mandatory to trade commodities. Using time and voyages charter instead reduce their assets and guaran-

⁴It is similar to a shipping lease agreement. The renter pays a daily commission, fuel and parking fees to the leasing company to transport the commodity. He has a full control on the vessel. However, other costs like maintenance, insurance or licensing are paid by the leasing company.

⁵In a voyage charter, the trader pays a metric ton freight rate to carry the commodity from a predetermined place A to a predetermined place B. The trader does not control the ship and therefore do not pay fuel neither port charges

tee them the same control on ships, especially for time charters. They can mobilize the right vessel size to react efficiently to market opportunities. Indeed, apart from linking international sellers and buyers, the other component of spatial transformation is to carry commodities to places where they can be sold at higher price. One of the main – or the main – sources of CTFs' profit is to take benefit of price differential between two places. Because the global oil market is imperfectly integrated, two regional markets for a similar grade can exhibit price spread that traders arbitrage. Local shocks can raise price in one specific area.

Infrastructures are the most valuable assets for spatial transformation, but sometimes, the latter can also be achieved within the same region. In the oil industry, exploration plants might be located inland and far from port facilities so that there is no competitive way to convey crude to the coast. This case is particularly relevant for agricultural and mining resources since farms and exploration sites are nearly always far from the coast. Solutions must be found to carry the resources to the coast and the port facilities. However, many countries, mainly in commodity-producing countries, do not have infrastructure to efficiently manage international trades. The CTF's role is therefore to select optimal systems to reduce transport costs. There are multiple options for inland trades but they reply to very specific transport condition. Rail and barge transports are low-unit-cost options but investment costs are high and must be backed by high transport flows. They are mainly used for mining and agricultural resources. For very isolated area, trucks are alternative. Fixed pipeline is a solution with low unit costs suitable to transport steady flow of liquid products. But is again a costly investment. When countries cannot afford to finance infrastructure to connect inland site to port facilities, CTFs can be involved in it. In order to gain new markets in high-potential countries but exhibiting a lack of infrastructure, CTFs can take part to the invest process.

They sometimes have to finance infrastructure to export it. Because of the collapse of the national railway company in 1990, the Colombian railway network is no more inte-

grated and its transport costs are not viable for international trade. In 2018, Trafigura, involved in Colombian oil trading, invested \$1 bn in the country's infrastructure with a river transport system to cut costs for oil trading (Buchan, 2018^[43]). Thanks to its alliance with Impala terminals, a multimodal logistics arm of Trafigura, they could invest in the Barrancabermeja port to move crude from interior to the main Pacific port CTFs can invest in all kinds of local infrastructure such as trucks, rails and, of course, fixed pipeline, involving high capital costs but ensuring a low transport cost per barrel. International trades are managed through shipping lines, which bring them to own port facilities. This is mandatory to be able to take or prepare delivery of commodities as needed. However, even if many commodity traders own tank fleets, they also trade through independent companies because vessels are interchangeable. Their role is to select the right one to the line and the destination port.

Commodity traders provide time transformation

The second key role attributed to commodity markets is to deal with disjoint timing. Suppliers may be constraint by seasonal production while the demand is a linear, or the opposite. These cases are easily understood for agricultural economics in which the harvest only occurs once or twice a year. It is also true for energy markets in which demand is usually higher during winter when the demand for domestic heating increase for example. Energy commodities must also deal with demand shocks like high investments in a developing country that would lead to a rise of the economic activity should increase significantly energy demand in this country. CTFs must be able to feed this demand while the supply remains constant. The opposite that is a positive production shock facing a constant demand brings CTFs to find a solution to manage the market disequilibrium. A major source of profits for CTFs is to use their inventory facilities to reduce excess supply or demand. They usually own storage capacities in strategic locations, big ports connecting major markets like Amsterdam or Rotterdam are for the European markets or Singapore for the South-East Asian one.

Without agents dealing with storage facilities, any shocks on the market, whether it comes from the supply or the demand, major imbalances would persist between regional markets. Indeed, it is sometimes too costly for suppliers to shut down or even slow down oil extraction sites when they face an oversupplied market. While an increase of production capacity rate to adapt to a positive demand shock is also costly. Supply is weakly elastic to demand or price changes and takes time to adapt to demand shifts and energy and oil demand are inelastic to supply shocks. Furthermore, imbalances exacerbate commodity price volatility. That is why inventory management is critical to absorb market shocks (Wright and Williams 1982, Deaton and Laroque 1992 and 1996). Once again, the infrastructure's ownership is highly valuable for the commodity traders to adjust their inventory levels. Owning facilities provide flexibility to traders. Raise their inventories level in oversupplied markets can prepare them to reply in short delay to any positive demand shock in the future. It gives them an arbitrage power for reacting quickly to any shock on the market without being exposed to varying storage charges when contracting inventory facilities.

Commodity traders can also provide commodities physical transformation

In its pure definition, commodity traders are not involved in the supply chain transformation and cover time and spatial transformations described above. However, they can still transform commodities when needed to ease trade. Indeed, crude products are rarely standardized but rather specific to their production or extraction site. Oil grades vary subsequently depending on the area they are supplied, and we cannot expect the same use for light sweet crudes than for heavy ones. Nevertheless, the light sweet crude supply is insufficient to balance the world demand. Grade mismatch are key nowadays because of the raise of environmental regulation that does not enable some heavy polluting crude to be refined. CTFs need to take part to commodity transformation to make supply meets demand requirement. In the oil industry, it is common to see traders owning downstream assets, especially blending facilities. It offers other spatial transformation opportunities

by making more supply and demand areas suitable for matching. What is more, blending capacities give them opportunity to mix different grades to meet demand. They enable CTFs to arbitrate oil from different grades.

2.2.3 Price spread create arbitrage opportunity for physical traders

In spite of international reference prices, the oil industry can hardly be depicted as perfectly integrated. Any mispricing or geographical price spread creates arbitrage opportunities for physical traders. Thanks to the infrastructure described above, they have the capacity to buy cheap and sell at a higher price, simultaneously or not, between regions. It is actually the core business of commodity traders and their main source of profit. What is more, thanks to blending facilities that more and more commodity traders own, they can also take advantage of changes in quality spread prices. By taking advantage of spreads between different regions, commodity traders contribute to the market integration since mispricing will disappear once traders will have taken advantage of every arbitrage opportunity.

Physical traders can take advantage of geographical spreads

The market fragmentation can be represented through geographical spreads that makes oil prices for the same grade and similar delivery varying across regions. The key component to identify arbitrage opportunity on geographical spread is to consider the cost-and-carry relationships that link crude prices. This methodology is used for oil exhibiting similar grades, but it is a useful tool to price crude on a benchmark. Carrying costs include physical transport, insurance, losses, customs duty costs and pipeline tariffs. The cost-and-carry model describes changes of crude spreads even between the reference crude oils. Kinnear (2001) described the WTI price as follows:

$$P_{WTI,t} = P_{Br,t} + C_{Br} + D \quad (2.1)$$

Where $P_{Br,t}$ and P_{WTI} are the Brent and WTI prices at time t , C_{Br} is the carrying cost for trans-Atlantic trade of Brent barrels. D is the quality discount, it is often set to 30 US cents (Kinnear, 2001^[171]).

Any non-justified spread creates potential arbitrage opportunity. Kleit (2001^[174]) concluded on the decrease of arbitrage costs between oil regional markets in the 1990s decade to demonstrate the globalization of the oil market. Fattouh (2010^[98]), showed that crude oil spreads corrected for quality and carrying costs deviate from zero create arbitrage opportunities. Their two-regime threshold autoregressive model shows that the spread must reach a threshold to cover arbitrage costs, which depends on quality of the studied crudes.

Regional spreads are sensitive to local trading accidents

The oil industry can provide many examples of market fragmentations, even momentary fragmentations, which are frequent in case of trading accidents. The final quarter of 2017 provided several examples of accidents that did not let crude oils to access to the international, or even just the regional, market. Leaks on the Keystone pipeline on November the 6th of 2017 led to its shutdown. The pipeline carries around 590 thousand barrels per day of crude from Alberta to US markets. The shutdown created unbalances on US markets, thus undersupplied. The WTI rose by 2.6% the day the leak has been announced. However, bottlenecked barrels in Alberta, unable to be traded to the U.S., created a local oversupplied market raising the discount for Western Canada Select at \$16.00 below the WTI benchmark (according to Shorcan Energy brokers)⁶. Furthermore, another example of trading accident appeared just a month later. On December the 7th of 2017, the biggest British pipeline from North Sea oil and gas fields has been shut down two weeks for repairs. The cracked pipeline led to a major disruption in gas flows and a sharp increase in crude oil prices. The infrastructure usually carries around 450 thousand barrels of Forties per days, while the Forties is the largest of the crude oil that determine the Brent benchmark. The accident raised Brent price by 9% at the end of 2017 because

⁶Kevin O'Hanlon and Nia Williams, *Keystone pipeline spill pushes oil higher, fuels TransCanada opponents*, Reuters, 11/17/2017

of an increasing demand for Brent. The shock being specific to the North Sea market, it pushed Brent-WTI margin from \$5.26 to \$6.88 per barrels, 30% increase in only three weeks.

Changes of the legal framework is another source of local shocks

Other local shocks that also impact the grade spread are regional changes of the legal framework. It is particularly relevant for environmental issues on the demand side. Since 2006 for the United-States, petroleum-based diesel is restricted to ultra-low-sulphur diesel (ULSD) whose sulphur content is under 0.15%. A more recent example is the new regulation from the International maritime Organization (IMO) that limited, since 2020, the sulphur content in marine fuels for ocean-going vessels to 0.5% against 3.5% since 2012. It should result in a decrease of the demand for high-sulphur refined product. Thus, on the US market, commodity traders must be able to redirect high-sulphur oil mostly to the Gulf Coast where refineries have the downstream assets to upgrade oil products (EIA⁷, the effects of changes to Marine Fuel Sulphur Limits in 2020 on Energy markets, 2019). Once more, the role of commodity traders in this situation is to take advantage of these unbalances to spot gaps in the market. If the geographical spread does not equal the cost of the geographical transformation of the commodity, there an arbitrage opportunity. The ability to raise high trading volume is again key component to make the operation profitable. By doing so, commodity traders ensure prices to bring back to their equilibrium, contributing to the market integration.

Quality spreads

Once considered each regional market, it seems, at first, difficult to consider the oil market integrated since crude from one site cannot be substituted by other origins without loss of value – that is the cost to transform crude oil in order to correct the potential quality spread and the cost associated with the geographical spread. Differences in grades lead

⁷EAI, Energy Information Administration.

to price spreads that can be defined as the price difference between different grades of crudes on the same date once corrected for the location, if necessary. Two components dominate grade definition. The quality of the crude oil rises when it exhibits low-density⁸ – we say light oil – and low-sulphur – we say sweet oil – content. These two characteristics are met, with tight differences, for the Brent and the WTI, two of the most traded crude oils. The Brent is slightly lighter with a 38 API gravity against 39.6 for WTI, but the former is sweeter with a 0.24% for the US crude against a 0.37% for the other. The third benchmark, Dubai/Oman, exhibits higher density and sulphur content which made it a medium-sour oil. Each grade corresponds to a specific demand, and buyers of sour oil must have the infrastructure to deal with impurities. As an example, light sweet crude oil is used for gasoline, kerosene and high-quality diesel production.

Quality differences contribute to fragmentation of the oil market exhibiting specific price for each origin and grade. Sour crude oils cannot be priced at the same level as sweet light crude oils. High-sulphur oil involves more transformations downstream to improve its quality and make it available for larger markets. Consequently, these oils induce higher refining margins that decrease their crude price. It remains that these crudes are priced relatively to a benchmark. Most of the time, crude prices rely on one of the three main reference prices: the Brent, the WTI and the Dubai crude oil. The three have the advantage of being widely traded on liquid future markets. Brent, WTI and Dubai crude oil future contracts offer a public price that gathers the market information on crude trades. Financial prices are able to react quickly to any market changes like the demand or supply changes, events on pipelines or any other transport event that impact oil trades and any macroeconomic event that may impact oil prices. Thanks to its high quality and because it is a waterborne⁹ crude, the Brent gathers all the criteria to be the most widely

⁸The oil density is measured either by the American Petroleum Institute (API) or the National Institute of Standards and Technology (NIST), both US organizations with small differences in their calculation methods, based on the Baumé Scale that measures the density of liquids with water as the 0 benchmark of the scale.

⁹Waterborne crude refers a crude oil that is sold loaded on a ship, by opposition to a trade through pipeline. Therefore, a waterborne crude is more suited for international trade.

used price anchor and the largest oil futures contract. According to the ICE, it is the barometer for around 70% of global crude oil. WTI is the reference for American crude oils, while Dubai does the same for Middle East and South Asian and Australian oils. The following figure, provided by the ICE, provides a simplified map of the influence of the three main oil benchmarks.

Figure 2.1: Global crude oil benchmarks



Source: Intercontinental Exchange (ICE)

The aforementioned discussion leads to defined oil prices with a premium or a discount over the benchmark. For the same origin, destination and delivery date we have:

$$P_t^{crude} = P_t^{Benchmark} + / - spread_t \quad (2.2)$$

The particularity of the previous equation is that the spread is not a constant. Because of specific demands and supplies for crudes, premium for higher crude quality can drive the spread up. However, any dislocation of the previous relationship creates arbitrage opportunities for commodity traders that brings the market back to the balance. This will be observed whether the spread does not equal the costs of transforming the quality of the lower grade to the higher one. Nowadays, most of oil physical traders own blending facilities to combine crude from various origins and suit with quality requirements. Such

infrastructure enables them to potentially bypass shock on refining margins that does not make low quality grade a viable trade on the market. Moreover, commodity traders have the port infrastructure and the easy access to shipping services to raise high volume of commodities to make the arbitrage profitable. Prices for various grades must then go back to their long-term equilibrium.

2.3 Commodity traders provide risk management services for producers

Commodity traders operate at the heart of commodity transformation by connecting supply and demand in the international trade network. Nevertheless, we can reduce their role to physical trade management. The most known characteristic of commodity traders, which make them controversial actors in the industry is their closeness to financial markets which derive from international trade. Indeed, any foreign trade expose to multiple risks that subsequently raise transaction costs for producers. It is their access to financial market, and more precisely derivatives markets, plus their high trading volume to create economies of scale that constitutes their main added-value. CTFs use commodity derivatives markets to offer risk management services to producers. Commodity derivatives are financial contracts underlying a standardized commodity for a specified trade. Future contracts have become key component of commodity markets. They offer reference price for standardized contract in a liquid market. Contrary to long-term contract setting physical trades, futures are standardized and quoted on organized financial markets. They can thus pool market information to determine commodity prices and react to any market information.

The West Texas Intermediate (WTI) is quoted on the New York Mercantile Exchange (NYMEX) since 1983 and accounts for the delivery of 1,000 US barrels. The price is set for a delivery free-on-board in Cushing in US dollars. The city is the main US trading hub for crude oil. The WTI emerged as the reference price for the US market. The Euro-

pean reference price relies on the Brent. Brent future contracts, that describe the delivery of 1,000 barrels too, are traded since 1988 on the open outcry International Petroleum Exchange of London, which became the Intercontinental Exchange since 2005. Nevertheless, physical actors of the industry cannot set their financial trades on future contracts, because they do not necessarily trade on financialized commodity, and WTI trades do not necessarily use Cushing for delivery place for example. Future contracts are used for trade support and provide hedging and information services for the industry.

2.3.1 Flat risk management

Commodity traders ensure the tight relationship between futures and physical prices thanks to their risk management skills. Hedging relies on the idea that cash market and futures prices tend to move together. Changes are not necessarily identical, but they are assumed to be close enough to offset. The relationship between physical and financial markets is consolidated by CTFs' operations. Their typical activity can be summarized in the following steps:

- 1:** CTFs agree to purchase and sell with two counterparties.

Traders are not supposed to take part to the production process, so they buy commodities only to sell it in the future. To avoid being ending up with commodities without destination for reselling, they simultaneously agree to buy and sell the commodity as an intermediary between an upstream and downstream producers for crude oil trades. They commonly sign a long-term contract without fixing the trading price, which is determine at the transaction date. However, it is at this moment that they negotiate their margins over a crude oil benchmark. For example, they can benefit from a discount, like 50 basis points to the WTI index, when they purchase crude oil, and a premium, 50 basis points over the index, when they deliver it to the downstream buyer. Simultaneously linking producers on multiple segments enables traders to lock their profit margins, 100 basis

points here. CTF's profit in this operation is independent of the underlying commodity price.

2: Once the agreement is found, CTFs are exposed to flat price risk, WTI price fluctuations would impact their profits in this case. If the index price increases when CTFs take delivery of the crude and then decreases when they resell it at the second transaction date, CTFs exhibit substantial losses. Traders thus use their proximity to financial market to offset the price risk. They take futures contracts against every physical trade and sell their contracts at transaction dates. A simple example is presented hereafter:

Let us assume a commodity trader agree to take the delivery of a 100,000 barrels of WTI on January 2021 and find an agreement to sell it on July 2021. The trader takes opposite positions on the Future market by selling 100 WTI futures contracts of 1,000 barrels each. For simplicity, we assume cash and future prices are identical at \$50 per bbl on January. What if the WTI price decreases to \$45:

Table 2.1: Flat price hedging

| | Cash Market | Cash price | Future Market | Future price |
|---------|--|------------|--|--------------|
| January | Buy cash crude oil barrels | \$ 50 | Sell July WTI Future contracts | \$ 50 |
| July | Sell cash crude oil barrels | \$ 45 | Buy July WTI Future contracts | \$ 45 |
| Result | Loss on the cash position : \$ 500,000 | | Gain on the Future position : \$ 500,000 | |

Gains on Future positions equal losses on the cash position. From the trader's perspective, the net selling price remains \$50/bbl.

2.3.2 Determination of future prices

In table 2.1, the example presents identical cash and future prices, what is not relevant. In commodity markets, we state that the reference price is the future price, however, the local cash price for a commodity must be adjusted for carrying condition such as freight, insurance, interest rates and storage costs as well as quality differences and other local market specificities. Therefore, even if the future price is always converging to the spot price when the contract is close to maturity, both are not equal. The future price can

exceed the expected spot one, in this case we talk about contango, and the expected spot price can exceed the futures one, we say backwardation markets.

In the *Treatise on Money* (1930^[167]), Keynes, later extended by Hicks (1939^[138]), stated that quoted forward prices must fall below expected spot prices. He justified this spread by the “normal backwardation” theory. He showed that, in a risk-neutral economy, there is no profitable trading opportunity since futures prices should equal the expected spot price. Prices can be defined in the cost-of-carry model, where the future price must equal the expected spot one plus the cost of carrying the commodity until the delivery date. Any difference would create an arbitrage opportunity that would bring prices back to equality. However, backwardation is said to be “normal” because the spread reveals a risk premium on spot prices which arise when one of the market counterparties is more risk-averse than the other. If producers or hedgers are more risk-averse, they might be willing to trade futures contracts at prices below the expected spot one. Keynes also stated that hedgers tend to be short on the financial market, while counterparties – basically speculators – tend to be long.

Still, normal backwardation does not explain how expected the spot price can be lower than the futures price in contango markets. As an alternative to the Keynes-Hicks theory of normal backwardation, Kaldor (1939^[163]) founded the basis of the theory of storage by considering that the risk premium paid by hedgers to their counterparts is determined based on net carrying costs. The framework involves the convenience yield, that relates inventories and the spread between the nearest futures price and the spot price. The convenience yield must be deduced from carrying costs and has a direct influence on the basis. It is defined as the difference between the spot and the closest future contract price net of storage and other carrying costs. Basically, it depicts the net value of inventory ownership. The market will highly value stock holding when inventories are scarce because it gives to the agent an advantage to quickly respond to any demand. The resulting value had been described as the return for storage as depicted by Working (1949^[280]). Hence, the

convenience yield increases (decreases) when inventories decline (increase) and spot prices net of carrying costs rise above (reduce below) futures prices (Brennan, 1958^[38]; Fama and French 1988^[96], Ng and Pirrong 1994^[210]). The theory of storage has the advantage of explaining both backwardation and contango markets. Working (1934^[280]) had already shown the convenience yield curve for wheat Chicago futures spreads between May and July¹⁰ between 1896/7 and 1915/6 and between 1921/2 and 1929/30. However, he shows that the curve is a concave function meaning that if convenience yield is bounded in backwardation, it is not for contango markets.

For oil markets, the convenience yield can be computed by using the closest future price as a proxy for spot price, S_t (Gibson and Schwartz, 1990^[106]). The Future price Fut_t for a one period maturity based on the cost-of-carry model (Brennan 1958^[38], Fama and French 1988^[210]), can therefore be presented as follow:

$$Fut_t = S_t \cdot \exp(rf_t + sc_t - cy_t) \quad (2.3)$$

Where rf_t is the exogenous interest rate, sc_t the storage cost, cy_t the convenience yield which describes how much the ownership of the asset is valued (Kaldor 1939^[163], Working 1949^[280]). The benefit from holding the commodity is negatively correlated with stocks (Fama and French 1988^[96], Ng and Pirrong 1994^[210]), which is empirically documented (Deaton and Laroque 1992^[7] and 1996^[79], Routledge *et al.* 2000^[238], Gorton *et al.* 2012^[112]). The yield can widely vary during the time-period of the futures contract until it converge to the spot price.

2.3.3 Converting flat price risk into basis risk management

The convenience yield can widely vary during the time-period of the futures contract until it converges to the spot price at the end. The basis can change significantly, and even turn from positive to negative when the market switch from backwardation to contango.

¹⁰Which is the end of the crop-year for wheat

An increase of the basis benefits to the hedger, while a decrease brings to losses. So, when futures markets are using for flat price risk management, the hedger became instantaneously expose to the basis risk. Indeed, by taking back the example from table 2.2, we can show that basis changes impact the hedger's profit:

Let us assume a commodity trader agree to take the delivery of a 100,000 barrels of WTI on January 2021 and find an agreement to sell it on July 2021. The trader takes opposite positions on the Future market by selling 100 WTI futures contracts of 1,000 barrels each. On January, the cash price in \$50/bbl and the future price is 49\$/bbl, hence a basis equals to \$1/bbl. If the basis increase by \$0.5, we have:

Table 2.2: Increase of the basis

| | Cash Market | Cash price | Future Market | Future price | basis |
|---------|--------------------------------------|------------|--|--------------|--------|
| January | Buy cash crude oil barrels | \$ 50 | Sell July WTI Future contracts | \$ 49 | \$ 1 |
| July | Sell cash crude oil barrels | \$ 45 | Buy July WTI Future contracts | \$ 43.5 | \$ 1.5 |
| Result | Loss on the cash position : \$ 5/bbl | | Gain on the Future position : \$ 5.5/bbl | | |

The traders losses \$0.5 per barrel he trades, which is loss of a \$50,000.

On the contrary, if the basis decrease by \$0.5, we have:

Table 2.3: Decrease of the basis

| | Cash Market | Cash price | Future Market | Future price | basis |
|---------|--------------------------------------|------------|--|--------------|--------|
| January | Buy cash crude oil barrels | \$ 50 | Sell July WTI Future contracts | \$ 49 | \$ 1 |
| July | Sell cash crude oil barrels | \$ 45 | Buy July WTI Future contracts | \$ 44.5 | \$ 0.5 |
| Result | Loss on the cash position : \$ 5/bbl | | Gain on the Future position : \$ 4.5/bbl | | |

In this second situation, we see that the trader benefit from the change in the basis. We can also notice that these changes can be exacerbated when the market switches from a contango to backwardation, and conversely.

The two previous tables also presented us that an increase in the contango markets create extra benefits for commodity traders by strengthening their profit. It also supports the idea that commodity markets are a specific research area. Futures, and more generally derivative markets, for commodity trading cannot be approached similarly as traditional financial tools because of the particularities of the underlying assets. Hedgers must use their specific knowledge of the market to make expectation on the changes of

the basis. It gives credit to the particular role of independent commodity traders. While producers are directly exposed to flat price fluctuations, CTFs can focus on basis risk management. Indeed, oil trading by non-independent commodity traders are realised through subsidiaries with their own profit function to pursue their objectives. What is more, they own storage facilities and are involved in international trade of the underlying commodities. They must be able to centralise information more efficiently than other financial operators and producers who also need to manage production process. Pooling information enables them to maximize their profits, but also to provide hedging services more efficiently and to reduce transaction costs for their clients. Finally, absorbing flat price risk is efficient for CTFs as basis fluctuations are lower than flat price ones. Indeed, above from small fluctuations spot and futures prices evolve together.

We must underline that price management using futures markets works for financialized commodities. For other commodities, or just grade, that do not have futures contracts, CTFs must be able to manage cross-hedging methods. The later bring the hedger to find futures contracts whose underlying asset is positively correlated to the commodity to be hedged. Consequently, the trader must also make expectation on the grade premium or discount to the reference futures' underlying asset.

2.3.4 Other risks to be managed

Managing flat price risk is not the only role of commodity traders. Connecting local markets where commodities are supplied to the international whose reference price is usually in USD, involves a high currency risk exposure. Again, the access to derivative markets is key to manage this risk. The negative impact of exchange rate volatility and international trade is demonstrated for long (Hooper and Kohlhagen 1978^[146], Baldwin and Krugman 1989^[22]), and is particularly strong for commodity traders handling large volume of trades. Currency risk can be managed through derivatives contracts.

Moreover, transaction of large volume of commodity across continent expose to the variability of freight costs. The freight rate is the price charged for the delivery of a cargo from one destination to another. This cost is varying depending on the commodity to be traded, the vessel, the route for the transaction. Freight rates are determined in a competitive market (Beenstock and Vergottis 1993^[32]) that relies strongly on the demand for shipping services. Tvedt (2003^[262]) showed the high volatility of freight rates in period of oil shocks and concluded on the presence of idiosyncratic component in volatility. He also concluded that bigger vessels are exposed to bigger volatility than small ones. Freight hedging commonly involves forward freight agreements (FFA). These are standard contracts traded over-the-counter covering routes, time of settlement, contract size and the freight rate. They are used similarly to futures contracts for flat price risk management. The hedger takes opposite positions on the FFA market while he is executing its physical transaction. That is to say, he buys FFA when he agrees on a future physical delivery, and sell FFA when the transaction occurs in order to lock its freight rate.

2.3.5 Other risk management solutions

Futures contracts are just one instrument to manage risk exposure for CTFs. Other financial tools such as options – the right to buy or sell an underlying commodity at a stated price during predetermined period – and swaps – two parties agree to exchange a variable price for a fixed one in a commodity trade¹¹ – for the two other most known derivatives contracts. They are also widely used to hedge other than the price risk exposure and more precisely the currency and interest rate risks. However, the purpose of this chapter is not to provide an exhaustive list of commodity financial instruments, but rather to discuss the specific role of CTFs in the industry.

¹¹Commodity swaps enable parties to lock a trading price.

Recently, CTFs started to launch vertical integration strategies. Owning upstream and/or downstream assets gives self-hedge opportunities. It creates cushions to partly offset shocks occurring in different segments of the value chain. A positive shock on crude happens at the expense of refining margins. Integrating upstream units can ensure the overall margins on both sides of the supply chain. Another benefit of integration is deal with underdeveloped markets. Many developing countries with fast-growing demand fail to be supplied because they do not have capacities neither the finance to build it. Consequently, they remain out of the international commodity trade web. In order to earn market shares, commodity traders invested in downstream assets in these countries to be able to supply them. Controlling assets of the supply chains can give them advantages to ensure high trading and to reduce volume risk.

Integration became particularly dynamic in metal and oil industries in which Glencore and Trafigura are two leaders. The merger with Xstrata in 2013 made Glencore a major producer of the copper especially. Energy industries are also concerned by the trend and both traders account for the important oil producers. A table recording asset ownership among major commodity traders in all industries is provided in appendix. Integration offers many solutions for traders but is also costly. It gives a commodity price exposure to traders whose role is to manage commodity risks. They now face two opposite goals that make them more sensible to commodity shocks. The example of Glencore and Xstrata is again the most famous one. Contrary to other independent commodity traders, Glencore is a public company which launched an initial public offering (IPO) in 2011. The company is now subjected to market opinion and fluctuation, which also made it more easily observable. The Xstrata merger has been very costly for the company which became highly indebted. The operation occurred few before the fall of commodity prices in summer 2014 known as the end of the commodity super-cycle. The company registered many losses on its mining activity with a huge decrease in metal prices, while a traditional CTF not involved in the production process can fill its economic role and maximize its benefits in this situation. It can value the most its storage capacities and benefit from

higher margins to offer trading solutions to its clients. To reduce their debt, the newly major metal producer had to raise capital through equity which initiated a strong share price declining from GBX 344 at the merger in May 2013 to GBX 90 by the end of 2015.

2.4 The analyze of commodity price drivers are essential to risk management

We have now stated that the key contribution of commodity traders in the industry is to ease international trades by providing multiple services among which we find risk management. It is worthy to remind that commodity traders showed up in the 1970s when producers needed the market to trade their assets to external and independent actors. Vertical integration stopped being the dominant framework and the market could offer reduced organization costs. However, because of disjoint timing, spatial distance between producers or with consumers, trades raise a lot of uncertainty. Fluctuation of exchange rate can lead to major losses so does changes of freight rates which can subsequently raise carrying costs for example. But what constitute the main specificity for commodity trading is the price volatility exposure. Because, there are standardized contracts underlying these commodities, their price is public and the market liquid. Prices can quickly react to any change in the fundamental or investors dominant positions. A shock on commodity markets is likely to quickly be reverberated to prices. Producers' earnings are therefore highly sensitive to commodity price management. Especially considering that many commodity exporters are developing countries whose commodity earnings directly impact their growth rate for the following years, their external debt, government budget and terms of trade when commodity sector either is important (Arezki and Brückner 2012^[13]). Consequences are as important for importing countries for which an increase in commodity prices deteriorate their balance of payments. Commodity traders' duty is to provide efficient hedging services to make the market an available option for producers. They must be able to make proper expectations on prices in order to adapt their

hedging strategies to price level and volatility changes. They use to do it by identify the volatility model that fit with the commodity price. Indeed, volatility is used to forecast the variability of price returns and adapt its hedging strategies accordingly (Engle and Patton, 2007^[89]). Consequently, identifying the drivers of price volatilities is critical for commodity traders' hedging activity.

In this new section, we offer to identify the drivers of energy price volatilities by using autoregressive conditional heteroskedasticity (ARCH) models. More specifically we analyze the impact of macroeconomic and financial variables on four energy price volatility that are the Brent, the WTI, the natural gas and the Coal from 1999 to 2019. We divide our data sample into three subperiods that are (i) the pre-crisis period (1999-2008), (ii) the crisis period that cover period from 2008 until the end of the so-called commodity super-cycle in summer 2014, and (iii) one last period from 2014 to 2019. We aim to show that drivers significantly change through time.

In a second attempt, we analyze the impact of supply and demand factors on the long-term component energy price volatility. We overtake the mismatch frequency between daily energy prices and monthly factor-specific variables by using mixed-frequency GARCH models. If the first GARCH models allow us to conclude on the impact of macroeconomic and financial factors on the short-term volatility, we aim to show that volatility trends are subject to fundamental factors.

2.4.1 Commodity price drivers

Historically, there is a well-established literature focusing on the drivers of commodity price levels but the one dealing with price volatility is not as developed. The Prebish (1950^[230]) - Singer (1950^[253]) framework states that the commodity prices relatively to manufactured ones tend to fall. Furthermore, supply shocks, that can come from political uncertainty, bad weather conditions for agricultural products, or productivity shocks can have large effects on prices. Because of inelastic demand functions, the variance of prices is

likely to exceed the variance of the fundamental supply shocks (Deaton 1999^[78]). Storage shocks, initiated by speculators also impact prices (Deaton and Laroque 1992^[7]). Nevertheless, their role can be mitigated as storage costs and commodity prices only exhibit low autocorrelation (Deaton and Laroque 1996^[79]). The relationship may be more prominent through storage costs which are sensitive to demand shocks and interest rates (Deaton 1999^[78]). What is more, while every commodity industry is specific and face specific supply shocks, it is proved for long that pairs of commodity prices are correlated. Oil prices use to comove with other unrelated commodities (Pindick and Rotemberg, 1990^[223]).

The literature also gives an important role to the commodity “financialization” to animate short-term price cycles while real business cycle impact long-term price cycles (Arezki *et al.*, 2014^[14]). Financialization characterized a commodity that is used by financial investors as a part of an asset class. The phenomenon is highly valuable for commodity markets as it raises liquidity by bringing investors willing to match hedgers’ positions on futures markets. It contributes to price discovery mechanisms and price stabilization. However, it also brings noise tradings and momentum strategies in commodity markets. Indeed, while investors tend to “nothing long positions” strategies when prices increase, a bust leads them to turn to short positions, which exacerbates price volatility. Because commodities are used as financial assets for portfolio diversifications, investors create strong interrelationships between commodity prices and equity returns (Hamilton and Wu 2014^[124], Robe and Büyüksahin 2014^[45]). What is more, as unrelated commodities are used for the same purpose, it induces co-movement of commodity prices among sectors.

The literature of the determinants of commodity price volatility is growing research field. Drivers are divided between sector-specific and exogenous. Sector-specific determinants rely on the fundamentals of commodity markets. We stated previously that supply and demand elasticities are inelastic at least on the short run. However, Baumeister and Peersman (2009^[30]) and Hamilton (2009^[123]) have observed a decline of both elasticities

for crude oil starting 1980s what they explained by the beginning of crude oil futures trading contracts on the NYMEX. Indeed, futures contracts took a major role in crude price mechanisms leading to a diminishing price sensitivity to physical trades. Baumeister and Peersman also exhibited that the increase of volume of oil transactions on the spot market in the 2000s reinforced its positive correlation with prices which is coherent. It also leads to faster price reactions to demand and supply changes, hence a positive relationship with the volatility. On the contrary, supply and demand for agricultural prices tend to remain inelastic (Ott 2014^[215]). The effects of oil inventories also remain uncertain. Petroleum oil inventory levels of the OECD exhibit negative correlation with WTI price spreads (German and Ohana, 2009^[102]). However, between 2000 and 2008, Pirrong (2011^[227]) founded a positive relationship by taking the U.S. inventory levels. Commodity futures markets occupy a increasing role on price volatilities. In 2009^[234], Ripple and Moosa analyzed on the relationship between open interest and oil price volatility. They showed that the number of outstanding contracts at the end of a trading day increases the market depth and reduce volatility.

Exogenous factors are not specific to commodity industries but still highlight a tight relationship with them. Macroeconomic indicators and major events, whatever they come from the market, political or even weather shocks, also show a strong relationship with price volatilities. Karali and Power (2013^[165]) analyzed the impacts of macroeconomic variables on the time-varying volatility of energy commodities quoted on the U.S. futures exchanges. They use GARCH models allowing for asymmetric effects and a GARCH-BEKK model¹² (Engle and Kroner 1995^[88]) to study the spillover effects between macroeconomic variables and volatilities. They found a positive reaction of crude oil return to Treasury bill rate changes, a negative impact of industrial production and inventory changes. Interestingly, they also concluded on strong reaction to major event like the 2008 financial crisis or the September 11, 2001 terrorist attacks or the Hurricane Katrina in 2004, which raise concerns on changes of volatility components. The impact of exchange

¹²BEKK model are named after Baba, Engle, Kraft and Kroner, 1990^[16]

rates on commodity prices has been widely studied too. Because most of commodity are traded in U.S. dollar, changes the U.S. currency against other major currencies directly impact commodity producers' purchasing power and create pression on OPEC oil prices (Yousefi and Wirjanto, 2004^[286]). A similar and significative relationship is founded for U.S. dollar fluctuation and agricultural product prices (Baffes and Etienne 2016^[19]). As exposed for commodity price levels, because of the financialization phenomenon, prices are found to be correlated to stock market returns. However, the relationship does not seem to be linear but volatile. By using Dynamic conditional correlation (DCC) GARCH models, Creti *et al.* (2013^[72]) presented deeper spillovers during the 2007-2008 financial crisis.

2.4.2 Empirical model

Building on this research question, the volatility analyzis will be based on generalized autoregressive conditional heteroscedasticity (GARCH) models (Engle, 1982^[87], Bollerslev, 1986^[36]). It provides a simple model widely used in the literature for volatility analyzis. GARCH specification allows changes of the conditional density of price series, that is to say that the unconditional distribution of the series can induce time-dependent conditional variances and leptokurtosis. These characteristics fit perfectly with commodity price volatilities (Baillie and Myers, 1991^[20]). We can present the specification for the commodity price level P_t with a standard $AR(1)$ process as follows:

$$\log(P_t) = \mu + \gamma_2 \log(P_{t-1}) + \varepsilon_t \quad (2.4)$$

ε_t denotes a heteroscedastic error term. We set $\gamma_2 = 1$, which gives :

$$\log(R_t) = \mu + \varepsilon_t \quad (2.5)$$

R_t refers to price return. Equation (2) is the mean equation and will enable us to extract the heteroscedastic error term series of the commodity return equation. In our

demonstration, the mean equation will be defined as an ARMA(p,q) model:

$$\log(R_t) = \mu + \sum_{n=1}^k a_n \log(R_{t-n}) + \varepsilon_t + \sum_{m=1}^l b_m \varepsilon_{t-m} \quad (2.6)$$

Where a_n is the autoregressive parameter and b_m is the moving average parameter.

The variance of ε_t , denoted σ_t^2 , follows a GARCH(p,q) process, with p=q=1 when:

$$\text{Var}(\varepsilon_t) = \sigma_t^2 = \omega + \sum_{j=1}^q \alpha \varepsilon_{t-j}^2 + \sum_{i=1}^p \beta \sigma_{t-i}^2 \quad (2.7)$$

Equation (5) is the variance equation σ_t^2 and conditions the mean volatility to be strictly positive ($\omega > 0$). The sum of parameters α and β determines the persistence parameter which provide a proxy of the persistence of the volatility to shocks. It must be positive and lower than 1. A parameter higher than one indicate an unstable model. Estimation of equation (3) also provides a measure of the long-run unconditional variance of the series through the time-independent term: $\frac{\omega}{(1-\alpha-\beta)^{1/2}}$

For the purpose of the demonstration, we included external variables to the variance equation and choose a GARCH(1,1) specification. GARCH(1,1) is often said to be the most widely specification of GARCH model, especially for commodity price volatility studies (Hansen and Lunde, 2005^[126]).

$$\text{Var}(\varepsilon_{t,j}|F_j) = \omega_j + \alpha \varepsilon_{t-1,j}^2 + \beta \sigma_{t-1,j}^2 + \sum_{i=1}^n \gamma_{I,j} F_{t-1,j}^n \quad (2.8)$$

Where j is the commodity studied and $F_{t-1,j}^n$ is a lagged logarithm change of the vector of factors explaining the price volatility.

Nevertheless, GARCH models do not allow for negative parameters and commodity price volatilities are rarely linear. On the contrary, they exhibit asymmetric movements between increasing and decreasing trends. Consequently, we choose an Exponential GARCH (EGARCH) model to deal with non-linearity derived from asymmetric behaviors in volatility (Ji and Fan, 2012^[156]). It brings us to examine the ratio of error correction term and the lagged volatility (Nelson 1991^[206]). The other benefit of EGARCH models over the

classic GARCH is to remove the restriction on positive coefficient:

$$\log(\sigma_{t,j}^2) = \omega_j + (\alpha_j z_{t-1,j} + \gamma_j (|z_{t-1}| - E|z_{t-1}|)) + \beta \log(\sigma_{t-1,j}^2) + \sum_{i=1}^n \gamma_{I,j} F_{t-1,j}^n \quad (2.9)$$

Where α_j gives the sign effect that is the asymmetric reaction to increasing or decreasing volatility and γ_j the size effect which is similar to the classic ARCH coefficient. Therefore, the parameter α_j is always negative, while γ_j is positive.

Data

We use a multi-commodity spectrum of daily energy price series that is composed of four settlement price of future contracts: the West Texas Intermediate exchanged on the NYMEX, the Brent traded on the ICE, the Henry hub natural gas quoted on the NYMEX and the coal traded on the ICE. The dataset spans twenty years from 1999 to 2019 which let us determine three subperiods in order to account to changes of the energy price volatility sensitivity to its drivers. We define a pre-crisis period from 01/01/1999 to 09/15/2008 exhibiting low and relatively stable prices. A crisis period starting with the collapse of Lehman Brother until 06/22/2014, when crude oil prices dropped significantly which is considered as the end of the commodity supercycle. The last period, from 06/22/2014 to 06/04/2019, is the post crisis period, but characterized by relatively low prices. We expect prices to be more sensible to financial variable during the crisis period than the two others.

Table 2.4: Summary statistics for returns to energy prices (daily data)

| 1999:2018 | Brent | WTI | Natural gas | Coal |
|-------------|-----------|------------|-------------|-----------|
| Mean | 0.00017 | 6.1849E-05 | 3.14E-05 | 3.02E-05 |
| Std. dev | 0.02165 | 0.0234 | 4.35E-02 | 1.20E-02 |
| Maximum | -0.42722 | -0.4083 | -5.89E-01 | -8.01E-02 |
| Minimum | 0.13151 | 0.2128 | 6.33E-01 | 8.04E-02 |
| Skewness | -1.06830 | -0.6726 | 3.42E-01 | -8.97E-02 |
| Kurtosis | 25.43800 | 18.5864 | 3.18E+01 | 8.78E+00 |
| Jarque-Bera | 170867*** | 95900*** | 184040*** | 3809.5*** |

We only study the sensitivity of energy price volatility to financial variables. Indeed, many factors specific variable like demand, supply and storage data are not available on a high frequency data. Furthermore, because of the low-price sensitivity of supply and demand factors, we can expect the daily price volatility to more reactive to financial factors. We therefore include three variables to the GARCH variance equation. The effect of interest rates on price volatility is captured with the 10 years U.S. government bonds $GT10_t$. The exchange rate is the trade weighted U.S. dollar index for goods $USindex_t$. Both of these variables are taken from the St. Louis Federal Reserve Bank. Finally, we use the return of the S&P 500 index $SP500_t$, from the Bloomberg database, for equity market proxy. Descriptive statistics of commodity price series are presented in table 2.4. Therefore, the EGARCH model to be estimated is as follow for each “j” commodity:

$$\log(R_t) = \mu + \sum_{n=1}^k a_n \log(R_{t-n}) + \varepsilon_t + \sum_{m=1}^l b_m \varepsilon_{t-m}$$

$$\log(\sigma_{t,j}^2) = \omega_j + (\alpha_j z_{t-1,j} + \gamma_j (|z_{t-1}| - E|z_{t-1}|)) + \beta \log(\sigma_{t-1,j}^2) + \gamma_{1,j} GT10_t + \gamma_{2,j} SP500_t + \gamma_{3,j} USindex_t \quad (2.10)$$

Results

We found significant changes for the impact of equity market returns across the periods. The model exhibits no significant impact of the S&P500 for any of the three energy price volatilities during the pre-crisis period. On the contrary, the variable is significant and negative for the Brent, the WTI and the coal during the crisis period. The higher coefficients found in third periods for the oil products seem to indicate that the influence of the market return is getting bigger since the 2008 financial crisis. Equity index decreases have been linked to sharp economic slowdown, especially during the crisis period which made investors turning to commodity markets for portfolio diversification. Hence a decrease in the market raised the demand for commodity assets. This result is coherent with findings of Choi and Hammoudeh (2010^[61]) who found, by using a Markov switching GARCH, that Gold, crude oil and copper, on the period 1990-2006, were used as diversifier for in-

Table 2.5: Brent and WTI EGARCH model

| | Brent | | | WTI | | |
|--------------------------|-----------------------|-------------------------|-------------------------|------------------------|------------------------|------------------------|
| | 1999-2008 | 2008-2014 | 2014-2019 | 1999-2008 | 2008-2014 | 2014-2019 |
| Mean equation | | | | | | |
| μ | 0.0010** (0.0004) | -0.0001 (0.0004) | 0.0006 (0.0005) | 0.0010** (0.0004) | -0.0001** (0.0004) | 0.0004** (0.0005) |
| ar1 | | -0.3228*** (0.0049) | | | -0.7443*** (0.0217) | |
| ar2 | | -0.9886*** (0.0039) | | | -0.5297*** (0.0229) | |
| ar3 | | | | | 0.3797*** (0.0233) | |
| ma1 | | 0.3125*** (0.0011) | | | 0.7699*** (0.0313) | |
| ma2 | | 0.9879*** (0.0001) | | | 0.5458*** (0.0293) | |
| ma3 | | | | | -0.3490*** (0.0266) | |
| Variance equation | | | | | | |
| ω | -0.2271* (0.1239) | -0.0965*** (0.0070) | -0.0701*** (0.0033) | -1.0307*** (0.2850) | -0.1112*** (0.0239) | -0.0659*** (0.0043) |
| α | -0.0190 (0.0183) | -0.0469*** (0.0104) | -0.0267*** (0.0093) | -0.0734*** (0.0212) | -0.0367*** (0.0139) | -0.0385*** (0.0111) |
| β | 0.9731*** (0.0148) | 0.9901*** (0.0002) | 0.9882*** (0.0000) | 0.8743*** (0.0343) | 0.9870*** (0.0022) | 0.9894*** (0.0000) |
| γ | 0.0960* (0.0532) | 0.0889*** (0.0052) | -0.0021 (0.0021) | 0.1538*** (0.0286) | 0.1631*** (0.0266) | 0.0057 (0.0080) |
| GT10 | 0.0045 (0.0028) | 0.0078*** (0.0025) | -0.0091*** (0.0014) | 0.0167** (0.0083) | 0.0050 (0.0043) | -0.0065*** (0.0018) |
| SP500 | -0.3643 (1.0750) | -8.0760*** (1.3813) | -11.0770*** (1.6675) | -0.2954 (1.5247) | -6.5211*** (1.6703) | -8.9534*** (1.9137) |
| Usindex | 2.0126 (3.6036) | -12.0808*** (3.9248) | 9.5862*** (2.3255) | 11.6440*** (4.5007) | -7.2973 (4.6770) | 6.6403*** (2.5096) |
| LLh | 6209.026144 | 4378.762 | 2943.182 | 6033.314 | 4193.249 | 2891.073 |
| Persistence | 0.9731 | 0.9901 | 0.9882 | 0.8743 | 0.9870 | 0.9894 |
| Half-Life | 25.4426 | 69.4360 | 58.5727 | 5.1586 | 52.7882 | 65.3296 |
| Mean Var | 0.0004 | 0.0004 | 0.0005 | 0.0005 | 0.0005 | 0.0005 |

*, ** and *** indicate 10%, 5% and 1% significance levels

Robust standard errors in parentheses

Table 2.6: Natural gas and coal EGARCH model

| | Natural gas | | | Coal | | |
|--------------------------|------------------------|-----------------------|------------------------|------------------------|------------------------|-----------|
| | 1999-2008 | 2008-2014 | 2014-2019 | 1999-2008 | 2008-2014 | 2014-2019 |
| Mean equation | | | | | | |
| μ | 0.0011** (0.0005) | -0.0011** (0.0005) | 0.0000 (0.0006) | -0.0002 (0.0002) | -0.0001 (0.0001) | |
| ar1 | 0.1954*** (0.0104) | | 0.1066*** (0.0324) | 0.2040*** (0.0256) | 0.2469*** (0.0247) | |
| ar2 | -0.6265*** (0.0230) | | -0.0523* (0.0315) | 0.0549** (0.0243) | | |
| ar3 | | | -0.0860*** (0.0313) | | | |
| ma1 | -0.1827*** (0.0113) | 0.1132 (0.0200) | -0.0220 (0.0333) | | | |
| ma2 | 0.5770*** (0.0235) | -0.1038 (0.0205) | | | | |
| ma3 | | -0.0374** (0.0181) | | | | |
| Variance equation | | | | | | |
| omega | -0.1366 (0.0402) | -0.0848** (0.0400) | -0.3405*** (0.0999) | -0.1721*** (0.0232) | -0.3728*** (0.0812) | |
| α | 0.0477 (0.0127) | -0.0111 (0.0143) | 0.0640*** (0.0247) | 0.0233* (0.0121) | 0.0371* (0.0190) | |
| β | 0.9711 (0.0056) | 0.9869*** (0.0047) | 0.9427*** (0.0136) | 0.9834 (0.0018) | 0.9518*** (0.0091) | |
| γ | 0.2707 (0.0214) | 0.2347*** (0.0235) | 0.4302*** (0.0394) | 0.1684*** (0.0210) | 0.2066*** (0.0323) | |
| GT10 | -0.0080 (0.0050) | 0.0009 (0.0057) | -0.0170 (0.0214) | 0.0104** (0.0048) | -0.0165 (0.0131) | |
| SP500 | -0.2186 (1.4915) | -0.0892 (1.7355) | -0.8453 (3.3112) | -4.7443*** (1.7416) | 2.0206 (2.7291) | |
| Usindex | -13.8411 (3.7601) | -7.6359 (5.0382) | 1.0335 (8.3861) | -1.9383 (5.0656) | 8.1177 (6.8163) | |
| LLh | 4748.067 | 3409.829 | 2441.618 | 5139.373 | 3492.801 | |
| Persistence | 0.9711 | 0.9869 | 0.9427 | 0.9834 | 0.9518 | |
| Half-Life | 23.6330 | 52.4604 | 11.7373 | 41.4489 | 14.030 | |
| Mean Var | 0.0022 | 0.0014 | 0.0016 | 0.0001 | 0.0002 | |

*, ** and *** indicate 10%, 5% and 1% significance levels
Robust standard errors in parentheses

vestment on the US market. Creti *et al.* (2013^[72]) show that the financial crisis increased the financialization of commodities like oil, coffee and cocoa. Commodities are exposed to the “speculation phenomenon”, that is to say that investors trade commodities looking for short-term returns. Moreover, the use of oil contract as a hedge against equity market could potentially explain this relationship. Decrease in equity return is likely to increase the demand of oil contracts and hence a high volatility. The relationship is demonstrated for emerging markets (Basher and Sadorsky, 2015^[28]) and for Gulf Cooperation Council countries¹³ countries (Maghyereh *et al.*, 2017^[190]). However, US markets do not seem to exhibit the same relationship (Smiech and Papiez, 2017^[287]), this role remain to gold only.

Concerning the U.S. dollar index, the impact diverges between commodities and may have either a positive or a negative impact on price volatilities. The result is negative for the Brent during the crisis period which corroborates Aloui *et al.* (2013^[7])’s findings that an USD depreciation raises crude oil prices and can thus contribute to price volatility with a stronger relationship during the financial crisis. Wu Chang and Chang (2012^[282]) also concluded on the negative relationship but also demonstrated the link is strengthening since 2003. This former argument could explain the negative coefficient found for the natural gas which is also traded in USD. Positive coefficients for the WTI during the pre and the post-crisis periods highlights that price volatilities are sensitive to any changes of the USD exchange rate because commodities are traded in USD.

2.4.3 Sector-specific factors and commodity price volatilities

Former results are critical to assess the role of financial indicator on commodity’s price volatilities on a high frequency basis. Nevertheless, GARCH models fail to reflect the influence of sector specific factors, like supply and demand variables usually available on a monthly frequency, while disruption of the supply-demand balance of the market nearly always lead to major price disruption and sharp volatility increase (Baumeister and Kil-

¹³The Gulf Cooperation Council is a political alliance established in 1981 between Saudi Arabia, Bahrain, Oman, Kuwait, Qatar and United Arabic Emirates

ian 2016). Furthermore, supply and demand factors exhibit a poor sensitivity to price changes but it does not mean that they are rigid on the long run. We can reasonably expect these variables to be significant indicators of the long-run price volatility. The introduction of mixed frequency data in GARCH models created a new impetus for commodity price dynamic analysis. Ghysels *et al.* (2004^[104]) introduced Mixed Data Sampling (MIDAS) regression models sampling time series at different frequencies. MIDAS models distinguish two components, a high frequency and a lower one, that enable explanatory variable to be specified at a different frequency basis. The use of mixed-frequency variable on GARCH models started with the Engle and Rangel (2008^[90])'s Spline-GARCH model that specified the short-term component as a GARCH process evolving around the long-term component. The latter is composed of multiple knots of the same size and is regressed on macroeconomic variables. Their Spline-GARCH with macroeconomic variable outperform classic GARCH(1,1) on equity indexes. Engle *et al.* (2013^[86]), in an empirical study on the determinants of long-term Bitcoin volatility, formulated the GARCH-MIDAS by introducing low-frequency macroeconomic variables directly into the specification of the long-term component. It allows us to investigate the role of fundamentals of the oil physical market into energy price volatility. Indeed, the literature always gave a key role to supply shocks in explaining oil price changes (Barsky and Kilian, 2004^[27]). In 2009^[168], Kilian reassessed the role of demand shocks by highlighting the positive relationship between oil prices and both the U.S. real growth and the U.S. consumer price index. Kilian and Hicks (2013^[170]) showed that repeated positive demand shocks explained the sharp price increase between 2003 and 2008.

In this new section, we describe a GARCH-MIDAS model similar to Engle *et al.* (2013^[86]), where the long-term component is expressed as a function of supply and demand factors. The specification is widely used to study the impact of macroeconomic variable on financial time series. Many applications are provided on the drivers of cryptocurrency volatilities for which macro variable could not match the very high-frequency. Conrad *et al.* (2018^[66]) exhibited strong positive relationship between the long-term

bitcoin volatility and global economic activity indicators. The authors also show that gold and copper long-term component is positively related to the S&P 500 and VIX realized volatility. But they conclude on a negative relationship between the long-term copper volatility and the economic activity index. On the U.S. stock market, Conrad and Loch (2015^[66]) showed that macro variables (the term spread, housing starts, corporate profit and the unemployment rate) can be critical to specify the long-frequency stock market component. Conrad and Kleen (2020^[67]) demonstrated the superiority of GARCH-MIDAS models over other volatility models¹⁴ for the S&P 500 returns and the housing starts and the industrial production growth rate and the Chicago Fed National Activity Index – three monthly data. We can therefore expect the long-term component of energy price volatilities to be related to physical market fundamentals of the oil industry. By using a regime switching GARCH-MIDAS model, Pan *et al.* (2017^[216]) found that macroeconomic variables (mainly depicted as demand factors) and short-term structural breaks (related to the the supply side¹⁵) and financial crisis, raise oil price volatility. In 2019, Mei *et al.*^[201] used a GARCH-MIDAS model to highlight that the monetary policy uncertainty indicator (based on Baker *et al.*, 2016^[21]) triggers the WTI price volatility. They also show that GARCH-MIDAS using both the former indicator and the economic uncertainty one (also derived from Baker, 2016) as explanatory variables provide more accurate prediction of the oil volatility.

Factor-specific data

In this section, we propose to model the four energy price volatilities previously presented (the WTI, Brent, natural gas and coal) by introducing oil market fundamentals as explanatory variables of the long-term component during the period 1999 to 2019. Pan *et al.* (2017) had used the Kilian index as a proxy for global demand. In order to provide

¹⁴The author compared the kurtosis of returns, the autocorrelation function of squared returns, the R^2 and the forecasting performance of the GARCH-MIDAS model with heterogeneous autoregressions, realized GARCH, High-frequency-based volatility and Markov-switching GARCH models.

¹⁵The author show that wars and geopolitical events trigger volatility regime switching.

an original analysis and complement this work, we choose to focus our analysis on central players in the energy product supply and demand market. Thus, we choose to use the monthly variation of the Chinese industrial production index (IPI), the country being the first consumer of energy products. Moreover, episodes of growing demand from emerging countries has been associated to strong price increase and low volatility until 2008 and on the period 2010-2014. Thus, we expect oil price volatilities to be negatively impacted by the demand factor. Then we choose to use OPEC production as a supply factor. The influence of the organization on prices has been widely demonstrated in the literature (Wirl and Kujundzic, 2004^[277]; Brunetti et al., 2013^[41]). We also expect a negative relationship between supply factor and energy price volatility since changes on the supply sides, especially decreasing production are likely to raise uncertainty.

Moreover, we propose to analyze the impact of the realized volatility of an economic activity indicator on the long-term component as uncertainty on economic activity should bring to positive effects on oil uncertainties. We follow Kilian (2009^[168]) and Conrad *et al.* (2018^[66]) by using a dry cargo bluk index as a measure of global real economic activity. The Baltic dry index (BDI) provide a benchmark for the cost of shipping goods for 23 different shipping routes and is reported by the Baltic Exchange in London. A raise of the global economic activity increases the demand for shipping services and the BDI. Consequently, an increase of the realized-volatility of this indicator is supposed to create uncertainty on the economic activity. We can expect it to be positively correlated to oil price volatility. We also test for the impact of economic activity and the OPEC oil production on the natural gas and the coal. Oil products being partial substitutes of these two commodities they are sensible to oil supply too.

Construction of the GARCH-MIDAS model

To capture the impact of supply and economic activity variables on energy return volatilities, we adopt a GARCH-MIDAS framework. Contrary to classical GARCH models, the conditional variance is decomposed into a short-term and high frequency component

and a long-term and low-frequency component. It enforces us to consider explanatory variables explaining the long-term component cannot influence the short-term one. This framework allows for the introduction of the economic activity and the OPEC production as monthly observations to determine the energy price volatilities. We still consider energy price volatilities on a daily basis. Each commodity price return is defined as $R_{i,t} = 100(\ln(P_{i,t}) - \ln(P_{i,t-1}))$, with $t = 1, \dots, T$ is the monthly frequency and $i = 1, \dots, N_t$, the number of days within the month t . We assume the conditional mean equation of energy price returns to be modeled as follow:

$$R_{i,t} = c + \varepsilon_{i,t} \quad (2.11)$$

With c the constant and $\varepsilon_{i,t}$ the residuals whose pattern is described by:

$$\varepsilon_{i,t} = \sqrt{h_{i,t}\tau_t}Z_{i,t} \quad (2.12)$$

$Z_{i,t}$ is the innovation that is supposed to i.i.d., with a mean equal to zero and a variance equal to one. τ_t denotes the long-term component of the conditional variance while $h_{i,t}$ relates the short-term component following a GARCH(1,1) process given by:

$$h_{i,t} = (1 - \alpha - \beta) + \alpha \frac{\varepsilon_{i-1,t}^2}{\tau_t} + \beta h_{i-1,t} \quad (2.13)$$

Equation 2.13 imposes $\alpha > 0$, $\beta > 0$ and $\alpha + \beta < 1$. On a monthly frequency, the long-term component is given by the slowly varying function of the explanatory variable X_{t-k} that is successively the Chinese IPI, the OPEC oil production and the realized volatility of the Baltic Dry Index:

$$\tau_t = \mu + \sum_{k=1}^K \phi_k(\omega_1, \omega_2) X_{t-k} \quad (2.14)$$

Where $\phi_k(\omega_1, \omega_2) X_{t-k}$ denotes weights that are parametrized via a Beta weighting scheme. By construction, the weights $\phi_k(\omega_1, \omega_2) > 0$ and sum to one. Weights are monotonically

declining with the restriction $\omega_1 = 1$:

$$\phi_k(\omega_1, \omega_2) = \frac{(k/(K+1))^{\omega_1-1} (1 - k/(K+1))^{\omega_2-1}}{\sum_{j=1}^K (j/(K+1))^{\omega_1-1} (1 - j/(K+1))^{\omega_2-1}} \quad (2.15)$$

We follow Conrad and Loch (2015^[68]) and Conrad and Keen (2020^[67]) for the specification of the MIDAS lag length. We choose the number of lags that implies a monotonically decreasing weighting scheme with weight close to zero for the last third of K . However, we diverge from Dai *et al.* (2020^[74]) who use a 36 months and three years lagged data for the calibration window. Lag lengths differ substantially between commodities and external factors. The weighted schemes for the optimal lag length are presented in appendix B.

Results

Table 2.7: Brent and WTI MF-GARCH model

| 1999 : 2018 | Brent | | | WTI | | |
|----------------|-----------------------|------------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| | BDIRV | IPI | OPEC | BDIRV | IPI | OPEC |
| Number of lags | 6 | 31 | 21 | 6 | 7 | 20 |
| mu | 0.0574 (0.0349) | 0.0502 (0.0372) | 0.0574 (0.0351) | 0.0813** (0.0374) | 0.0663 (0.0461) | 0.0788*** (0.0376) |
| alpha | 0.0611*** (0.0050) | 0.0579*** (0.0031) | 0.0645*** (0.0065) | 0.0751*** (0.0049) | 0.0618*** (0.0100) | 0.0791*** (0.0065) |
| beta | 0.9279*** (0.0004) | 0.9287*** (0.0000) | 0.9125*** (0.0027) | 0.9131*** (0.0003) | 0.9382*** (0.0102) | 0.8984*** (0.0025) |
| m | 1.1195*** (0.2491) | 1.2449*** (0.0659) | 1.2703*** (0.1383) | 1.3012*** (0.2489) | 0.1111 (0.5889) | 1.4470*** (0.1553) |
| theta | 0.0092** (0.0043) | -0.1836* (0.0954) | 0.3275** (0.1578) | 0.0095*** (0.0034) | 0.0101 (0.0188) | 0.2543 (0.1625) |
| ω_2 | 13.7767 (11.1160) | 11.1144*** (4.4345) | 4.0802*** (1.0288) | 15.5357* (8.9847) | 22.5371 (17.3988) | 3.7280*** (1.1139) |
| LLh | -5620.8936 | -4358.4000 | -4816.4112 | -5801.6488 | -5769.1610 | -5031.1884 |
| BIC | 11289.1576 | 8762.8310 | 9679.4234 | 11650.6680 | 11585.6500 | 10109.0360 |
| Obs. | 2806 | 2791 | 2791 | 2806 | 2805 | 2792 |

*, ** and *** indicate 10%, 5% and 1% significance levels

Robust standard errors in parentheses

Tables 2.7 and 2.8 reports results for the parameters estimate of GARCH-MIDAS models for energy price returns. First, we look at the impacts of the OPEC production and economic activity on the crude oil return series. The θ parameter indicate a positive reaction of the Brent volatility to the Chinese economic activity. The interpretation of

Table 2.8: Natural gas and Coal MF-GARCH model

| 1999 : 2018 | NG | | | Coal | | |
|----------------|------------------------|-------------------------|------------------------|-----------------------|------------------------|-----------------------|
| | BDIRV | IPI | OPEC | BDIRV | IPI | OPEC |
| Number of lags | 6 | 6 | 6 | 45 | 30 | 24 |
| mu | -0.0725 (0.0845) | -0.0604 (0.1227) | -0.0591 (0.1222) | 0.0226 (0.0644) | 0.0079 (0.0380) | -0.0230 (0.0360) |
| alpha | 0.2782*** (0.0006) | 0.1593*** (0.0223) | 0.1575*** (0.0226) | 0.1290*** (0.0413) | 0.0963*** (0.0289) | 0.0973*** (0.0143) |
| beta | 0.6891*** (0.0009) | 0.8407*** (0.0233) | 0.8425*** (0.0232) | 0.7737*** (0.0548) | 0.8101*** (0.0373) | 0.8711*** (0.0057) |
| m | 3.9405*** (0.2214) | 0.2014 (0.9194) | 0.3573 (0.8133) | -3.9511 (3.5018) | 0.0206 (0.1571) | 0.5217* (0.3005) |
| theta | -0.0104** (0.0050) | -0.0567*** (0.0210) | -0.1182* (0.0663) | 0.1147 (0.0873) | -2.9461*** (0.8096) | 0.9209* (0.5200) |
| ω_2 | 26.5819*** (6.5022) | 64.2158*** (13.6442) | 53.3870*** (5.0920) | 3.3021*** (1.2333) | 1.0000*** (0.2713) | 4.6125 (3.0724) |
| LLh | -7298.9195 | -7416.6481 | -7416.7587 | -678.5439 | -1146.1507 | -1323.8179 |
| BIC | 14645.2026 | 14880.6599 | 14880.8810 | 1392.8847 | 2331.7436 | 2688.0861 |
| Obs. | 2802 | 2802 | 2802 | 1315 | 1330 | 1336 |

*, ** and *** indicate 10%, 5% and 1% significance levels

Robust standard errors in parentheses

this coefficient requires to use the results of the weighted function (see Appendix B). For the Brent, a 0.3015 weight is found for the first lag, meaning that the one standard deviation in the Chinese IPI level would lead to a decrease in the long-term component of the next month's volatility by $\exp(\theta x \kappa_1) = \exp(0.184 \times 0.3015) - 1 = 0.0569$ that is a 5.69%. Because of the monotonically decreasing characteristic of the Beta weighted function, the impact of deviation the Chinese IPI on further months' volatility keep decreasing, the decrease of the long-term component falls to 4.05% the second, 2.86% the third one until reach bellow 1% starting the sixth month finally no residual effect after the thirty-seventh month. This result is consistent with Pan *et al.* (2017^[216]) and Conrad *et al.* (2014^[69]) who found an increasingly counter-cyclical effect of the oil volatility that increase during recession. The role of demand in oil price changes kept increasing during the 2000s (Kilian, 2009^[168]). However, contrary to these authors, we do not find a significant parameter for the impact of the Chinese IPI on the WTI long-term component volatility. We can explain it by the different time span used in this study which focuses only on the twenty past years while Conrad *et al.* and Pan *et al.* and analyzed oil volatility from 1993 to

2011 and from 1988 to 2015 respectively. At the first sight, the significant positive coefficient found for the effect of the OPEC production on the long-term component of the Brent return volatility may seem surprising. Pan *et al.* (2017^[216]) concluded on a negative relationship between oil production and volatility which is consistent with the rise of oil price volatility after production cuts from OPEC members in the 1980s and 1990s decades (Kilian 2009^[168]). Moreover, this is in time with the conclusions of Baumeister and Kilian (2016^[29]) that showed that oil price became more sensitive to production changes after 2014. The explanation may rely on the studied period that spreads from 1999 to 2019 and therefore presents a substantial part of it on the high-volatility 2014-2019 period. The first decade of the 2000s until 2008 and the following years from 2010 to 2014 exhibit relatively low volatility and more prominent role of demand factors to drive price changes. Whereas, the last period of time span show OPEC production cuts decided with the objective to restore the balance in an oversupplied market and the price stability. Hence, a reverse causality that bring prices to force OPEC agreement to reduce price volatility that justify the positive coefficient.

The two other energy price returns studied here – the natural gas and the coal – both present negative coefficient as a reaction to the Chinese IPI, which is explained by the counter-cyclicity reaction of energy commodity to changes of the global demand, and more precisely to the Chinese demand here. The effect is particularly large for the long-term component of the coal price return volatility. Results suggest a 45% volatility increase in the first month following a one standard deviation of the Chinese IPI. Consequences spread through time as there is still a 10% volatility increase in the tenth month and we must wait for the twentieth month to see effects fall below one percent. Indeed, China accounts for more than 20% of the world coal consumption (IEA¹⁶). Concerning the impact of the OPEC production, both coefficients are significative but while it is negative for the natural gas, it is positive for coal. The partial substitution between the natural gas and coal with oil for urban heating, electricity production and other industrial pro-

¹⁶IEA, International Energy Agency

duction justify significant coefficients we found. Their prices are found to be correlated with oil prices. Hartley *et al.* 2008^[133] used a VECM to prove it for natural gas, while Bachmeier and Griffin (2006^[17]) found a weak correlation for both commodities with oil. Consequently, fundamental of the oil market have direct impact on natural gas and coal. However, our GARCH-MIDAS model concludes on different signs. They indicate that a decrease of the OPEC production raises natural gas volatility whereas they decrease the coal one. It seems that coal also benefited from OPEC decisions on supply cuts to restore oil price stability. On the contrary, because of the oil indexation of natural gas contracts (Chiappini *et al.* 2019^[59]), a production cut is a sign that oil prices are supposed to raise on following weeks, which decrease natural gas competitiveness. Therefore, it increases uncertainty on the natural gas markets.

We then look at the impact of the volatility of the Baltic Dry Index (BDI) which serves as an indicator of the economic activity volatility on the long-term component of the energy commodities. As in Pan *et al.* (2017^[216]) and Conrad *et al.* (2015^[68]), we find a positive and significant parameter. Here, the effects are very close for the WTI and the Brent, with a 0.1% increase of the long-term component to a one standard-deviation of the volatility of the BDI. However, we find a counter-cyclical movement for the natural gas to the BDI.

2.4.4 Final remarks on the energy price volatility

This empirical study reviews the drivers of the volatility for four energy commodity price returns. We show in an EGARCH model the high sensitivity of energy price volatilities to financial indicators on a high frequency basis. Our most important findings concern the use of recently developed MIDAS-GARCH models that allow us to test for the effect of market fundamentals. While the effect of economic activity and oil production had been previously demonstrated, we focus on the impact of the Chinese demand which is often depicted as the main driver of commodity demand in the 2000s years, the OPEC

production. We confirmed the counter-cyclical behavior of the Brent oil volatility to the economic activity but concluded on a positive reaction to OPEC production. Both WTI and Brent appeared to sensitive to economic activity spillover, while the analyzis of natural gas and coal is useful to test the robustness of the model on other energy commodities and to discuss their relationship with crude oil price volatility. Further analyzis on this thematic would bring us to focus on the causality of the demand and supply drivers on energy prices since OPEC supply targets rely more and more on price stability concerns.

2.5 Conclusion

This section showed the critical services provided by commodity traders to ease trades in the oil industry. While it is the market openness that enable traders to develop their specific skills, we also reach to the conclusion that traders are key components of the market. Indeed, market trades exposed producers to a higher risks than the previous full vertical integration of oil producers. Market trades led to new kind of transformations – time and spatial – and risk transfers, especially price risk transfer. Without midstream actors able to provide risk management services, market trades would be too costly to be competitive relatively to vertical integration.

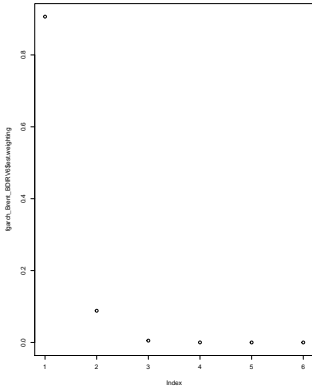
Appendix

Appendix A - Preliminary tests on returns to energy prices (daily data)

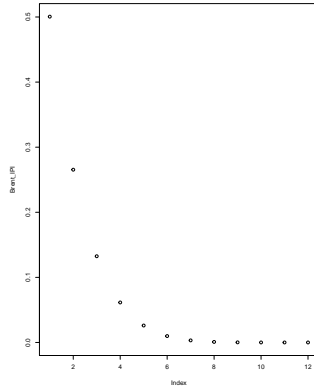
| | | 1999:2008 | 2008:2014 | 2014:2018 |
|-------------|-----------------|-------------|-------------|-------------|
| Brent | ADF test | -36.2645 | -30.1215 | -24.4860 |
| | Ljung Box test | 28.78 | 161.75 | 49.6325 |
| | ARCH LM test | 22.91202*** | 52.6466*** | 54.8696*** |
| WTI | ADF test | -36.3698 | -29.8178 | -24.2916 |
| | Ljung Box test | 23.369 | 81.296 | 85.8194 |
| | ARCH LM test | 19.3094*** | 41.6388*** | 31.0375*** |
| Natural gas | ADF test | -42.2323 | -33.4593 | -23.6339 |
| | Ljung Box test | 782.51 | 171.91 | 205.9023 |
| | ARCH LM test | 377.5213*** | 74.0414*** | 179.4499*** |
| Coal | ADF test | / | -24.9169 | -20.4784 |
| | Ljung Box test | / | 150.02 | 44.5665 |
| | ARCH LM test*** | / | 140.0761*** | 30.9881*** |

Appendix B - MF-GARCH weighting Scheme

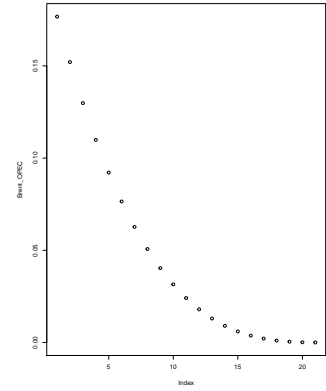
(a) Brent



Baltic index RV

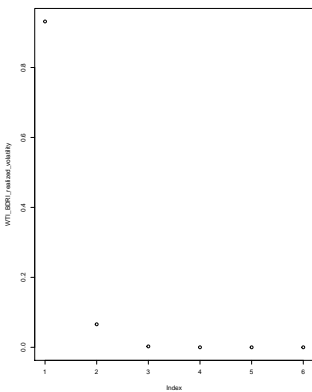


IPI

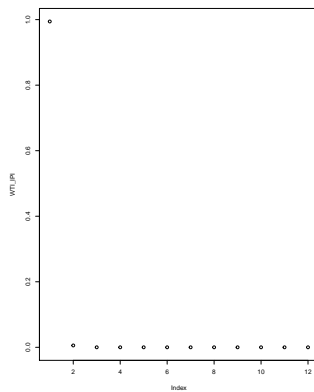


OPEC

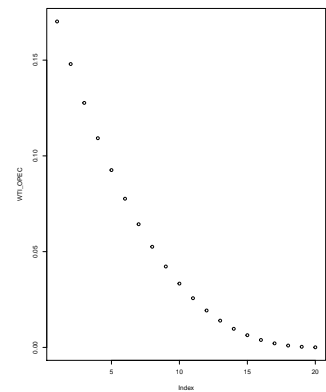
(a) WTI



Baltic index RV

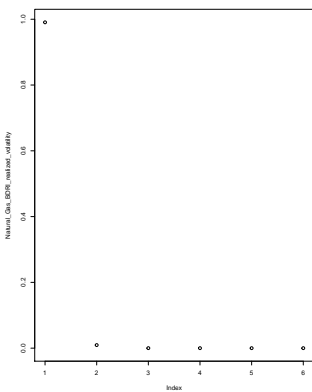


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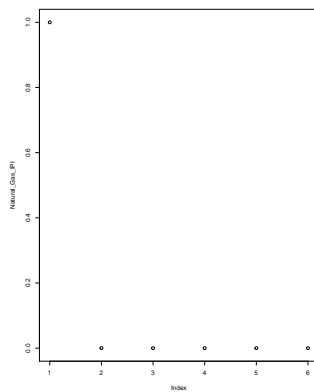


OPEC

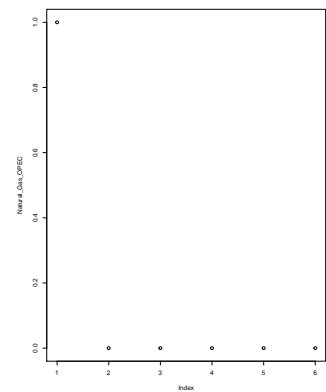
(a) Natural Gas



Baltic index RV

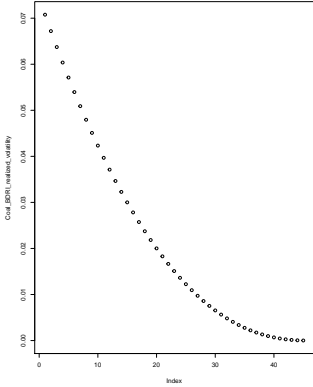


IPI

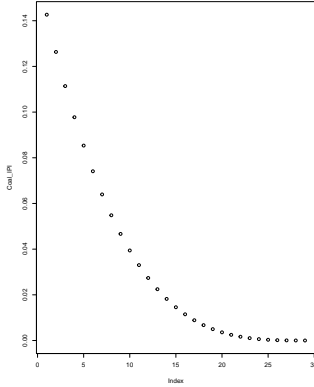


OPEC

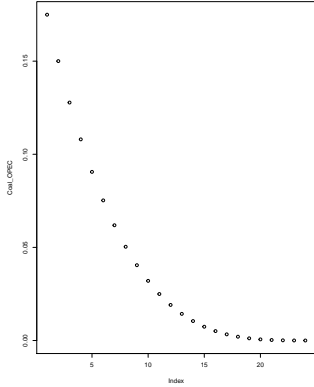
(a) Coal



Baltic index RV



IPI



OPEC

Part II

Essays to model physical traders'
contribution to connect regional oil
markets

We have now established that the study of the oil industry is incomplete if it does not include physical traders. They are the missing link between supply and demand but also the link between the physical and financial markets. Thus, they contribute to making the oil market “*one great pool*”, in which any regional market, whatever its size, is integrated into the international market. In this second part, we wish to highlight the skills of commodity traders in the oil industry. In traditional international trade theory, producers are said to transfer their work force or their productivity. In the case of commodity traders, it is their skills and infrastructure that are transferred. Therefore, control of the transport infrastructure places the commodity traders on the land of the network.

Chapter 3

The international oil trade network

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3.1 Introduction

The dominant framework for the study of international trade flows is usually based on the gravity equation (Tinbergen 1962^[260], Anderson 1976^[10]). The association between bilateral trade flows, economic masses and distances benefits from strong theoretical and empirical supports (Anderson and Van Wincoop 2004^[11], Helpman and Melitz^[137], Chaney 2008^[54]). Nevertheless, applications to commodity bilateral trades do not seem to be relevant when considering commodity traders. The gravity equation is essential to identify the pattern of bilateral oil trade, but it must also take into account the particular role of export-platform countries. These countries are essential for the distribution petroleum products to any oil-importing country. Therefore, we can expect that the gravity effect rather concentrates into hub countries whose role is to link producers and end-users from different regional markets. Indeed, commodity-specific trade flows do not necessarily link supplying and demanding countries since the fact of being a major player of the industry industry is not a sufficient condition for organizing international trade flows. This function seems to be transferred to hub countries. They bring together all mandatory characteristics and infrastructures of international trade. They have port infrastructures to manage the geographical transformation, storage facilities for the time transformation, blending facilities or liquid financial derivative markets to hedge price, currency and freight risks, among others. Therefore, it seems more accurate to represent international trade flows as a network describing flows as market connections.

To describe this manufactured goods trade flows, De Benedictis and Tajoli (2011^[77]), explained that the simplest representation of the international trade web is to draw a network. They recommend to use straight line directed segments representing trade flows that link exporters to importers. In their paper, they assign a weight to segments relative to their trade value. By connecting all countries, they obtain a graph representing the “World Trade network” and its evolution over time. As in the gravity equation, the major commodity exporters and importers are likely to be characterized by a high centrality,

as they account for a substantial part of international trade. But the main advantage of the network analysis is to shade light on countries, also considered as central, whose relative importance depends on their trading partners. The graph can then show that the organizational power is distributed among exporters, importers but also intermediaries.

The emergence of the graph theory finds its premise in sociology (Scott 1988^[244] and 2011^[245], chap 2), and gained the interests of economic researchers in recent years. Ji *et al.* (2014^[155]) have built a global oil trade network and showed that oil relies on regional trading blocs. They explained this by the influence of stronger geopolitics and diplomatic relationships. The applications of the graph theory are now widespread. The methodology has been used by Ji et Fan (2014^[157]) to highlight the evolution of the market integration, in terms of price correlation, of oil markets from 2000 to 2011.

The network analysis reveals its key contribution when it comes to analyzing the role of countries in the structure of trade. Freed from the bilateral trade constraint, this framework can focus on the influence of core countries. Fagiolo *et al.* (2010^[94]), conducted a weighted-network analysis and showed that, while most countries have weak trade links, there is a group of countries which is connected to the main trade clusters and poorly-connected countries at the same time. They play a key role in connecting the regional markets. Hub countries tend to attract the main commodity trade flows and redirect them to major markets. Peng *et al.* (2019^[217]) demonstrated that Rotterdam, Singapore and Antwerp display a “hub-and-spoke” structure¹ that is consistent over time. Imai *et al.* (2009^[150]) showed the superiority of “hub-and-spoke” ports in European costly shipping trades. Since hub countries pool trade flows and the industry information, hubs play a key role in the market price mechanism to provide reference prices. Heather (2012^[136]), examined the gas price mechanism in continental European hubs and concluded that, if the number of gas hub is likely to increase in the future, only few should be sufficiently liquid to offer reference prices. Shi *et al.* (2016^[247]) showed, based on the East-Asian

¹A hub-and-spoke network connects every vertices of a network through a single edge.

market that liquid hubs need to provide contract flexibility for both inflows and outflows. This condition is also mandatory for hub indexation prices in the area.

In this chapter, we aim to analyse the role of commodity traders in the oil trade network. We have already stated that they have the key economic duty to reconcile, in time and space, buyers and end-users or raw materials. Our contribution to the literature is to highlight their capacity to be the missing link between producers and end-users. We use centrality measures derived from the network analysis of the oil bilateral trades between 1998 and 2016 to identify a group of hub countries that is composed of Belgium, Indonesia, Korea, Malaysia, Netherland, Singapore, the United-States and the United-Kingdom. We can easily remark that physical traders largely localized trading desks in these countries. They can be seen as optimal places to organize trades into the main consumption markets thanks to their port infrastructures and the relative political stability. Netherland and the United-kingdom are historically two of the main countries in which oil producers emerged, Shell and BP respectively. Together with Belgium, they are the ideally located to feed the European market, so are Korea, Malaysia and Singapore for the Asian Market. Finally, the United-States is both a major producing and consuming market. In the second section of the chapter, we develop a gravity equation that include a clear distinction between oil producers' exports and oil hub countries' (*OHC*) exports to see if trade oil pattern is sensitive to the nature of the exporter. We find that hub countries can flow barrels to small markets and widely diversify the destination of their exports, whereas crude oil producers trade larger volume but to a smaller number of destinations. Such a result echoes with commodity traders' role to connect supplier and end-users.

The remainder of this chapter is organized as follows. In section two, we present the main tools of the network analysis and the database before we describe and comment the evolution of crude oil international market organization from 1998 to 2016. We estimate different centrality measures such as the out-closeness, in-closeness, betweenness, eigenvector and transitivity indices to identify the OHC. In section three, we quantify the

impact of centrality measures into oil bilateral trade flows through a gravity model. We show that commodity traders, through oil-re-exporting countries, change the patterns of international trade flows.

3.2 The oil trade network

In this first section, we aim to transform oil bilateral trades into a network linking, directly or indirectly, oil producers to oil consumers. Using a matrix adjacent to the network allows us to develop centrality measures to identify hub countries. First, we discuss the growth of the network analysis in the economic literature. Second, we present the data and third we model the network.

3.2.1 The network analysis an expanding research framework

A new field of empirical research has emerged with the application of the graph theory analysis in social sciences thanks to the contribution of Jackson and Rogers (2007^[152]) on the randomness of social network and friend relationships. The framework quickly offered new potential for market integration studies that differ from the cointegration analysis of price series. These studies are highly connected to geographical economics. Chaney (2014^[55]), based on Krugman's model (1980) analysed the formation of social networks between exporters and importers. Instead of discussing the randomness of friend relationship, the author analyses the randomness of international contract formation. He concluded that being connected to a higher number of contacts increase the ability to attract new contacts and increase international flows.

Applications are now widely diversified to show network transmission of international financial flows and risk exposure (Giudici and Spelta, 2016^[108] and Giudici *et al.* 2020^[107]). Fagiolo *et al.* (2010^[94]), used a weighted network approach to study the empirical properties of international trade relationships. Their model highlights a core-periphery structure of international trade in which rich countries have strong connections. In Calatayud *et al.*

(2017^[46])’s study, the network approach measures the degree of connectivity of countries to their international freight markets. They used a ‘support network’, composed of information on liner shipping services, port infrastructure and trade facilitation procedures to explain connection to international markets. They emphasized the role of infrastructure and the investment strategy of transport companies as key connecting factors between international markets. In line with basics of comparative advantages, they showed the United States’ connections depend on its international trade activities and that countries are sensitive to the development of their shipping lines. These findings are coherent with the observations of Jacobs (2014^[153]) who concluded that Rotterdam and Amsterdam are two designated places to trade commodities thanks to their capacity to link both financial sector – for financing and hedging issues - and distribution – because of storage and transportation capacities. Yang and Fan (2015^[284]) used geographical information system and complex networks analysis to represent the oil trading system and examine the changing structure over time. They explained that the emergence of importing hub such as Singapore, a resource-poor country, can rely on the country’s financial infrastructure and port facilities to support oil trade flows. They also identified Netherlands as a hub because of its large number of import partners.

3.2.2 Data

In order to represent the world trade network, we follow De Benedictis et al. (2014^[76]) and use the Cepii’s Baci database (Gaulier and Zignago 2010^[101]). The Baci database is based on exports and imports trade flows reported by the UN Comtrade website. We use both crude and refined oil trade flows (HS codes 27,000 and 27,100 respectively) to study if both commodities have the same pattern of trade. We consider exports and imports data of all reporting countries in order to show that oil hub countries *OHC* provide a key contribution to link big oil producers with small importing countries. The database covers flows from 1998 to 2016, the latest available data at the moment we write this

chapter. Trade flows are measured by the USD constant value. In order to control our findings on a more aggregated dataset, we build a third dataset in which we sum the value of trade from both HS code 27,000 and 27,100. The UNCOMTRADE database record 201 countries involved in refined products international trades during at least once from 1998 to 2016. While 140 countries are recorded for crude oil trades. Results are presented in the following table:

Table 3.1: Top 25 of exporters and importers of both crude and refined oils on yearly average (2000-2016)

| Top 25 of exporters and importers | | | |
|-----------------------------------|--------------------|------------|--------------------|
| ISO code | Total import | ISO code | Total export |
| USA | 238870583.1 | SAU | 154644821.7 |
| CHN | 104498639.1 | RUS | 149109764.4 |
| JPN | 96072426.8 | ARE | 62231156.1 |
| NLD | 70366117.26 | CAN | 53156012.02 |
| KOR | 65841585.27 | NGA | 50754150.8 |
| IND | 59591051.87 | NLD | 49223445.44 |
| DEU | 55248938.81 | USA | 45888215.14 |
| SGP | 52387908.77 | NOR | 45480103.32 |
| FRA | 45817851.69 | VEN | 41582011.32 |
| GBR | 40736364.13 | KWT | 41538443.28 |
| ITA | 40568052.95 | IRN | 40004733.8 |
| ESP | 32634558.14 | IRQ | 37412082.44 |
| BEL | 29834265.03 | GBR | 35500977.44 |
| CAN | 24620228.95 | SGP | 35349249.25 |
| IDN | 20384226.65 | AGO | 30378274.53 |
| THA | 19843443.32 | MEX | 30186275.13 |
| AUS | 17854878.16 | DZA | 27857295.94 |
| BRA | 15939646.38 | KOR | 24241707.36 |
| MEX | 12890301.25 | LBY | 24132280.27 |
| MYS | 12831062.19 | QAT | 23916841.05 |
| TUR | 12802884.99 | KAZ | 22938345.43 |
| SWE | 12528304.94 | IND | 22050642.61 |
| ZAF | 12441990.77 | MYS | 19399612.37 |
| POL | 11783576.55 | BEL | 16964280.76 |

Countries which are both in the top 25 of importers and exporters are in bold

On average over the period 1998-2016, Saudi Arabia and Russia are the two countries with the highest value of export flows, far ahead of the United Arab Emirates, Canada

and Nigeria, the following countries. The United States are the main importing country of the set, followed by China and Japan. But the main result of this table is that 10 countries are present in both rankings (countries in bold in table 1). It indicates that they are both main importers and exporters over the period. In order to control the role of these countries in the oil international web, we compute centrality measures.

3.2.3 International oil trade network model

As in Barigozzi *et al.* (2010^[24]) and De Benedictis and Tajoli (2011^[77]), our trade network is represented as the set $G = (V, E, a)$, in which $V = \{v_1, v_2, \dots, v_n\}$ represents the number of country nodes, and $E = \{e_{i,j}\}$ represents trade flows, the edges of the network. n is the number of countries, i and j are exporting and importing countries ranging from 1 to n . In the network, we have potential trade flows both from i to j and from j to i , meaning we have $n!$ trade relationships. Edges, the trades flows, are weighted by the value of the trade $a_{i,j}$. In case there is no actual trade between i and j , we give it a zero-value. It allows us to build our adjacency matrix G in which columns are exports from country i to country j in row:

$$G_{i,j} = \begin{pmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,j} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,j} \\ \vdots & \vdots & \ddots & \vdots \\ a_{i,1} & a_{i,2} & \cdots & a_{i,j} \end{pmatrix}$$

We defined the degree $k_i(t)$ as the total value of trade flows of a country i . k_i^{out} is the exports value from country i , and k_i^{in} the import value from country i . Hence, $k_i(t) = k_i^{out}(t) + k_i^{in}(t)$. In order to weight trade according to their relative importance, we use the weighted degree node strength ($s_i(t)$) as the sum of weights of edges for a country i at year t . Similarly, we have: $s_i(t) = s_i^{out}(t) + s_i^{in}(t)$.

There are multiple measures for network centrality. Our aim is to identify commodity trading countries within the crude oil market web.

The hub score

The hub score, as defined by Kleinberg (1998), is used to determine the relative importance of country “ i ” in the network. It is the principal eigenvector of $hub_t = G(t) * G(t)^t$, where $G(t)^t$ is the transpose matrix.

Oil producing countries appear to display the highest hub score.

The authority score

The authority score goes by pair with the hub score, which measure the connectivity of country to the others. The more a country is connected to hub, and the higher is its authority score. Using directed graphs allow us to have different value for hub and authority score which is defined as $authority(t) = G(t)^t * G(t)$. The authority score gives a central position to demand markets.

The eigenvector centrality

The eigenvector centrality measures the proximity of a country to other core countries. Consequently, the centrality score of a country depends on the score of its trading partners.

$$\lambda C^e(G(t)) = g C^e(G(t)) \quad (3.1)$$

$$\text{With } \lambda C^e(G(t)) = \sum_j a_{i,j} C^e(a)$$

Where, $C^e(G^t)$ is the eigenvector with the largest eigenvalue. $\sum_j a_{i,j} C^e(a)$ the centrality of country i 's partners, weighted by the value of their flows $a_{i,j}$. As a consequence, λ is the proportionality factor. Countries with high eigenvector centralities trade with many countries that are trading considerably with many other countries.

The betweenness centrality

The betweenness centrality, $B_i(t)$, is a centrality measure we consider to capture the ability of a country to be a key link between two other countries. A country acting as an intermediary platform between other countries will exhibit a high betweenness centrality. Choi *et al.* (2014^[60]), used it to identify intermediary countries in international trade and conclude they have a high bargaining power.

$$B_i(t) = \sum_{j \neq k, j, k \neq a} \frac{\tau_{j,k}^i G(t)}{\tau_{j,k} G(t)} \quad (3.2)$$

The betweenness centrality $B_i(t)$ of a country is the number of shortest paths $\tau_{j,k}^i G(t)$ between j and k in $G(t)$ that pass through i while $\tau_{j,k} G(t)$ is the total number of shortest paths between j and k in $G(t)$.

The transitivity index

The transitivity index, also named the cluster index, $trans_i(t)$, let us quantify the position of a country in the network. The index gives the probability that adjacent vertices of a vertex are connected together. It is the share of country i 's partners that already trade with each other. $1 - trans_i(t)$ gives us the share of countries that linked thanks to country i . This indicator is critical to identify the OHC as it measures the capacity of these countries to connect the ones which do not trade directly.

Grubel and Lloyd index applied on in-degree and out-degree

The index, GL , is a measure of intra-industry trade of good (Grubel and Lloyd 1971^[118]). We propose the use of the index as a revealing indicator for countries that are both exporting and importing crude or refined oil. We consider the relative weight of strength in-degree and out-degree of a country:

$$GL_i = \frac{|s_i^{out} - s_i^{in}|}{s_i^{out} + s_i^{in}} \quad (3.3)$$

A GL index close to 0 means that the country i 's in and out degree are balanced, the country is both an exporter and an importer. While a GL_i index close to 1 indicates the country is a net importer or exporter.

3.2.4 Results

We computed the average value for both crude and refined oils, and display the top 30 country for each measure in Appendix A. We decide to select the countries that are in the top 30 in the ranking of each of the measures of centrality calculated as oil hub countries (OHC). We results for the countries concerned are presented in table 5. It indicates that, out of Mexico and India, the countries identified in table 1 as both exporters and importers have a central role in the international oil web. Mostly, their centrality measures, the transitivity and the GL indicators seem to confirm these countries are OHC. Their characteristics are summarised in the following table:

Table 3.2: Oil hub countries on average on the period 2000-2016

| ISO code | Hub score | Authority score | Transitivity | Eigenvector | Betweenness centrality | GL |
|----------|-----------|-----------------|--------------|-------------|------------------------|--------|
| BEL | 0.0574 | 0.0308 | 0.1579 | 0.1084 | 815.2941 | 0.2964 |
| GBR | 0.1890 | 0.0518 | 0.1440 | 0.0483 | 5100.3529 | 0.1131 |
| IDN | 0.0455 | 0.0692 | 0.3208 | 0.1465 | 2126.3421 | 0.4743 |
| KOR | 0.0896 | 0.1924 | 0.1810 | 0.0294 | 3432.9412 | 0.4880 |
| MYS | 0.0407 | 0.0159 | 0.2471 | 0.0262 | 4030.4706 | 0.2124 |
| NLD | 0.0874 | 0.1264 | 0.1463 | 0.1072 | 9244.3529 | 0.1645 |
| PAN | 0.0017 | 0.0202 | 0.3886 | 0.0440 | 265.3158 | 0.5397 |
| SGP | 0.0322 | 0.0925 | 0.1835 | 0.0933 | 11753.4706 | 0.1849 |
| USA | 0.0229 | 0.9588 | 0.1107 | 0.8824 | 18469.9412 | 0.7102 |

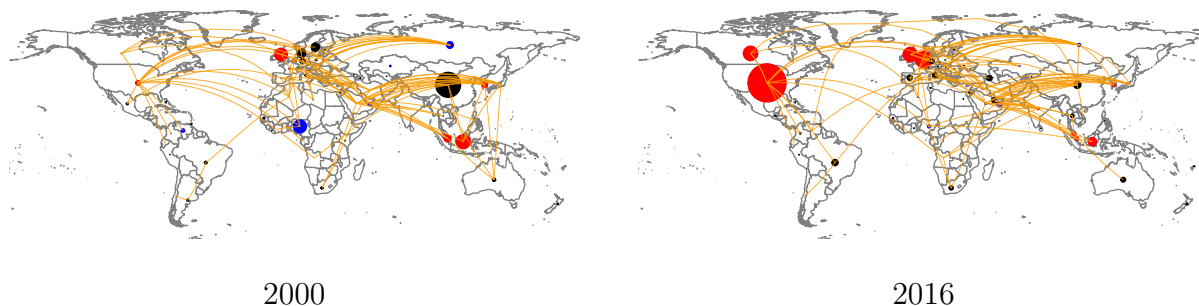
Our group of oil hub countries is consistent with the findings of Peng *et al.* (2019^[217]) since most of the cities they defined as ‘‘hub-ports’’ in 2009 and 2016 are represented our dataset. In their 2016 top 10 hub-ports, Rotterdam (Netherlands), Singapore, Antwerpen (Belgium), Amsterdam (Netherlands), Yeosu (South Korea), Panama, Houston (the

United-States) and Dumai (Indonesia) are part of our dataset. On the contrary the United Arab Emirate, whose Fujairah port is found to be a hub, are not included because the *GL* indicator indicates they are mainly an oil exporter. Finally, Turkey exhibits centrality measures lower than the countries previously presented. Moreover, we can notice that these countries are spread between main regional markets.

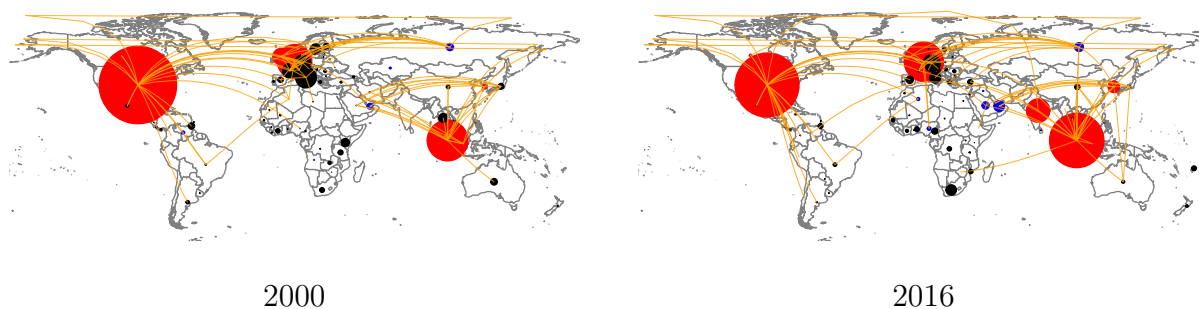
To take a better appreciation of the oil structure, we turn to geographical information system. It allows us to visualize spatial patterns of crude oil network. We choose 2000, 2005, 2010 and 2016 as representative years to illustrate the evolution of networks over time. It confirms that countries other than the major producers and consumers can be a “hub” country occupying a central position on the network. While the network can be relatively sparse in 2000, we can trade flows turning more and more to countries that we have defined as OHC. The following figures present the evolution of the network from 2000 to 2016, while the pictures of trade networks in 2005 and 2010 are in appendix B.

Figure 3.1: Crude and refined oil trade web (in USD), using betweenness centrality

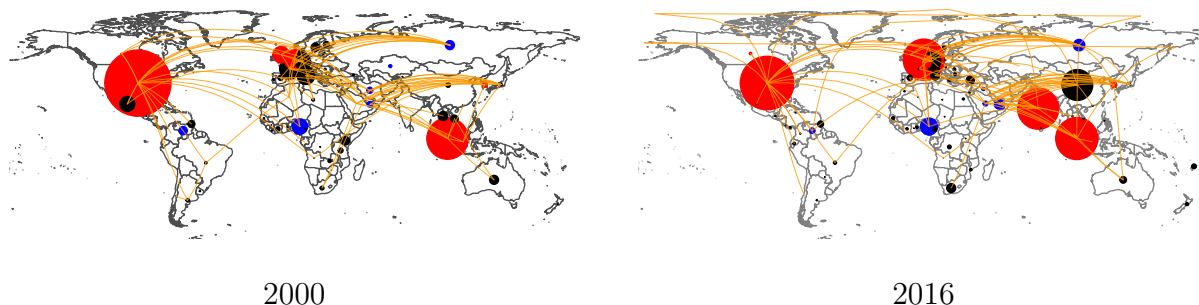
(a) Top 100 crude oil trade flows (in USD)



(b) Top 100 refined oil trade flows (in USD)



(c) Top 100 of the sum of crude and refined oil trade flows (in USD)



Size of the circle are equal to the betweenness centrality divided by 3000.

OHC are in red, major oil producers in blue and others in black.

3.2.5 Comments

Graphs confirms centrality analysis results which exhibit that OHC centrality increased significantly from 2000 to 2016. While in 2000, crude oil exporting countries displayed the highest centrality measures, their influence seemed to have relatively reduced at the benefit of oil importing countries and OHC. The main changes have happened between

2010 and 2016 with an increase in the OHC.

Results for refined products displays a similar trend but with higher centrality measures for export-platform countries which clearly dominate the market. The access to blending facilities and refining units can explain exacerbated results. The graph presenting results for the mixed database (crude + refined), is also coherent with the transformation units located in these countries. Crude oil can be imported and exported once transformed into a refined oil product.

3.3 The role of commodity hub countries

Now that we have identified OHCs, we focus our efforts on valuing the role of these countries in the oil international market. We assume there is a gravity effect with OHCs attracting oil trade flows. The basic gravity model assumes that trades amount between a pair of countries is positively impacted by their size and negatively impacted by the distance between them (Anderson 1979^[10]). The basic representation of the gravity equation is shown as follows:

$$\ln(T_{I,j}) = \beta_0 + \beta_1 \ln(D_{i,j}) + \beta_2 \ln(GDP_i) + \beta_3 \ln(GDP_j) + \beta_4 X_i + \beta_5 X_j + \varepsilon_{I,j} \quad (3.4)$$

Where $T_{I,j}$ is the value of oil exports from “i” to “j”, $D_{i,j}$ the distance between countries “i” and “j” and X_i is country “i”’s specific factor variables.

3.3.1 The gravity equation to model international trade flows

Gravity equations are empirical tools widely used to explain the pattern of international trade. In this chapter, we do not question the assumptions of the equation nor do we offer an extension to the model, but we propose to study whether hub countries modify oil international trades. Thus, we do not make an exhaustive presentation of gravity models and their evolutions, but we focus on the main contributions of the models.

Theoretical foundation of the gravity equation

The pioneering study on the gravity equation was carried out by Tinbergen (1962) to highlight the negative link between distance and international trade flows. The theoretical foundations have been provided by Anderson (1979), who gave a micro-foundation to the model by deriving the GE from the expenditure system model. He set the key assumptions of product differentiation by country of origin, which relies on the Armington elasticity (1969), and constant elasticity of substitution expenditure. Bergstrand (1985) also significantly contributed to the theoretical foundation of the model by deriving the GE from a general equilibrium model. Deardorff (1998), demonstrated the consistency of the GE with Hecksher Ohlin model through two equations.

Anderson and van Wincoop (2003) give new impetus to this field of study by deriving a micro-founded gravity equation from a general equilibrium model. The particularity of their approach is to consider the existence of equilibrium prices according to the origin and destination of trade flows. They call this effect the multilateral resistance term, i.e. the average transaction cost for exporters and importers to trade with any partner. This result undermines McCallum's conclusions and allows them to conclude that the border effect is weaker, even if it is not negligible. The gravity model has since been extended in many ways with applications to heterogeneous firms (Melitz 2003).

Therefore, empirical contribution and extension could exhibit a strong dynamic. Baier and Bergstrand (2001) empirically analysed the impact of income similarities between trade partners, tariff and transport-cost reduction in the growth of international trade flows within 16 OECD groups. Eaton and Krotum (2002^[84]) described the influence of Ricardian comparative advantages in trade flows with perfect competition and constant return to scale concluding that countries with different advantages are more likely to trade together. The model has also been extended to heterogeneous firms in the 'new new trade

theory”, mainly popularised by Melitz (2003), Antras and Helpman (2004) and Chaney (2008).

The gravity equation benefits from solid theoretical basis to analyse the pattern of trade flows and the influence of transport costs. Krugman (1980^[177]) showed the negative impact of the distance and other trade barriers on trade flows, with monopolistic competition and increasing returns to scale.

Gravity models to analyse homogenous good trade flows

Gravity equations specific to commodity trading must focus on trade in homogeneous goods. Thus, they require disaggregated data. Anderson and van Wincoop (2004^[111]) have shown that transaction, transport or tariff policy costs, as well as multilateral resistance, are sector-specific. The gravity equation can thus be applied to data at an aggregate or sectoral level (Yotov *et al.* 2016^[285]). Feenstra *et al.* (1998^[99]) showed that the “home market effect” was more important for homogeneous than for heterogeneous goods. Berthelon and Freund (2007^[33]) confirmed these results by showing that homogeneous, bulky and high-tariff goods are distance-sensitive.

Nevertheless, the application of gravity models to commodities does not benefit from the same impetus. Indeed, commodities, and even more energy products, are characterised by high concentration of natural resources in few areas while the demand is worldwide. Therefore, there is a low sensitivity of both demand and supply to price variations. A poor response to the distance-elasticity is expected if the commodity is weakly substitutable. Still, the gravity equation is a critical tool for explaining commodity international trades. By regressing trade flows on distance measures, we can detect oil sub-markets, in which it is reasonable to assume that each area has at least one OHC managing trades flowing through it. Barnes and Bosworth (2015^[25]) demonstrated the increase of the gas market integration since liquefied natural gas (LNG) is internationally traded. They explained this phenomenon by a decrease in transport costs between regions in LNG trades, while compressed natural gas markets remain regional. Balistreri *et al.* (2010^[23]) also adopted

a gravity equation approach to identify the elasticity of substitution for highly disaggregated data covering six crude oil and seven refined petroleum products. They found that, in the long run, transport costs are essential to determine the pattern of trade because of the homogeneity of crude oils, making them sensitive to any change in price and costs.

Gravity equations and export-platform countries

The limit of the gravity equation in the study of the oil international trade network is the particular role occupied by physical traders. They might not be neither a major producer neither a major consumer, but they represent a considerable part of international trades. They are intermediaries that allow producers and end-users to meet. They echo with export-platform countries. Indeed, this framework examines the role of foreign productive investment through the cost of establishing foreign plants relatively to the costs of shipping costs (see Tintelnot, 2017^[261]). Plant location does not necessarily rely on countries' factor productive but must match with other characteristics like the geographical proximity of demand markets. Export-platforms are countries hosting foreign direct investments (FDI) whose output is largely redirected toward third countries. A high value is associated with horizontal investments to target the destination that would enable the investor to integrate neighbours' markets at the lowest costs (Ekholm *et al.* 2003^[85])². Nevertheless, in the case of commodity trading, export-platform countries do not have to transform the commodity but can benefit from its infrastructures to reorient it towards demand markets.

3.3.2 Model specification

First, we run a basic model that only include the traditional components of bilateral trades flows. The benchmark specification of our gravity equation account for basic distance-factors that are both importers and exporters GDP the share of a common

²Vertical investment, on the contrary, are set to benefit from low-cost location, Ekholm *et al.* (2007^[85]) showed that both horizontal and vertical investment are key characteristics that influence FDI into export-platform FDI.

frontier $contig_{od}$, of a common language $comlang_{od}$ and the existence of historical colonial links $colony_{od}$.

$$X_{od,t} = \beta_0 + \beta_1 GDP_{o,t} + \beta_2 GDP_{d,t} + \beta_3 contig_{od} + \beta_4 comlang_{od} + \beta_5 colony_{od} + \varepsilon_{od,t}$$

Where $X_{od,t}$ are trade flows from the origin country o to the destination country d and $\varepsilon_{od,t}$ the error term. We divide our sample into two subgroup in order to analyze if the pattern of oil trade flows changes with the nature of the exporter, *i.e.* if the exporter is considered as an OHC or if it as a crude oil producer.

Then, we extend the model by introducing two dummy variables OHC_o and OHC_d to highlight the gravity effect of OHC. The first takes the value 1 when the exporter has been defined as an OHC in the previous section, 0 otherwise. It shows whether hub countries tend to export a larger volume of petroleum products. OHC_d is a similar dummy variables for importers. It must show if hub countries attract higher flows of oil than other importing countries:

$$X_{od,t} = \beta_0 + \beta_1 GDP_{o,t} + \beta_2 GDP_{d,t} + \beta_3 OHC_o + \beta_4 OHC_d + \beta_5 contig_{od} + \beta_6 comlang_{od} + \beta_7 colony_{od} + \varepsilon_{od,t}$$

3.3.3 The management of zero trade flows

The main econometric issue of the gravity equation is the consideration of the zero trade values. They are frequent in sector-specific gravity equations because of the isolated location of some countries, transport costs or small size economies (Frankel 1997^[100], Silva and Tenreyo 2006^[250], Helpman *et al.* 2008^[137]). This problem is particularly acute in commodity trade flows because of the strong geographical constraint on producing countries. If a significant part of international trades flows through OHCs thus, it can be expected that producing and consuming countries do not trade directly, hence the presence of many zero trade flows in our database.

Conventional gravity equation is modelled in log-linear form which is inappropriate for zero trade flows. This issue involves to change the specification of the model. A first solution can be to remove zero trade values from the database. However, this methodology presents some biases. Burger *et al.* (2009^[44]) and Martin and Pham (2015^[194]) showed that zero-trade flows are not random but give information on countries trade partners. Omitting zero trade flows from the model does not allow the model to state on the nature of zero trade flows between countries.

Silva and Tenreyo (2006^[250]) argued that the log-linear form of gravity models is not consistent in case of heteroskedasticity, which is inherent in trade flows data. They recommend the use of the Poisson-pseudo maximum likelihood (PPML) estimator in which the dependent variable is measured in level instead of the log-linear form. Authors showed that the model is more robust in the presence of heteroskedasticity. What is more, because the dependent variable is treated in level, the PPML estimator is not affected by the distribution of zero trade flows. Fally (2015^[95]) demonstrated that the PPML estimator is also consistent with time-varying fixed country fixed effects. Empirical research largely used the PPML estimator for assessing international trade (Westerlund and Wilhelmsson 2011^[269], Anderson and Yotov 2012^[12]).

3.3.4 Data

We use crude and refined oil bilateral trade flows from the Baci database previously presented. We include into the gravity equation classical distance measure. The geodesic distance between pairs of countries which uses GPS coordinates of the most important cities is used to calculate the distance (Mayer and Zignago, 2011^[198]). We also use dummy variables indicating contiguous countries for the border effect (*contig*), the share of a common language (*comlang*), if countries ever had a colonial link (*colony*) and if countries share a free trade agreement (*FTA*). Dummy variables for *OHC* and centrality measures are derived from the network analysis.

Similarly to the first section and the network analysis, we keep the same number of countries in the analysis. We analyse trades involving 140 countries for crude oil trades, and 201 countries for refined oil trades. Our sample records trades from 1998 to 2016.

3.3.5 Results

We run our model on the total of crude and refined oil products and also offer to compare results from two sub-samples: the first describes OHCs' export while the second only present producers's exports. Because of the specific role of the United States being both a major oil trading place but also oil producers, the country is in both sub-samples.

Table 3.3: PPML panel estimates of crude oil bilateral trade flows. Sample Period 1998-2016

| | | | | with OHC dummies | | |
|--------------------|------------------------|-------------------------|------------------------|------------------------|------------------------|------------------------|
| | Full sample | Producers | OHC | Full sample | Producers | OHC |
| (Intercept) | -9.4776*** (0.6957) | -15.7250*** (0.7802) | -8.6368*** (2.5277) | -12.0472 (0,8760) | -13.6469 (0,8629) | -13.2687 -18 598 |
| dist | -0.6994*** (0.0384) | -0.8269*** (0.0423) | -0.9731*** (0.1149) | -0,8508*** (0,0385) | -0,8272*** (0,0429) | -0,7359*** (0,0750) |
| GDP_o | -0.0145 (0.0166) | 0.2414*** (0.0221) | 0.3016*** (0.0526) | 0,2153*** (0,0217) | 0.2375*** (0,0228) | 0,3736*** (0,0524) |
| GDP_d | 1.0060*** (0.0168) | 1.0388*** (0.0150) | 0.6704*** (0.0564) | 0,9328*** (0,0201) | 0,9629*** (0,0206) | 0,6764*** (0,0406) |
| OHC_o | | | | -2.2860*** (0,1012) | | |
| OHC_d | | | | 0,5759*** (0,0813) | 0,5012*** (0,0843) | 1.3533*** (0,1561) |
| FTA | -0.8882*** (0.0989) | -0.4214*** (0.0902) | 0.7749*** (0.2284) | -0,4509*** (0,0830) | -0.4724*** (0,0883) | 11.863*** (0,1843) |
| contig | 0.4500*** (0.1059) | -0.0493 (0.1006) | -0.0362 (0.2221) | 0,0916 (0,0981) | 0.0248 (0,1035) | 0,6050*** (0,2314) |
| comlang | -0.0238 (0.0996) | -0.4446*** (0.1174) | 0.7823*** (0.1816) | -0,4736*** (0,1089) | -0.5871*** (0,1236) | 0,3162* (0,1662) |
| colony | -0.3862*** (0.1394) | 0.2694** (0.1305) | 0.8298*** (0.1755) | 0,1139 (0,1189) | 0,1744 (0,1323) | 0,8413*** (0,1698) |
| Time fixed effects | Yes | Yes | Yes | Yes | yes | yes |
| Pseudo LLh | -1.88E+10 | -1.44E+10 | -1.32E+09 | -1.58E+10 | -1.41E+10 | -1.18E+09 |
| \bar{R}^2 | 0.2935 | 0.4392 | 0.1637 | 0.4211 | 0.4304 | 0.3227 |
| Obs. | 72270 | 22099 | 50171 | 72270 | 50171 | 22099 |

*, ** and *** indicate 10%, 5% and 1% significance levels
Robust standard errors in parentheses

Table 3.4: PPML panel estimates of refined oil bilateral trade flows. Sample Period 1998-2016

| | | | | with OHC dummies | | |
|--------------------|------------------------|-------------------------|------------------------|------------------------|------------------------|------------------------|
| | Full sample | Producers | OHC | Full sample | Producers | OHC |
| (Intercept) | -8.5677*** (0.7140) | -16.6667*** (0.7041) | -2.7398** (1.3346) | -5.7793 (0,7675) | -11.9958 (0,7231) | -3.4441 (1.2944) |
| dist | -0.6531*** (0.0445) | -0.8947*** (0.0451) | -0.4128*** (0.0672) | -0,5854*** (0,0461) | -0,9011*** (0,0466) | -0,3570*** (0,0647) |
| GDP_o | -0.3813*** (0.0166) | 0.6978*** (0.0247) | 0.1469*** (0.0304) | 0,3354*** (0,0214) | -0.6720*** (0.0236) | 0,1775*** (0,0311) |
| GDP_d | 0.5935*** (0.0090) | 0.6540*** (0.0123) | 0.5291*** (0.0137) | 0,5003*** (0,0105) | 0,4943*** (0,0146) | 0,5007*** (0,0139) |
| OHC_o | | | | 0,3793*** (0,0540) | | |
| OHC_d | | | | 1.0816*** (0,0560) | 1.4435*** (0,0717) | 0,7600*** (0,0804) |
| FTA | -0.0001*** (0.0985) | -0.4116*** (0.0903) | 0.3198** (0.1417) | -0,0792 (0,1040) | 26.0000*** (0,0000) | 0,4067*** (0,1430) |
| contig | 0.5110*** (0.1099) | -0.2795*** (0.0942) | 1.1496*** (0.2046) | 0,7739*** (0,1261) | -0,1571 (0,1082) | 1.2886*** (0,2122) |
| comlang | 0.2840*** (0.0772) | 0.1235* (0.0746) | 0.3106*** (0.1204) | 0,0548 (0,0888) | 0,0000*** (0,0000) | 0,1383 (0,1362) |
| colony | 0.0719 (0.0684) | 0.4321*** (0.1009) | 0.0837 (0.1041) | -0,0239 (0,0786) | 0,2510** (0,1096) | 0,0479 (0,1148) |
| Time fixed effects | yes | yes | yes | yes | yes | yes |
| Pseudo LLh | -8.99E+09 | -4.43E+09 | -4.05E+09 | -8.38E+09 | -3.99E+09 | -3.90E+09 |
| \bar{R}^2 | 0.3007 | 0.4069 | 0.2712 | 0.3392 | 0.4527 | 0.3366 |
| Obs. | 72270 | 50171 | 22099 | 72270 | 50171 | 22099 |

*, ** and *** indicate 10%, 5% and 1% significance levels

Robust standard errors in parentheses

Results of gravity models in tables 3.3 and 3.4 tend to confirm the influence of OHC in organizing oil international trades. First, we present how commodity traders modify international trade flows, second, we focus on the impact of centrality measures.

OHCs modify trade flows

The gravity models developed here largely conclude on different trade patterns for the exports of OHCs compared to oil producing countries. We report significant changes in the results of models including dummy variables for trade flows involving physical traders relatively to our base model presented in the three first column of tables 3.3 and 3.4.

OHCs' exports rely on their strong international relationships.

The negative impact of the distance and a positive impact of the GDP on the value of trade flows in both crude and refined oil base models is consistent with the literature. Nevertheless, our subsample already exhibits some changes in the base models. OHC are highly linked to their trading partners and usually share strong commercial relationship with them. On the contrary, oil producing countries are not uniformly spread around the world and mainly trade with countries to which they can supply their output. But these markets or countries are not necessarily close to them. As a consequence, we find a negative sign for the free trade agreements variable in the full sample model and in the sub-model on producers' exports in table 3.3 and 3.4. Oil producing countries are located in very specific areas and do not necessarily have trade agreements with the whole set of importing countries. On the contrary, OHCs are partly characterized by their strong commercial relationships with its partners. They allow countries to which they are connected to access oil product. For similar reasons, the contiguity variable is significantly positive in table 3.4. Oil producing countries do not necessarily share common frontier with their trading partners while OHC can share frontiers with major oil consuming market, as is the case for Netherland and Belgium with Germany and France. A strong relationship can also explain why the share of a common language have a positive sign for crude oil OHC export and a negative one for oil producing countries' exports.

OHCs aggregate crude oil trade flows and redirect them to consuming markets as a crude or refined product.

With regard to the model including OHC dummy variables, crude and refined oil models present some disparities.

In the crude oil models (table 3.3), the coefficients of base model variables are quite similar. Nevertheless, the negative sign on the OHC_o variable may seem counter-intuitive considering the hub gravity assumption that we defend here. It indicates that the value of crude oil export decreases when the exporter is an OHC. Nevertheless, this result is perfectly coherent with the idea that oil producing countries export large volume of crude

oil to a relatively low number of destinations. Presumably they export large volumes to OHC considering the positive sign of OHC_d variables in the three cases studied here. Therefore, the role of OHC is to gather crude oil export flows from producers to redirect them toward a wide variety of consuming markets in a smaller volume. We can also see that the positive sign of crude oil trade flows from OHC to other OHC indicates that these countries share a high volume of trade flows. Thus, it seems that they are able to allocate trade flows to regions where flows are the most needed.

In the refined oil model (table 3.4), we can underline some differences. In the sub-model with producers' exports the GDP of the exporting countries has a negative impact of the value of exports. Again, OHC_d has a positive sign but the value of export increases when the origin country is an OHC. This result must be considered with the findings of table 3.3. As we presented in chapter 2, commodity traders own more and more blending and refining facilities which are frequently located close to port infrastructure to ease trade. Therefore, we can expect the pattern of trade to be explain as follow: crude oils are imported from oil producers by OHC which reexport them as refined products. It leads OHC to export higher volume of refined products than crude oil producers that focus on the upstream segment.

3.3.6 The introduction of centrality measures

Finally, in order to capture the specific role of OHC in organizing international trade, we choose to include centrality measures from the graph theory:

$$X_{od,t} = \beta_0 + \beta_1 GDP_{o,t} + \beta_2 GDP_{d,t} + \beta_3 C_{o,t} + \beta_4 C_{d,t} \beta_5 OHC_o + \beta_6 OHC_d \\ + \beta_7 contig_{od} + \beta_8 comlang_{od} + \beta_9 colony_{od} + \varepsilon_{od,t}$$

C_o and C_d factors are centrality measures for exporters and importers respectively. We choose three centrality measure.

- The transitivity index is used as a proxy for intermediation services between oil producing and oil consuming countries. A higher index indicates that the country's partners do not trade together at time t .
- The eigenvector centrality indicates the importance of a country while taking into account to the importance of its trading partners. This measure is relevant to value a country's trading links and its capacity to create a network including the main actors of the sector.
- The betweenness centrality is another measure of intermediation based on the eigenvector. It shows the ability of a country to be in-between two countries.
- The hub score indicates the relative importance of country i in the international trade network. This measure is relevant to capture the influence of major oil producers and OHC trading high volumes.
- The authority score measures connections to hubs. The more a country is connected to the main player of the network and the higher is its authority score. We can therefore expect the score to be a useful proxy of OHC's activities considering reexporting countries must be connected to both main producing and consuming markets.

Table 3.5: PPML panel estimates of crude oil bilateral trade flows on centrality indicators. Sample Period 1998-2016

| | C : Transitivity index | | | C : Eigenvector centrality | | | C : Betweenness centrality | | |
|--------------------|--------------------------|------------------------|-------------------------|------------------------------|------------------------|------------------------|------------------------------|--------------------------|-------------------------|
| | Full sample | Producers | OHC | Full sample | Producers | OHC | Full sample | Producers | OHC |
| (Intercept) | -0,7609*** (0,1346) | -0,9256*** (0,1597) | 0,3888** (0,1815) | -0,3019*** (0,1112) | -0,3929*** (0,1238) | 0,3997** (0,1740) | -0,3479*** (0,1102) | -0,4214*** (0,1242) | 0,4093** (0,1738) |
| dist | -0,8808*** (0,0375) | -0,8740*** (0,0421) | -0,6216*** (0,0751) | -0,8166*** (0,0384) | -0,8111*** (0,0440) | -0,6894*** (0,0767) | -0,8340*** (0,0388) | -0,8158*** (0,0435) | -0,7329*** (0,0694) |
| GDP_o | 0,0730*** (0,0261) | 0,0867*** (0,0227) | 0,2317*** (0,0629) | 0,2524*** (0,0236) | 0,8260*** (0,0277) | 0,5593*** (0,0678) | 0,2571*** (0,0273) | 0,2928*** (0,0283) | -0,1981** (0,0960) |
| GDP_d | 0,9586*** (0,0228) | 0,9902*** (0,0238) | 0,7757*** (0,0381) | 0,9747*** (0,0213) | 1,0034*** (0,0217) | 0,6735*** (0,0415) | 1,0375*** (0,0225) | 1,0587*** (0,0232) | 0,8255*** (0,0456) |
| C_o | -1,4405*** (0,0959) | -1,4613*** (0,0924) | -14,2625*** (1,5000) | -1,9159*** (0,5812) | -2,5841*** (0,9990) | -1,4576*** (0,3524) | -7,51E-05*** (0,0000) | -1,30E-04*** (0,0000) | 3,27E-04*** (0,0000) |
| C_d | -0,7041*** (0,1900) | -0,6639*** (0,2055) | -1,0290** (0,4959) | -0,5805*** (0,1221) | -0,5275*** (0,1254) | 0,1480 (0,2873) | -1,57E-04*** (0,0000) | -1,45E-04*** (0,0000) | -1,26E-04** (0,0001) |
| OHC_o | -1,6967*** (0,1141) | | | -2,2590*** (0,0992) | | | -2,2518*** (0,0959) | | |
| OHC_d | 0,5740*** (0,0774) | 0,5034*** (0,0792) | 1,4409*** (0,1605) | 0,7409*** (0,0806) | 0,6640*** (0,0844) | 1,3403*** (0,1589) | 1,0236*** (0,0850) | 0,9251*** (0,0865) | 1,4869*** (0,1769) |
| FTA | -0,4104*** (0,0967) | -0,4126*** (0,1040) | 0,8074*** (0,1964) | -0,4332*** (0,0815) | -0,4488*** (0,0861) | 11,348*** (0,1845) | -0,4313*** (0,0843) | -0,4496*** (0,0907) | 1,0088*** (0,1908) |
| contig | 0,0281 (0,1198) | -0,0377 (0,1303) | 1,2919*** (0,2268) | 0,1803* (0,0981) | 0,1114 (0,1024) | 0,7633*** (0,2281) | 0,1485 (0,0998) | 0,1061 (0,1047) | 0,7144*** (0,2183) |
| comlang | -0,7609*** (0,1346) | -0,9256*** (0,1597) | 0,3888** (0,1815) | -0,3019*** (0,1112) | -0,3929*** (0,1238) | 0,3997** (0,1740) | -0,3479*** (0,1102) | -0,4214*** (0,1242) | 0,4093** (0,1738) |
| colony | 0,2815** (0,1268) | 0,3533** (0,1404) | -0,1142 (0,2170) | -0,0383 (0,1313) | 0,0017 (0,1470) | 0,5637*** (0,1823) | 0,1371 (0,1183) | 0,1909 (0,1318) | 0,5795*** (0,1955) |
| Time fixed effects | Yes | yes | yes | Yes | yes | yes | Yes | yes | yes |
| Pseudo LLh | -1,47E+10 | -1,31E+10 | -1,035E+09 | -1,55E+10 | -1,39E+10 | -1,15E+09 | -1,53E+10 | -1,38E+10 | -1,07E+09 |
| \bar{R}^2 | 0,4931 | 0,5272 | 0,3839 | 0,3761 | 0,3787 | 0,3482 | 0,4074 | 0,4077 | 0,4108 |
| Obs. | 72270 | 50171 | 22099 | 72270 | 50171 | 22099 | 72270 | 50171 | 22099 |

*, ** and *** indicate 10%, 5% and 1% significance levels
Robust standard errors in parentheses

Table 3.6: PPML panel estimates of refined oil bilateral trade flows on centrality indicators. Sample Period 1998-2016

| | C : Transitivity index | | | C : Eigenvector centrality | | | C : Betweenness centrality | | |
|--------------------|------------------------|------------------------|------------------------|----------------------------|------------------------|------------------------|----------------------------|---------------------------|---------------------------|
| | Full sample | Producers | OHC | Full sample | Producers | OHC | Full sample | Producers | OHC |
| (Intercept) | 0,0340 (0,0886) | -0,1090 (0,0833) | 0,1749 (0,1367) | 0,0669 (0,0938) | 0,2659*** (0,0771) | 0,0796 (0,1176) | -0,0837 (0,0816) | -0,2673*** (0,0792) | -0,0617 (0,1212) |
| dist | -0,5679*** (0,0475) | -0,9044*** (0,0473) | -0,3873*** (0,0665) | -0,5868*** (0,0424) | -0,8375*** (0,0436) | -0,4234*** (0,0572) | -0,7485*** (0,0463) | -0,9460*** (0,0464) | -0,6153*** (0,0715) |
| GDP _o | 0,1732*** (0,0305) | 0,3963*** (0,0411) | 0,2289*** (0,0424) | 0,3803*** (0,0270) | 0,8260*** (0,0277) | 0,0258 (0,0404) | 0,1160*** (0,0241) | -0,5637*** (0,0255) | -0,0936*** (0,0299) |
| GDP _d | 0,4997*** (0,0191) | 0,4896*** (0,0255) | 0,5741*** (0,0257) | 0,4578*** (0,0137) | 0,5065*** (0,0163) | 0,4069*** (0,0194) | 0,4673*** (0,0128) | 0,4517*** (0,0177) | 0,4501*** (0,0181) |
| C _o | 3,8901*** (0,3874) | 3,4437*** (0,4432) | -1,9548* (1,1039) | -0,4196*** (0,1303) | -4,1530*** (0,4472) | 0,9976*** (0,1845) | 8,20E-05*** (5,22E-06) | 8,58E-05*** (9,03E-06) | 9,37E-05*** (5,31E-06) |
| C _d | -0,0657 (0,2209) | 0,0519 (0,2884) | -1,1555*** (0,3019) | 0,4870*** (0,1212) | 0,0265 (0,1182) | 1,0349*** (0,1683) | 3,32E-05*** (4,91E-06) | 3,14E-05*** (5,66E-06) | 4,44E-05*** (7,61E-06) |
| OHC _o | 0,0318 (0,0599) | | | 0,4931*** (0,0558) | | | -0,0510 (0,0579) | | |
| OHC _d | 1,0634*** (0,0544) | 1,4495*** (0,0689) | 0,8259*** (0,0786) | 0,9632*** (0,0687) | 14806*** (0,0773) | 0,5715*** (0,0926) | 0,8852*** (0,0626) | 1,2481*** (0,0813) | 0,4420*** (0,0836) |
| FTA | -0,1292 (0,1065) | -0,6798*** (0,0982) | 0,4485*** (0,1430) | -0,0915 (0,1001) | -0,3782*** (0,0850) | 0,4340*** (0,1415) | -0,0969 (0,1013) | -0,5449*** (0,0946) | 0,3026** (0,1477) |
| contig | 0,7716*** (0,1308) | -0,1078 (0,1093) | 1,2266*** (0,2139) | 0,7516*** (0,1149) | 0,1206 (0,0873) | 0,9005*** (0,1797) | 0,5818*** (0,1234) | -0,2441** (0,1122) | 0,9942*** (0,2062) |
| comlang | 0,0340 (0,0886) | -0,1090 (0,0833) | 0,1749 (0,1367) | 0,0669 (0,0938) | 0,2659*** (0,0771) | 0,0796 (0,1176) | -0,0837 (0,0816) | -0,2673*** (0,0792) | -0,0617 (0,1212) |
| colony | 0,0057 (0,0779) | 0,1963* (0,1110) | 0,0054 (0,1122) | -0,0401 (0,0871) | 0,1094 (0,1053) | 0,3053** (0,1290) | 0,1737** (0,0813) | 0,4021*** (0,1073) | 0,4026*** (0,1164) |
| Time fixed effects | yes | yes | yes | yes | yes | yes | yes | yes | yes |
| Pseudo LLh | -8,218E+09 | -3,91E+09 | -3,89E+09 | -8,33E+09 | -3,80E+09 | -3,80E+09 | -7,94E+09 | -3,91E+09 | -3,41E+09 |
| R ² | 0,3393 | 0,4527 | 0,3366 | 0,3459 | 0,4542 | 0,3483 | 0,3634 | 0,4630 | 0,3975 |
| Obs. | 72270 | 50171 | 22099 | 72270 | 50171 | 22099 | 72270 | 50171 | 22099 |

*, ** and *** indicate 10%, 5% and 1% significance levels
Robust standard errors in parentheses

Centrality indices

Centrality measures also describe commodity traders' contribution to the world market. First, the transitivity variable displays variable measures depending on the sample and the petroleum product. A negative coefficient indicates that the lower the probability that the country's partners trade directly with each other, the larger the volume of oil traded by the intermediary. We thus observe negative coefficients in each of the three cases considered for crude and refined. Moreover, we note that this result is significantly negative for both exporters and importers. This result is the very characteristic of OHCs that is expected to link producers and consumers of hydrocarbons. With respect to refined oil trades flows, the negative relationship is only found for OHCs' exports.

Second, the eigenvector centrality variable has ambivalent effects depending whether the trade flows concern crude or refined products. It has a significant negative impact on the value of crude trade flows for both importers and exporter, with the exception of importers in the OHC export sub-model in which the coefficient is not significant. It shows that "central" countries can diversify supply and outlets to reduce trading risks. Conversely, countries which have a small number of trading partner have no choice but to trade larger volume. Refined oil trades flows exhibit different results. OHCs' exports are positively impacted by the eigenvector centrality.

Third, the betweenness centrality provide ambiguous results. Producers' exports reduce with their centrality position in the model. However, we do not give a lot of credit to this result considering that the most producers have a low betweenness centrality. On the contrary, OHCs' exports are positively linked to their centrality measure, which is coherent to our expectations and the results on the transitivity index. The centrality results for importing countries are coherent with our findings on the eigenvector variable. The negative sign indicates that importing countries with a core position in the network can diversify the origin of their supplies. Once again, the results differ significantly with

respect to refined oil trade flows. We find a positive relationship indicating that countries that can serve as intermediaries between countries export more and trade more with countries that are also central.

As a consequence, based on both the eigenvector and the betweenness centrality measures, it appears that crude oil trade flows are more diversified when the exporter and the destination of the export flow are considered as central. Refined oil trade flows have a different pattern of trade. Central countries exhibit a larger gravity impact to gather and trade large volume of refined products.

3.4 Conclusion

We offered to reconcile the centrality measures of graph theory with the traditional gravity equation for both crude and refined oil trade flows. The network analyses provided us measures to identify the hub countries in the international oil trade web. We could verify that hub countries are located in every major demanding markets. These places coincide with the concentration of commodity traders in countries with major port infrastructure. Therefore, we assume our centrality measures could be used to value the ability of traders to be an intermediary in international trades.

In order to test influence of hub countries in the pattern of trade flow, we built a gravity equation with two sub-samples depending on the nature of the exporter. We concluded that hub countries have a significant impact on the structure of international trade flows. Crude oil producers trade larger volume than hub countries which is coherent with their role to feed small market that cannot trade directly with producers. In the refined oil trade web, hub countries export larger volume, which can be explained by the refining facilities located in these countries. Furthermore, we found a strong gravity effect that indicate that trade in destination to hub countries significantly raise trade flows for both crude and refined products. The introduction of centrality measures in the second step of

our gravity model shows varying results. While a high centrality in crude oil trade flows seem to raise diversification of supplies and outlets, for refined oil, the higher centrality appears to raise trade flows.

In future works, an extension of the model could be envisaged in order to identify the characteristics that allow hub countries to modify the pattern of oil trade flows. We can imagine that the ownership of port infrastructures, access to a more developed credit market to finance large trade flows or the development of derivative markets to manage price risks are among the variables that could explain our results.

Appendix

Appendix A: Top 30 countries for every average score in 2005 and 2010

Table 3.7: Top 30 countries for every average score on a yearly basis from 2000 to 2016

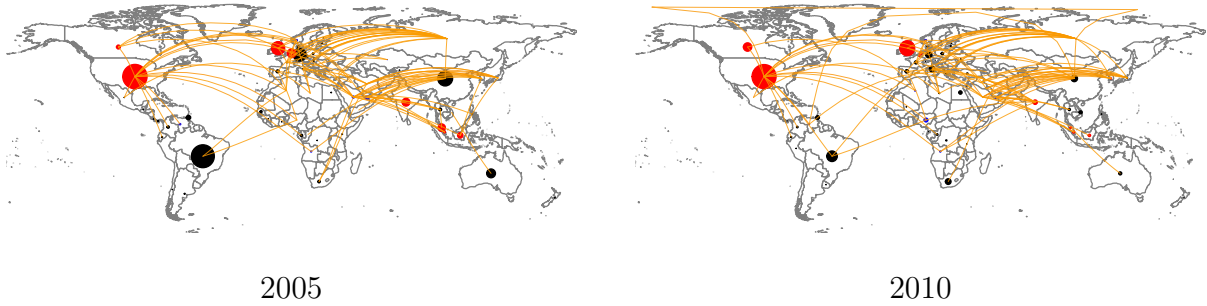
| Top 30 countries for every score | | | | | | | | | | | |
|----------------------------------|---------------|------------|-----------------|------------|---------------|------------|---------------|------------|------------------------|------------|---------------|
| ISO code | Hub score | ISO code | Authority score | ISO code | Transitivity | ISO code | Eigenvector | ISO code | Betweenness centrality | ISO code | ratio |
| CAN | 0.9316 | USA | 0.9588 | USA | 0.1107 | USA | 0.8824 | USA | 18469.94 | TUN | 0.0959 |
| SAU | 0.9297 | JPN | 0.2780 | FRA | 0.1304 | MEX | 0.3054 | SGP | 11753.47 | LTU | 0.1079 |
| VEN | 0.5654 | CHN | 0.2224 | GBR | 0.1440 | CAN | 0.2067 | IND | 10537.06 | GBR | 0.1131 |
| MEX | 0.4898 | KOR | 0.1924 | NLD | 0.1463 | BEL | 0.1084 | NLD | 9244.35 | CIV | 0.1190 |
| NGA | 0.3968 | IND | 0.1464 | DEU | 0.1503 | NLD | 0.1072 | NGA | 5191.59 | BLR | 0.1349 |
| RUS | 0.3035 | NLD | 0.1264 | CHN | 0.1558 | DEU | 0.0955 | GBR | 5100.35 | NLD | 0.1645 |
| IRQ | 0.2719 | SGP | 0.0925 | BEL | 0.1579 | SGP | 0.0933 | DEU | 4401.82 | SGP | 0.1849 |
| AGO | 0.2158 | FRA | 0.0847 | ITA | 0.1588 | FRA | 0.0716 | MYS | 4030.47 | SVK | 0.1867 |
| ARE | 0.1987 | DEU | 0.0799 | ESP | 0.1657 | ESP | 0.0647 | CHN | 3619.00 | VNM | 0.1867 |
| KWT | 0.1976 | ESP | 0.0728 | KOR | 0.1810 | CHL | 0.0596 | ITA | 3444.94 | DNK | 0.1925 |
| DZA | 0.1914 | ITA | 0.0696 | SGP | 0.1835 | JPN | 0.0502 | MEX | 3434.88 | BRA | 0.1928 |
| GBR | 0.1890 | GBR | 0.0518 | JPN | 0.1841 | CHN | 0.0495 | KOR | 3432.94 | LVA | 0.1964 |
| NOR | 0.1409 | THA | 0.0412 | ZAF | 0.1897 | GBR | 0.0483 | RUS | 3142.94 | MYS | 0.0197 |
| COL | 0.1402 | CAN | 0.0383 | TUR | 0.1907 | BRA | 0.0456 | ARE | 2966.94 | EST | 0.0189 |
| IRN | 0.1319 | ZAF | 0.0374 | CAN | 0.1972 | IDN | 0.0361 | FRA | 2876.65 | IDN | 0.2551 |
| KOR | 0.0896 | BRA | 0.0335 | IND | 0.1993 | GTM | 0.0356 | AUS | 2508.47 | FIN | 0.2669 |
| NLD | 0.0874 | BEL | 0.0308 | GRC | 0.2066 | GIB | 0.0352 | IRN | 2188.06 | GEO | 0.2763 |
| QAT | 0.0819 | IDN | 0.0293 | CHE | 0.2092 | PAN | 0.0349 | BRA | 2137.06 | PER | 0.2807 |
| ECU | 0.0774 | GRC | 0.0239 | RUS | 0.2116 | COL | 0.0345 | TTO | 2105.94 | BEL | 0.2964 |
| BRA | 0.0724 | POL | 0.0234 | AUS | 0.2129 | IND | 0.0312 | SAU | 2039.29 | ROU | 0.2972 |
| OMN | 0.0671 | TUR | 0.0212 | ARE | 0.2176 | KOR | 0.0294 | SWE | 1691.76 | BGR | 0.3020 |
| BEL | 0.0574 | PAK | 0.0202 | SWE | 0.2301 | AUS | 0.0276 | ZAF | 1634.76 | BOL | 0.3124 |
| LBY | 0.0510 | PHL | 0.0189 | MEX | 0.2459 | BHS | 0.0263 | FIN | 1519.18 | COD | 0.3131 |
| IDN | 0.0496 | SWE | 0.0162 | MYS | 0.2471 | MYS | 0.0262 | ESP | 1413.82 | SWE | 0.3203 |
| GAB | 0.0490 | MYS | 0.0159 | UKR | 0.2472 | PER | 0.0254 | COD | 1360.41 | PNG | 0.3283 |
| IND | 0.0431 | BLR | 0.0150 | BRA | 0.2476 | HKG | 0.0251 | TUR | 1235.35 | EGY | 0.3315 |
| MYS | 0.0407 | FIN | 0.0144 | THA | 0.2489 | HND | 0.0224 | IDN | 1111.35 | ISR | 0.3421 |
| COG | 0.0392 | PRT | 0.0140 | AUT | 0.2516 | ITA | 0.0198 | CIV | 979.35 | CAN | 0.3473 |
| TTO | 0.0366 | BHR | 0.0127 | DNK | 0.2548 | DOM | 0.0197 | VEN | 839.12 | AUS | 0.3540 |
| KAZ | 0.0344 | AUS | 0.0116 | BGR | 0.2603 | ECU | 0.0189 | BEL | 815.29 | MLT | 0.3561 |

Oil hub countries are in bold

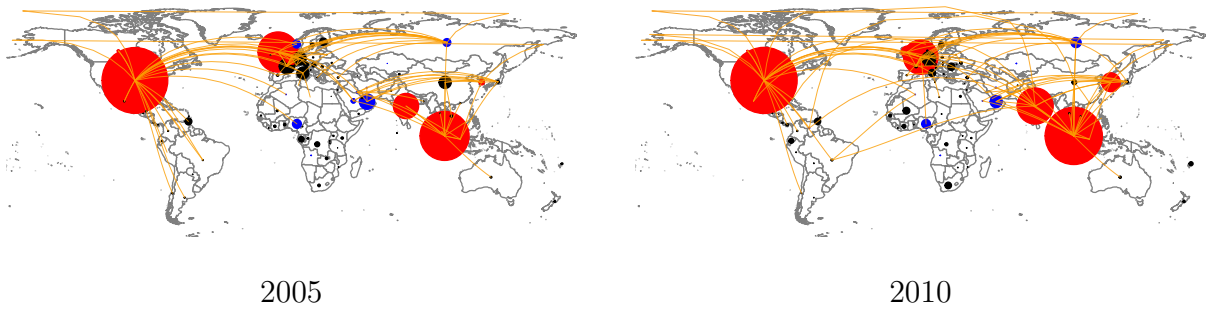
Appendix B: Crude and refined oil trade web (in USD), using betweenness centrality

Figure 3.4: Crude and refined oil trade web (in USD), using betweenness centrality

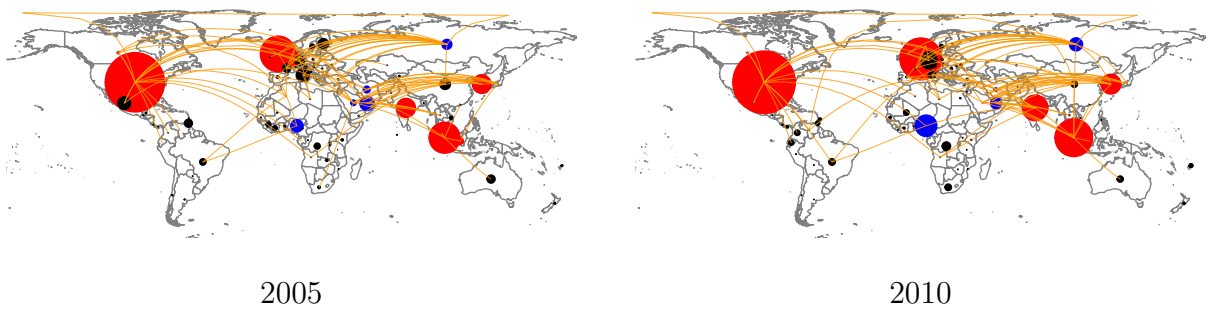
(a) Top 100 crude oil trade flows (in USD)



(b) Top 100 refined oil trade flows (in USD)



(b) Top 100 of the sum of crude and refined oil trade flows (in USD)



Size of the circle are equal to the betweenness centrality divided by 3000.

Oil hub countries are in red, major oil producers in blue and others in black.

Chapter 4

Commodity traders and market integration

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4.1 Introduction

Commodity traders's duty that is to reconcile in time and space producers and end-users around the world actually have more than one application. Their skills and infrastructures allow them to link producers to international markets. Indeed, a first barrier to the realisation of a commodity international market is simply that producers may not have access to the later. Transaction costs on the international market are supposed to be substantially higher than the one on local markets. Thus, without intermediaries, the producers might not have the incentive to trade out of their local market because of the costs associated to risk management. They must deal with international price references instead of the local one and also face exchange rate and freight risk, among others.

Thus, a naïve view would state that there is no reason why producers would necessarily benefit from trades on the international market. The negative impact of exchange rate risk on international trade has been widely documented and applications to the oil industry seems to be consistent with this literature. Indeed, although crude oil trade is usually denominated in US dollar, production costs can be paid in local currency. In 1973, Ethier^[92] showed that risk-averse firms' volume of trade decreases with exchange rate volatility. Demers (1991^[80]) demonstrated that firms do not have to be risk-averse to validate this conclusion. Indeed, he stated that because of the irreversibility of investment costs, uncertainty decreases production level and international trade over time. Rose (2000^[235]) and Rose and Van Wincoop (2001^[236]) highlighted the existence of a national money barrier in European trade in order to promote the currency union. The use of derivative market to hedge the currency risk tends to minimize the effect of volatility on trades. Grier and Smallwood (2007^[115]) concluded that the negative effect of real exchange rate volatility on trade is more likely to be observed in developing countries. Tenreyro (2007^[259]) even rejected traditional models used to identify the volatility effect on trades and rather used the PPML estimator and concluded that the nominal exchange rate volatility had no effect on trade. Broad and Romalis (2011^[39]) analyzed the twofold

causality between the exchange rate volatility and the volume of trade and conclude on a negative impacted coming from the first to the second. Their results are stronger when trades involve exporters from developing countries among which we can find commodity exporters. They are assumed to be more risk-averse because they are less able to hedge against the real exchange rate volatility. Thus, the modest results on the relationship between exchange rate volatility and trade would mainly concern developed countries. In our case, we must remark that commodity producing countries, because of their lack of skills and financial infrastructure in many cases, might still face a high negative impact of the exchange rate on their trade flows.

As a consequence, the role of commodity traders is essential to transfer their skills to commodity producers. This is actually in times of high uncertainty that they might be the most valuable in the industry. Their close relationship with derivatives markets as well as their network extended on both producing and demanding markets enables them to hedge price and currency risk in exchange for commissions. It makes them the agent that moves commodities from local to international markets. Consequently, contrary to basic expectations on international trades, we can expect that international price, but also exchange rate, volatility would increase the volume of international trade because it is likely to increase trade with physical traders to hedge these risks.

Moreover, in this chapter, we support the idea that connecting local producers to the international market contributes to the oil market integration. Indeed, regional price differences are explained by local changes of the fundamentals, in terms of quality, carrying or transport costs. We have seen in the chapter 2 that any price spread that does not correspond to these fundamentals creates arbitrage opportunities that traders exploit until it disappears. Commodity traders' core business, that is to buy the commodity where it is the cheapest to resell it at the highest price, must reduce regional unbalances. By doing so, they also became an intermediary between crude oil suppliers located in different regional markets. Therefore, commodity traders have a critical contribution to ensure the

market integration and create a global oil market. They can gather the information from varying producing and demanding markets.

Our contribution to the analysis of the oil market integration is to analyze the long-term relationship between regional oil prices by using a graph analysis. Numerous academic studies, mainly relying on the cointegration analysis, prove the integration for commodities that can be traded at the international level, like oil products. In this chapter, we offer to verify the integration of crude oil market by observing the evolution of the crude oil prices correlation over the past years.

In this chapter, we aim to demonstrate that physical traders are critical players to connect regional market and ensure the oil market integration, especially in times of high uncertainty. This fourth chapter is organized as follows. First, we present a two-step theoretical model demonstrating the role of physical traders to connect local producers to the international market. Second, we analyze the oil market integration by using tools from the graph analysis.

4.2 The role of commodity traders in connecting local producers to the international market¹

The primary ambition of this section is to show how commodity traders can modify international trade flows by bringing local producers to take part into the international trade web. This specific approach requires to take into account the existence of futures markets which are inextricably linked to physical traders' activities. In order to hedge their trading margins, traders indeed make extensive use of this type of derivative products that enable them to buy at a high price and possibly resell them at a lower price while maintaining

¹The model presented in this first section comes from the article co-authored with Raphaël Chappini and Yves Jégourel and published in *Economics Bulletin* (Volume 39, Issue 3, pages 2002-2013) in 2019: *Explaining the role of commodity traders: A theoretical approach*^[58]

a profit margin. In this respect, it is crucial, to underline that the existence of a futures market not only influences the implementation of price risk management strategies, but also has important consequences on the formation of commercial prices between the various players of the value chain. Indeed, it should be recalled that commodity futures markets are not “solely” intended to offer price risk management tools. An organized financial market offers, in fact, a public price reference, observable by all, without costs and without delay. As summarised by Black (1976^[34]), “looking at futures prices for various transaction months, participants in this market can decide on the best times to plant, harvest, buy for storage, sell from storage, or process the commodity”. Considered as a fair price, this reference also serves, in most “large” markets, as a basis for negotiation for commercial transactions between producers and physical traders, traders and end-users, or even between producers and end-users. Taking into account both the trader and the availability of derivative products (i.e futures contracts) radically changes the reality of international trade flows. The second ambition of this first section is to demonstrate it. Using a simple cobweb model based on Mitra and Boussard (2012^[202]), we examine the impact both of exchange rate volatility and commodity price level and volatility on the magnitude and timing of export flows of a commodity producer who can sell his product either to domestic and foreign end users or to an international physical trader.

Our results differ from the conventional literature on international trade in several ways and highlight interesting theoretical elements which can be used to understand the reality of export flows. First, as expected, we show that an increase in commodity prices leads to an increase in demand from the trader thanks to his particular hedging strategy and to his ability to benefit from an increased discount on commodity prices. Second, while an increase in the exchange rate volatility reduces export flows from the producer to the foreign end-user when no hedging strategies are implemented, the presence of a trader changes this relationship. The effect indeed becomes undetermined. Third, an increase in the expected international/futures prices volatility may increase exports which could appear as paradoxical. The hedging strategy is similar to an arbitrage between a flat price

risk and a basis risk which, although theoretically low, can cause the actual purchase or sale price of the commodity to vary (Brennan, 1958^[38]; Fama and French, 1988^[96]). To consider, from this perspective, that the existence of derivatives fully mitigates *per se* the risk linked to commodity price volatility would be inaccurate. Moreover, if one accepts the very common assumption that the use of futures contracts makes it possible to know whether the storage activity will be profitable or not, any uncertainty about the level of future prices may indeed lead producers to sell immediately and therefore, in all likelihood, to export, rather than to store. Our article is structured as follows: we specify in a first part the assumptions of our two-period cobweb model that we solve in a second part by considering successively the producer's export strategies and the corresponding trader's and buying & selling strategies. We then conclude.

Assumptions

Let's assume an open economy with a local producer operating in a given commodity industry, national and foreign end-users, and an international physical trader. The latter buys a given product from the producer only in period 1 and sells it to the end-user only in period 2. We consider a two-period model ($t = 1, 2$) where production is given (i.e. determined in period 0, which is not considered in this model). The whole production denoted \bar{Q} is available in $t=1$ and can be bought in the two periods (i.e. in $t = 1$ and in $t = 2$). However, we assume that demand from end-users only appears in period 2 and that there is no storage behavior from the end-users that could have led them to buy in period 1 for a use in period 2. In period 2, the producer can either sell his products to the national end-user or to the foreign end-user (exports). We consider that in $t = 1$, the producer can only sell his products to the physical trader. One key element can justify this assumption: the physical trader is able to buy the commodity whatever the price in $t = 1$ ². Thus, all flows from the producer to the physical trader, or from the producer to the foreign end-user are considered as exports. Furthermore, we assume that trades to foreign end-users and physical traders (exports) are all denominated in USD.

²As it is demonstrated in the following model.

Since the producer can only sell to the international physical trader, we have only one possible price in period 1 which is closely related to the international benchmark and is equal to, in the producer's currency:

$$P_1^{Cash(P,T)} = e_1 P_{1,2}^F - \alpha \quad (4.1)$$

Where $P_1^{Cash(P,T)}$ is the price paid by the physical trader to the producer. As we consider the decision process in period 1, the futures price $P_{1,2}^F$ is observed by both the producer and the international physical trader. $\alpha > 0$ is considered as a variable capturing both the physical trader profit margin on the buy-side and transportation costs.

In period 2, the producer can sell to the national end-user or to the foreign end-user. Two prices are therefore available:

$$\begin{cases} \hat{P}_2^{Cash(P,EU)} = \theta \hat{P}_2^I \\ \hat{P}_2^{Cash(P,EU^*)} = \hat{e}_2 \hat{P}_2^I \end{cases} \quad (4.2)$$

Where \hat{P}_2^I is the expected international price in t=2 ($\hat{P}_2^I = \hat{P}_{2,3}^F$)³. Both the international price and the future price are denominated in USD. We assume that it is the currency used for international trade in the model. However, both agents have to form expectations on prices in period 2, that are $\hat{P}_2^{Cash(P,EU)}$, the expected price paid by the national end-user to the the producer, and $\hat{P}_2^{Cash(P,EU^*)}$, the expected price paid by the foreign end-user to the producer. θ is a parameter and \hat{e}_2 is the expected nominal exchange rate (direct quotation) for the next period. Although the exchange rate does not appear explicitly in the first equation, these two prices are denominated in the national currency of the domestic producer. Because it is an exchange rate, e is a strict conversion variable between a foreign price and a national price, whereas θ must be understood as a parameter which

³Hats are used to represent next-period expected values for t=2, $\hat{x} = E[x]$

reflects the dissemination of an international price considered as the reference for setting global prices to national price. We assume that the producer is not able to rely on the futures market for hedging purposes. On the contrary, the physical trader has a full access to futures market in order to hedge his intermediation margin. He buys from the producer all the excess supply that is not stored by the producer.

The model

Stage one: The producer determines the optimal allocation between selling to the local end-user and selling to the foreign end-user in period 2

As in Mitra and Broussard (2012^[202]), the producer is risk adverse and myopic, he maximizes the expected utility from his sales to end-users at the end of the period 2, meaning that we need to identify the expected quantity traded to national end-users $\hat{Q}_2^{P,EU}$, and the expected quantity is traded to foreign end-users \hat{Q}_2^{P,EU^*} . By assuming that the producer can sell to the commodity trader only in period 1, we have $\hat{Q}_2^{P,EU} = \hat{q}_2^{P,EU} (\bar{Q} - Q_1^{P,T^S})$ and $\hat{Q}_2^{P,EU^*} = \hat{q}_2^{P,EU^*} (\bar{Q} - Q_1^{P,T^S})$, in which Q_1^{P,T^S} is the production supplied to the commodity trader in period 1, thus, $(\bar{Q} - Q_1^{P,T^S})$ is the remaining production available for sales in period 2. $\hat{q}_2^{P,EU}$ and \hat{q}_2^{P,EU^*} are shares of the production sold to national end-users and foreign end-users, respectively, thus, $\hat{q}_2^{P,EU} + \hat{q}_2^{P,EU^*} = 1$. The average utility function per unit of commodity in t=2, \hat{y}_2 , is based on the producer's revenue per unit in his local currency:

$$\hat{y}_2 = \hat{q}_2^{P,EU} \theta \hat{P}_2^I + \hat{q}_2^{P,EU^*} \hat{e}_2 \hat{P}_2^I \quad (4.3)$$

The utility function is based on a classic mean-variance equation:

$$\hat{U}_2 = \hat{y}_2 - \frac{1}{2} A_P Var(\hat{y}_2) \quad (4.4)$$

Where A_P is the producer's risk aversion coefficient. Based on the proofs in Appendix B, it gives:

$$\hat{U}_2 = \left(q_2^{P,EU} \theta \hat{P}_2^I + q_2^{P,EU*} \hat{e}_2 \hat{P}_2^I \right) - \frac{1}{2} A_P \left((\hat{q}_2^{P,EU})^2 \theta^2 \hat{\sigma}_P^2 + (\hat{q}_2^{P,EU*})^2 \left[\hat{e}_2^2 \hat{\sigma}_P^2 + (\hat{p}_2^I)^2 \hat{\sigma}_e^2 + \hat{\sigma}_e^2 \hat{\sigma}_P^2 \right] + 2 \hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e}_2 \hat{\sigma}_P^2 \right)$$

Where $\hat{\sigma}_P^2$ and $\hat{\sigma}_e^2$ are the expected future price volatility and the expected exchange rate volatility respectively. The producer maximizes his utility function. The first order condition (FOC) could be represented as:

$$\frac{\partial \hat{U}_2}{\partial \hat{q}_2^{P,EU}} = 0$$

Let B be equal to:

$$B = e^2 \hat{\sigma}_P^2 + \left(\hat{P}_2^I \right)^2 \hat{\sigma}_e^2 + \hat{\sigma}_e^2 \hat{\sigma}_P^2 \quad (4.5)$$

The FOC leads us to:

$$\hat{q}_2^{P,EU} = \frac{\theta \hat{P}_2^I - \hat{e}_2 \hat{P}_2^I + A_P (B - \theta \hat{e}_2 \hat{\sigma}_P^2)}{A_P (\hat{\sigma}_P^2 \theta^2 + B - 2\theta \hat{e}_2 \hat{\sigma}_P^2)} \quad (4.6)$$

Our aim is to investigate both the impact of exchange rate volatility and futures price volatility on exports flows.

Proposition 1 *An increase in exchange rate volatility has a negative impact on producers' export flows to foreign end-users in $t=2$.*

We compute the two partial derivatives of $\hat{q}_2^{P,EU}$. First, we show that:

$$\frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_e^2} = \frac{A_P \left[(\hat{P}_2^I)^2 + \hat{\sigma}_P^2 \right] (\theta - \hat{e}_2) \left(A_P \hat{\sigma}_P^2 \theta - \hat{P}_2^I \right)}{A_P^2 \left(\hat{\sigma}_P^2 \theta^2 + B - 2\theta \hat{e}_2 \hat{\sigma}_P^2 \right)^2} \quad (4.7)$$

Note that the denominator of Equation (7) is always positive. Thus, in order to assess the impact of exchange rate volatility on national sales, we only have to investigate the sign of his numerator. Using the fact that $\hat{q}_2^{P,EU*} + \hat{q}_2^{P,EU} = 1$, we know that $\hat{q}_2^{P,EU} \leq 1$, so we can demonstrate that⁴:

$$(\theta - \hat{e}_2) \left(A_P \hat{\sigma}_P^2 \theta - \hat{P}_2^I \right) \geq 0$$

As a consequence, we have:

$$\frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_e^2} \geq 0$$

Thus, we demonstrate that the higher the exchange rate volatility the higher the share of the sales from the producer to the national end-user. It decreases producer's exports in period 2.

Proposition 2 *An increase in the expected futures price volatility **may** have a positive impact on commodity export flows from the producer to the international end-user in $t=2$.*

In a second step, we investigate the relationship between international price volatility and exports. Therefore, we compute the following partial derivative⁵:

$$\frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_P^2} = \frac{-(\theta - \hat{e}_2) P_2^I A_P \left\{ (\hat{e}_2^2 + \hat{\sigma}_e^2) + \theta (\theta - 2\hat{e}_2) + A_P (\hat{P}_2^I)^2 \theta \hat{\sigma}_e^2 \right\}}{A_P^2 [\cdot]^2} + \frac{A_P^2 \hat{\sigma}_P^2 \theta \left((2\theta \sqrt{\hat{e}_2} - \sqrt{\hat{e}_2^3})^2 + 4\theta (\hat{e}_2^2 - \hat{\sigma}_e^2) \right)}{A_P^2 [\cdot]^2} \quad (4.8)$$

⁴See Appendix B

⁵See proofs in Appendix B.

As previously mentioned, the denominator is always positive. So in order to assess the impact of futures price volatility on national sales, we need to investigate the sign of the numerators. As the second term of the equation is strictly positive as long as $\hat{e}_2^2 > \hat{\sigma}_e^2$ ⁶, a sufficient, condition for equation (8) to be positive is that:

$$-(\theta - \hat{e}_2) \hat{P}_2^I A_p \left[(\hat{e}_2 - \theta)^2 + \hat{\sigma}_e^2 + A_p \left(\hat{P}_2^I \right)^2 \theta \hat{\sigma}_e^2 \right] \leq 0 \quad (4.9)$$

It is straightforward to see that $A_p \left[(\hat{e}_2 - \theta)^2 + \hat{e}_2 \hat{\sigma}_e^2 + A_p \left(\hat{P}_2^I \right)^2 \right] \geq 0$, so the sign of the relationship is only determined by $-(\theta - \hat{e}_2)$, given the fact that $\hat{P}_2^I \geq 0$ and $A_p > 0$. Based on their definition in section 2, both θ and \hat{e}_2 determine the sensitivity of cash prices paid by the national end-user ($\hat{P}_2^{Cash(P,EU)}$) and by the foreign end-user ($\hat{P}_2^{Cash(P,EU^*)}$), respectively, to the international price \hat{P}_2^I . For $\theta > \hat{e}_2$, the national price reacts more intensively to changes of the international price, hence $\hat{P}_2^{Cash(P,EU)}$ is more volatile than $\hat{P}_2^{Cash(P,EU^*)}$. As a consequence, the risk adverse producer decreases its sells to the national end-user. So, if $\theta > \hat{e}_2$, an increase in the expected international price volatility has a positive impact on exports, i.e both the share of sales to the foreign end-user in period 2 and the sales to the physical trader in period 1.

Stage two: The producer determines the optimal allocation between selling to the physical trader in period 1 and selling to end-users in period 2

In the first stage, we identified the expected repartition of sales in period 2, but the producers also need to determine the production supplied in $t=1$ and the production supplied in $t=2$. This time, the producer maximizes the expected utility function from his expected income (\hat{Y}) at the end of the period 2, meaning that we need to take into account both sales to commodity traders in $t = 1$ and sales to end users in $t = 2$:

$$\hat{Y} = Q_1^{P,TS} (e_1 \hat{P}_1^I - \alpha) + \hat{Q}_2^{P,EU} \theta \hat{P}_2^I + \hat{Q}_2^{P,EU^*} \hat{e}_2^{P,EU^*} \hat{P}_2^I \quad (4.10)$$

⁶Apart from extreme volatility episodes, it is reasonable to state that $\hat{e}_2^2 > \hat{\sigma}_e^2$. This condition could be understood as the squared first moment of the exchange rate being greater than the second moment of the variable e .

Furthermore, the latter equation displays a classic mean-variance utility function, as follows:

$$\hat{U}_2 = \hat{Y} - \frac{1}{2}A_P \text{Var}(\hat{Y}) \quad (4.11)$$

Where A_P is the absolute risk aversion coefficient of the producer.

It can be shown that⁷:

$$\begin{aligned} \hat{U}_2 = & Q_1^{P,TS} (e_1 P_1^I - \alpha) + (\bar{Q} - Q_1^{P,TS}) \left(q_2^{P,EU} \theta \hat{P}_2^I + q_2^{P,EU*} \hat{e}_2 \hat{P}_2^I \right) - \frac{1}{2} A_P (\bar{Q} - Q_1^{P,TS})^2 \\ & \left((\hat{q}_2^{P,EU})^2 \theta^2 \hat{\sigma}_P^2 + (\hat{q}_2^{P,EU*})^2 \left[\hat{e}_2^2 \hat{\sigma}_P^2 + (\hat{p}_2^I)^2 \hat{\sigma}_e^2 + \hat{\sigma}_e^2 \hat{\sigma}_P^2 \right] + 2 \hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e}_2 \hat{\sigma}_P^2 \right) \end{aligned} \quad (4.12)$$

To determine flows traded to the physical trader in $t=1$, the producer maximizes his utility function, the first order condition (FOC) is represented as:

$$\frac{\partial \hat{U}_2}{\partial Q_1^{P,TS}} = 0$$

The FOC leads us to:

$$Q_1^{P,TS} = \bar{Q} - \frac{\theta \hat{P}_2^I q_2^{P,EU} + \hat{e}_2 \hat{P}_2^I q_2^{P,EU*} - (e_1 P_1^I - \alpha)}{A_P \left((\hat{q}_2^{P,EU})^2 \theta^2 \hat{\sigma}_P^2 + (\hat{q}_2^{P,EU*})^2 B + 2 \hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e}_2 \hat{\sigma}_P^2 \right)} \quad (4.13)$$

For $Q_1^{P,TS} \leq \bar{Q}$.

Comment: We can see from the latter equation that the production sold in $t=2$ to end-users by the producer is:

$$\bar{Q} - Q_1^{P,TS} = \frac{\theta \hat{P}_2^I \hat{q}_2^{P,EU} + \hat{e}_2 \hat{P}_2^I \hat{q}_2^{P,EU*} - (e_1 P_1^I - \alpha)}{A_P \left((\hat{q}_2^{P,EU})^2 \theta^2 \hat{\sigma}_P^2 + (\hat{q}_2^{P,EU*})^2 B + 2 \hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e}_2 \hat{\sigma}_P^2 \right)} \quad (4.14)$$

In the numerator we have the difference between the average revenue per unit for the sales in $t=2$ $(\theta \hat{P}_2^I \hat{q}_2^{P,EU} + \hat{e}_2 \hat{P}_2^I \hat{q}_2^{P,EU*})$, and the revenue per unit for the sales in $t=1$,

⁷See proofs in Appendix C.

$(P_1^I - \alpha)$. The denominator being strictly positive and $A_p > 0$, the constraint $Q_1^{P,T^S} \leq \bar{Q}$ leads to $(\theta \hat{P}_2^I \hat{q}_2^{P,EU} + \hat{e}_2 \hat{P}_2^I \hat{q}_2^{P,EU*}) \geq (P_1^I - \alpha)$. It means that the expected average revenue for a sale in period 2 is equal or higher than the price for a sale to the physical trader in period 1. This observation makes sense because, otherwise, the producer would sell his entire production to the trader and there would not be any period 2.

As in the first stage, in order to investigate both the impact of exchange rate volatility and futures price volatility on trade flows with physical traders.

Proposition 3 *An increase in exchange rate volatility raises trade flows to physical traders.*

We compute the two partial derivatives of Q_1^{P,T^S} :

$$\frac{\partial Q_1^{P,T^S}}{\partial \sigma_e^2} = \frac{(\theta \hat{P}_2^I \hat{q}_2^{P,EU} + \hat{e}_2 \hat{P}_2^I q^{P,EU*} - (e_1 P_1^I - \alpha)) \left((\hat{q}_2^{P,EU*})^2 (\hat{P}_2^I)^2 + (\hat{q}_2^{P,EU*})^2 \hat{\sigma}_p^2 \right)}{A_P \left((\hat{q}_2^{P,EU})^2 \theta^2 \hat{\sigma}_P^2 + (\hat{q}_2^{P,EU*})^2 B + 2 \hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e}_2 \hat{\sigma}_p^2 \right)^2} \quad (4.15)$$

The denominator being strictly positive, the sign of $\frac{\partial Q_1^{P,T^S}}{\partial \sigma_e^2}$ relies only on the sign of his numerator. Moreover, it is straightforward to see that the product on the right-side of equation (13) is positive. Based on the comments on equation (13):

$$Q_1^{P,T^S} - \bar{Q} > 0 \Leftrightarrow \theta \hat{P}_2^I \hat{q}_2^{P,EU} + \hat{e}_2 \hat{P}_2^I \hat{q}_2^{P,EU*} - (e_1 P_1^I - \alpha) > 0. \text{ So } \frac{\partial Q_1^{P,T^S}}{\partial \sigma_e^2} > 0.$$

An increase of the exchange rate volatility brings the producer to sell more to the trader in $t=1$ in order to reduce his risk exposure.

Proposition 4 *An increase in the international/future price volatility raises trade flows to physical traders.*

$$\frac{\partial Q_1^{P,TS}}{\partial \hat{\sigma}_p^2} = \frac{(\theta \hat{P}_2^I q_2^{P,EU} + \hat{e}_2 \hat{P}_2^I q^{P,EU*} - (e_1 P_1^I - \alpha)) \left((\hat{q}_2^{P,EU} \theta + \hat{q}_2^{P,EU*} \hat{e}_2)^2 + (\hat{q}_2^{P,EU*})^2 \hat{\sigma}_e^2 \right)}{A_P \left((\hat{q}_2^{P,EU})^2 \theta^2 \hat{\sigma}_P^2 + (\hat{q}_2^{P,EU*})^2 B + 2 \hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e}_2 \hat{\sigma}_p^2 \right)^2} \quad (4.16)$$

Analogously to proposition 3, we have $\frac{\partial Q_1^{P,TS}}{\partial \hat{\sigma}_p^2} > 0$. The producer sells more to the trader in t=1 in order to reduce his price risk exposure.

Corollary *The introduction of physical traders may increase export flows.*

Without physical traders, an increase in the exchange rate volatility decreases export flows (Proposition 1). However, their introduction makes this statement uncertain because the production sold in period 1 to the physical trader is exported. We can see from Propositions 3 and 4 that when the producer's risk exposure raises because of an increase in the price and/or the exchange rate volatility, trade flows in period 2 should decrease. Consequently, an increase in the commodity price volatility raises international trade flows (Propositions 2 and 4 converge to the same conclusion), but the net effect of the impact of exchange rate volatility is uncertain: Propositions 1 and 3 diverge. Indeed, even if international trade flows coming from the producer to end-users in t=2 decrease, this concerns a smaller fraction of the production. So, paradoxically, an increase of the exchange rate volatility could even lead to more international trade if $-\Delta \hat{Q}_2^{P,EU*} < \Delta Q_1^{P,TS}$.

4.2.1 The commodity trader maximizes his profit

Until this point, we have discussed producer's sales by assuming that the trader will take the delivery of commodities in period 1 whatever the size of the volume sold, whereas the trader maximizes his profit. The trader expresses his own demand, Q_1^{P,T^D} , in t=1, Q_1^{P,T^D} , he buys at a price $P_1^{Cash(P,T)}$, carries the commodity held until period 2 and sells it to the foreign end-user at a price $\hat{P}_2^{Cash(T,EU*)}$. The physical trader is an international

player who trades only in USD:

$$\begin{cases} P_1^{Cash(P,T)} = P_{1,2}^F - \alpha \\ \hat{P}_2^{Cash(T,EU^*)} = \hat{P}_{2,3}^F + \hat{\beta} \end{cases} \quad (4.17)$$

α is a discount and $\hat{\beta}$ an expected premium, they represent the profit margin and the transportation costs on the buy-side and sell-side respectively. As we have assumed that the physical trader has a full access to the futures market, his long physical position in period 1 will be hedged by a short, i.e. selling, futures position according to the so-called “offset hedging” strategy. The physical trader buys in period 1 the quantity he can sell in period 2, thus $Q_1^{P,T^D} = \hat{Q}_2^{T,EU^*}$. Moreover, the notional amount of the futures contracts that are sold in period 1 (and therefore bought, i.e. cleared in period 2) is equal to the quantity of the commodity physically held between periods 1 and 2. The expected profit of the physical trader is therefore expressed as follow:

$$\hat{\Pi}^T = Q_1^{P,T^D} \left[\left(\hat{P}_2^{Cash(T,EU^*)} - \hat{P}_1^{Cash(P,T)} \right) + \left(P_{1,2}^F - \hat{P}_{2,3}^F \right) - c_T - i \right] \quad (4.18)$$

The trader’s profit depends on his hedging strategy. $Q_1^{P,T^D} P_{1,2}^F$ is his long position on the futures market in $t=1$, and $\hat{Q}_2^{T,EU^*} \hat{P}_{2,3}^F$ is his short position on the futures market in $t=2$ to hedge the price risk. As exposed in section 2, $P_{t,m}^F$ is the futures price in t for a maturity m which is used as the reference price, hence $P_t^I = P_{t,m}^F$. i is the interest rate for financing the acquisition of the commodity and c_T is the carrying cost between the two periods. As a consequence, we have:

$$\hat{\Pi}^T = Q_1^{P,T^D} (\alpha + \hat{\beta} - c_T - i) \quad (4.19)$$

In $t=1$, α and i are given on the market and c_T is a constant, thus, only $\hat{\beta}$ is uncertain. It allows us to defined the expected utility function of the commodity trader:

$$\hat{U}^T = \hat{\Pi}^T - \frac{1}{2}A_T \text{Var}(\hat{\Pi}^T) \quad (4.20)$$

Where A_T is the trader's risk aversion. Hence:

$$\text{Var}(\hat{\Pi}^T) = \text{Var}(Q_1^{P,T^D} \hat{\beta}) = (Q_1^{P,T^D})^2 \hat{\sigma}_\beta^2$$

The mean-variance utility function is:

$$\hat{U}_2^T = Q_1^{P,T^D} (\alpha + \hat{\beta} - c_T - i) - \frac{1}{2}A_T (Q_1^{P,T^D})^2 \hat{\sigma}_\beta^2$$

The commodity trader maximizes his utility function, the FOC could be represented as:

$$\frac{\partial \hat{U}_2^T}{\partial Q_1^{P,T^D}} = 0$$

$$Q_1^{P,T^D} = \frac{\alpha + \hat{\beta} - c_T - i}{A_T \hat{\sigma}_\beta^2} \quad (4.21)$$

The latter equation gives the trader's demand in $t=1$.

The condition for the physical trader to buy the commodity whatever the price in $t=1$ is met for Q_1^{P,T^S} given by equation (13) equals Q_1^{P,T^D} . It gives the discount parameter α^* :

$$\alpha^* = \frac{A_P D}{A_P D + A_T \hat{\sigma}_\beta^2} \bar{Q} - \frac{A_P D (\hat{\beta} - c_T - i)}{A_P D + A_T \hat{\sigma}_\beta^2} - \frac{A_T \hat{\sigma}_\beta (\hat{P}_2^I (\theta \hat{q}_2^{P,EU} + \hat{e}_2 \hat{q}_2^{P,EU*}) - e_1 P_1^I)}{A_P D + A_T \hat{\sigma}_\beta^2} \quad (4.22)$$

Where $D = (\hat{q}_2^{P,EU})^2 \theta^2 \hat{\sigma}_P^2 + (\hat{q}_2^{P,EU*})^2 B + 2\hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e}_2 \hat{\sigma}_p^2$.

4.2.2 The physical trader changes trade flows in the industry

Traditionally, the seller wants to trade at high prices, whereas the buyer is looking for low prices. Consequently, prices have a positive impact on supply and a negative one on demand. However, the presence of the physical trader brings to reassess these classic behaviors.

Proposition 5 *Both the producer's supply and the trader's demand react positively to international price changes.*

We can see from equation (13) that international prices do have a positive impact on the production supplied to the commodity trader in period 1:

$$\frac{\partial Q_1^{P,T^S}}{\partial P_1^I} = \frac{e_1}{A_P D} \quad (4.23)$$

We know that the denominator is always positive, thus $\frac{\partial Q_1^{P,T^S}}{\partial P_1^I} > 0$. It is an obvious result for a producer. Nevertheless, the physical trader's demand for commodities in period 1 appears to contrast with traditional industrial organization. Unlike the end-user, the trader does not take part in the production process. He is a midstream player whose activity is to buy and sell commodities at different specific times and locations. Thus, his profit margin does not depend on the spread between the cost of the input and the sale price of the output, but on the discount α and the expected premium $\hat{\beta}$. High prices lead to new trade opportunities for the physical trader. We can prove it by substituting α by α^* in equation (20):

$$Q_1^{P,T^D} = \frac{\alpha^* + \beta - c_T - i}{A_T \hat{\sigma}_\beta^2}$$

We have:

$$\frac{Q_1^{P,T^D}}{\partial P_1^I} = \frac{e_1}{A_P D + A_T \hat{\sigma}_\beta^2} > 0 \quad (4.24)$$

Moreover, we established in equation (20) that the discount α^* is neither a parameter,

neither imposed by the trader but the result of $Q_1^{P,T^S} = Q_1^{P,T^D}$. We can show that:

$$\frac{\partial \alpha^*}{\partial P_1^I} = \frac{A_T \hat{\sigma}_\beta^2 e_1}{A_P D + A_T \hat{\sigma}_\beta^2} > 0 \quad (4.25)$$

This very important result of our model is logical but also illustrates the reality of commodity international trade. A high price in period 1 fosters the producer's willingness to sell now but, all things being equal, hampers the end-users' demand. Because his price risk is fully hedged and because his profit does not depend per se on cash prices, the trader can then act as the sole counterparty to the producer and has, in this respect, all the more important bargaining power when prices are high.

4.2.3 Last remarks

This theoretical model aims to better reflect the role of physical traders and derivatives markets in the reality of commodity chains. Contrary to the theoretical corpus which tends to minimize the importance of both this type of economic agents and of the prices that form on commodity exchanges, we show that the presence of traders can significantly change the pattern of trade flows. Indeed, we achieve two significant results. First, a rise in prices increases the producer's exports thanks to the trader's capacity to absorb these volumes. Second, an increase in the volatility of international/futures prices could introduce uncertainty into the opportunity cost of holding inventories and could lead producers to sell their stocks to physical traders. Therefore, high volatility could paradoxically raise the volume of commodities traded on the international market. Consequently, physical traders contribute to ensure linkages between regional producers even when the risk exposure raises, which is critical to maintain the market integration whereas an increase in price or exchange rate volatilities could cause producers to retreat on their local market.

This model is of course very simple when compared to the reality of international trade and is subject to some limitations. In particular, we have not considered, for the sake of simplicity, market structure volatility (i.e. variation in the contango or backwardation

levels, but also the probability to move from contango to backwardation, or vice versa) whereas his impact is decisive on the effective commodity cash prices. This model should therefore be seen as a first step towards better describing and understanding, from a theoretical modelling perspective, the behavior of traders and their impacts on the reality of trade flows.

4.3 The global oil market integration

The fundamental characteristic for a market to be established is the ability of the asset to be easily traded. On a physical market a commodity is said to be perfectly liquidity if it can be easily traded from one place to another without any distinction for its origin and destination. This emphasis that the good must be homogenous enough so that agents have no preference as to its origins. That can be the case for manufactured products whose production processes are homogenous in various places. Nevertheless, commodity markets can hardly be expected to naturally meet this requirement of homogeneity. Thus, despite similar characteristics, crude oil physical products cannot be traded through a fully standardised contract because of inherent regional specificities. We must state that any extraction site supplies a specific crude oil whose quality, defined by density and sulphur content, can largely differ. Moreover, in a regional market, supply and demand can diverge because of the exposure to specific shocks on both sides. These varying particularities lead regional markets to display local crude oil prices that correspond, partly, to quality and regional imbalance. Still, it seems that many commodity markets, especially the oil market, are found to be integrated, assuming that there could be a global market. Even if prices differ from one place to another, as long as they follow a similar trend, we can consider the market to be global.

In this new section, we aim to provide further evidence of the oil market integration in recent years and discuss the role played by physical traders in ensuring it. First, we present the existing debate on the global oil market. Second, we developed indicators of

the market integration based on the graph theory. We construct a database composed of 15 crude oil prices spread between as much local markets, to test the integration of the oil markets. We find that the integration is not constant or stable through time. Contrary to the literature that conclude on more cointegrated prices through time, we find shocks that influenced the market integration. The network analysis also shows disparities in the market structure.

4.3.1 The oil market as one great pool?

By allowing producers to trade on the international market and taking advantage of arbitrage opportunities as presented in the previous chapters, commodity traders play a key role to ensure the market integration. Although market specificities and local shocks affect commodity price deviations from to the international benchmark, we still expect that price series share a common dynamic. Their contribution to the market integration is possible because of the high liquidity on oil markets. The high world demand connects regional markets to each other in order to transfer oil products where they are needed. Furthermore, because oil is traded on an open market, the oil price mechanism is relatively transparent. Indeed, liquid crude oil contracts are quoted on financial places and these financial prices serve as benchmarks for regional prices. All of these elements converge toward the definition of the oil market as "one great pool".

The oil market integration raised concerned of economic researchers right after the market openness of the 1970s. Based on the 1980 report of the Brandt Commission and the recommendation for a global oil agreement, Adelman (1984^[1]) has been the first to compare the international oil market to "one great pool". However, at first, studies did not converge on this issue. Weiner (1991^[267]) demonstrated that changes of market fundamentals do not seem to be fully transferred to regional markets. However, a major change in the literature emerged with the general application of the Johansen's cointegration methodology (1992^[159]) to analyse the interrelationship between crude oil price series.

Gülen (1999^[119]) gave evidence of the homogeneity of world oil markets by showing a large increase in pairwise cointegration relationships between 21 light crude oil markets during the period 1993 to 1996 compared to 1990 to 1993.

Recent studies focus on the incorporation of changes in the cointegration relationship. Hammoudeh *et al.* (2008^[125]) analysed the relationship between four of the main price references – Brent, WTI, Dubai and Maya⁸ – between 1990 and 2006. They built a momentum threshold autoregressive model showing that every pair of crude is cointegrated but that the Brent and WTI dominate the pricing process. Giuliatti *et al.* (2015^[109]) studied the long-term relationship between pairs of 32 crude oils from 1997 to 2011 following Pesaran’s pairwise comparison methodology (2007^[220]). They found a large majority of stationary pairs and conclude that the oil market can be qualified as “one great pool”. They also proved that crudes with similar characteristics converge faster after a shock. Kuck and Schweikert (2017^[178]) confirm this result by using a Markov-switching vector error correction model. They found that all Brent, WTI, Dubai, Bonny Light⁹ and Tapis¹⁰ crude oils are cointegrated from 1987 to 2015, but their key contribution has been to exhibit a stronger integration in times of high economic uncertainty.

The deeper market integration that is found in recent years can be explained by the improvement in information transmission technology and trading technics. Silverio and Szklo (2012^[251]) studied the contribution of futures market to the price discovery in spot markets. They found that the cointegration relationship between the WTI future price and the spot price raised from 2003 to 2010, with the exception of the year 2008. In addition, in this section we would like to highlight the role that physical traders can play in the integration. Indeed, As in Kuck and Schweikert (2017^[178]), if the increase in the integration is confirmed when the uncertainty is high, thus it can reveal physical traders

⁸Maya crude is a heavy sour crude oil produced in Mexico and is used as a benchmark for heavy sour oils, especially in the US Gulf Coast.

⁹Bonny Light is a light Nigerian crude oil

¹⁰Tapis crude is a very light and sweet Malaysian crude oil.

contribution.

4.3.2 Price co-movements

Most of empirical literature on commodity markets integration relies on the Johansen cointegration methodology (1988). Siliverstics *et al.* (2005^[249]) used this framework to show high integration within regional gas markets but concluded there are strong regional features. Bachmeier and Griffin (2006^[17]) demonstrated the low integration of crude oil markets using Vector-Error Correction Models (VECM). Other methodologies emerged like the convergence testing method based on Phillips-Sul (2007^[221]) to investigate the gas market, which is found to remain regional in Li *et al.*' 2014^[185]'s paper. However, the spread of the graph theory on economic issues, as presented in the previous chapter, has created a new research framework for the analysis of market integration. In contrast to the Johansen's cointegration methodology which studies market integration over a period, the network analysis provides a time-varying analysis of the market integration. Jia *et al.* (2017^[158]) focused on the time-varying crude oil market integration to show that changes of local market conditions and episodes of high volatilities impact the global integration. Ji and Fan (2016^[157]) used the graph theory analysis to show the increase of the crude oil market integration from 2000 to 2010 but also the decrease in the integration trend in 2011. They estimated VECMs to highlight the central role of the WTI as the price setter in the decade 2000 to 2010, while the Brent appears to be the new price setter starting 2011. Nevertheless, their crude oil Fee On Board (FOB) database comes from the U.S. Energy Information Administration (EIA) which stopped publishing it in 2012. Thus, in this section we aim to analyse the evolution of the crude oil market integration since 2012. Our results lead us to conclude on an increase of the market integration starting 2014, while the previous period, from 2012 to 2014, is characterised by a low market integration. As disruption in the market integration appear in the 2014 and 2019 price drops, we interpret the specific role of commodity traders to ensure the market integration

during these periods.

4.3.3 Modeling the crude oil market integration

To test the world crude oil market integration, our proposal is to study the evolution of the international crude oil market by using tools from the graph analysis. We choose to build a Minimum Spanning Tree (MST) for price series of some of the main oil producers. Contrary to cointegration analysis, the MST allows to investigate changes in price relationships and the relative status of each regional market in maintaining the market integrated. We use 14 weekly prices that we define as references from 14 crude oil markets divided into four main areas – North America, Europe, Middle East and Asia. We choose to present only one crude oil price per country to avoid biased high correlation coming from the same country. We only use Free On Board (FOB) prices from *Datstream*. Regional markets present grade differences, however we assume that the crudes are homogenous enough to follow similar price trends. Crude markets, price references, grades and a summary statistic are presented in the following table:

Table 4.1: Summary statistics

| Country | Crude oil | API gravity (°) | Sulphur content (%) | Mean | Standard error | Min. | Max. | Skewness | Kurtosis | Jarque-Bera test |
|----------------|-----------------------|-----------------|---------------------|---------|----------------|---------|----------|----------|----------|------------------|
| United Kingdom | Brent | 37.9 | 0.45 | 76.8622 | 27.2814 | 13.7700 | 126.9800 | 0.0963 | -1.2435 | 36.9162*** |
| United States | WTI Cushing | 42 | 0.45 | 70.1124 | 23.0403 | 13.6400 | 112.3100 | 0.0207 | -1.2152 | 34.4417*** |
| Oman | DME Oman crude | 33.3 | 1.06 | 54.1222 | 30.7481 | 12.4900 | 103.4200 | 0.1704 | -1.7010 | 70.4916*** |
| Russia | Urals, Baltic | 30.6 | 1.48 | 75.4161 | 27.3990 | 10.4300 | 124.3300 | 0.0765 | -1.2246 | 35.4961*** |
| India | MCI crude oil Mumbai | 25-40 | 0.1-0.3 | 71.3775 | 21.4821 | 28.0700 | 112.5900 | 0.1522 | -1.3394 | 44.0527*** |
| Dubai | Crude oil Dubai | 31 | 2.04 | 74.7599 | 26.1014 | 20.6800 | 123.4900 | 0.0813 | -1.2933 | 39.6323*** |
| Nigeria | Bonny Light | 34.5 | 0.14 | 78.4134 | 28.0505 | 9.0200 | 129.4800 | 0.0692 | -1.1736 | 32.5211*** |
| Angola | Girassol | 31 | 0.33 | 77.4095 | 27.6606 | 8.2200 | 128.9300 | 0.0781 | -1.1774 | 32.8541*** |
| S.Arabia | Arab light | 33 | 1.77 | 75.9979 | 27.2547 | 16.8000 | 127.5200 | 0.0629 | -1.2392 | 36.1619*** |
| Libya | El Sharara | 43.1 | 0.07 | 76.1813 | 27.7233 | 8.5200 | 129.0000 | 0.0987 | -1.2130 | 35.2012*** |
| Norway | Ekofisk | 37.5 | 0.23 | 77.7247 | 27.8133 | 10.2300 | 129.1800 | 0.0897 | -1.1983 | 34.2078*** |
| Sudan | Nile Blend | 32.8 | 0.05 | 74.3397 | 27.8896 | 13.8300 | 135.7100 | 0.2210 | -1.0692 | 31.1917*** |
| Mexico | Mexican mix (Isthmas) | 33.6 | 1.3 | 67.4375 | 25.0158 | 10.0400 | 111.3600 | -0.0369 | -1.1407 | 30.4068*** |
| Canada | WSC | 20.1 | 3.64 | 70.7748 | 20.7065 | 30.2500 | 112.0000 | 0.1454 | -1.4428 | 50.6314*** |

Table 1 present the influence of grade differences on crude prices. We observe that sweeter crudes – Bonny light, Girassol, Ekofisk and the Nice Blend – show higher prices on average. They are all highly volatile and Jarque-Bera tests reject the normal distribution of the price series.

4.3.4 Construction of the Minimum Spanning Tree

We follow Ji and Fan (2016^[157]) and Coelho *et al.* (2007^[64]) methodology to analyse the time-varying characteristics and stability of the crude oil market. We first build the correlation coefficients of the countries of the data:

$$C_{i,j}^T = \frac{\sum_{t=1}^T (r_{i,t} - \bar{r}_i)(r_{j,t} - \bar{r}_j)}{\sqrt{\sum_{t=1}^T (r_{i,t} - \bar{r}_i)^2 \sum_{t=1}^T (r_{j,t} - \bar{r}_j)^2}} \quad (4.26)$$

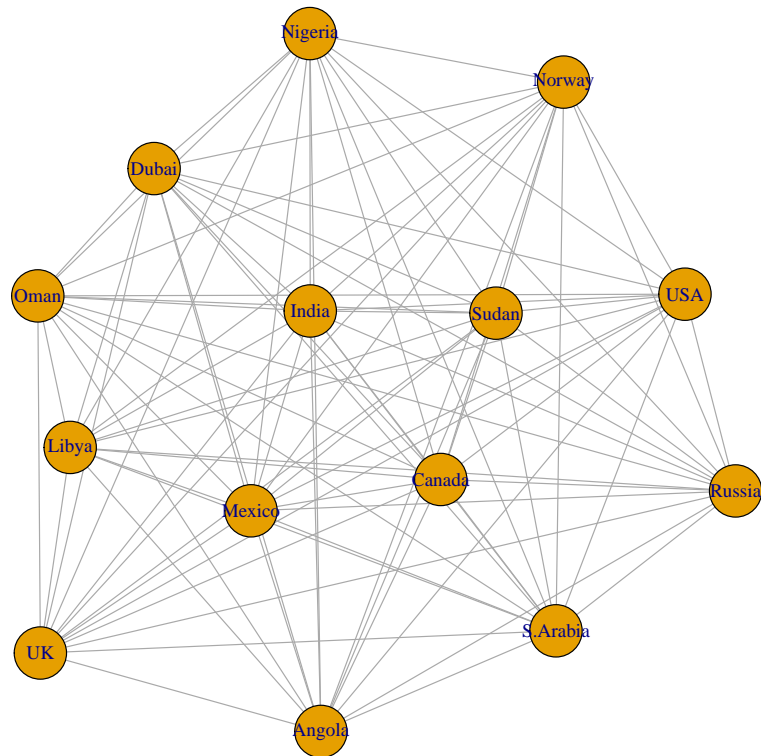
Where i and j are two different crude oil prices, $C_{i,j}$ is the correlation coefficient, $r_{i,t}$ the one period log-return of the crude i at the period t , and T is the sample length.

Correlation coefficients serve to determine distances $d_{i,j}$ for graph representation. However, coefficients cannot fulfil the axioms of Euclidian distance (Gower, 1966^[113]) that are: (a) $d_{i,j} = 0$ is and only if $i = j$, (b) $d_{i,j} = d_{j,i}$ and (c) $d_{i,j} \leq d_{i,k} + d_{k,j}$. Thus, we convert correlation into a metric distance following Mantegna (1999^[191]):

$$d_{i,j} = \sqrt{2(1 - C_{i,j}^T)} \quad (4.27)$$

$d_{i,j}$ is defined as the distance between crude oil prices. The smaller is $d_{i,j}$ and the higher is the correlation between the prices. The correlation matrix is substituted by the distance matrix to construct the graph.

Figure 4.1: Complete graph of the crude oil world market on 2009-2020

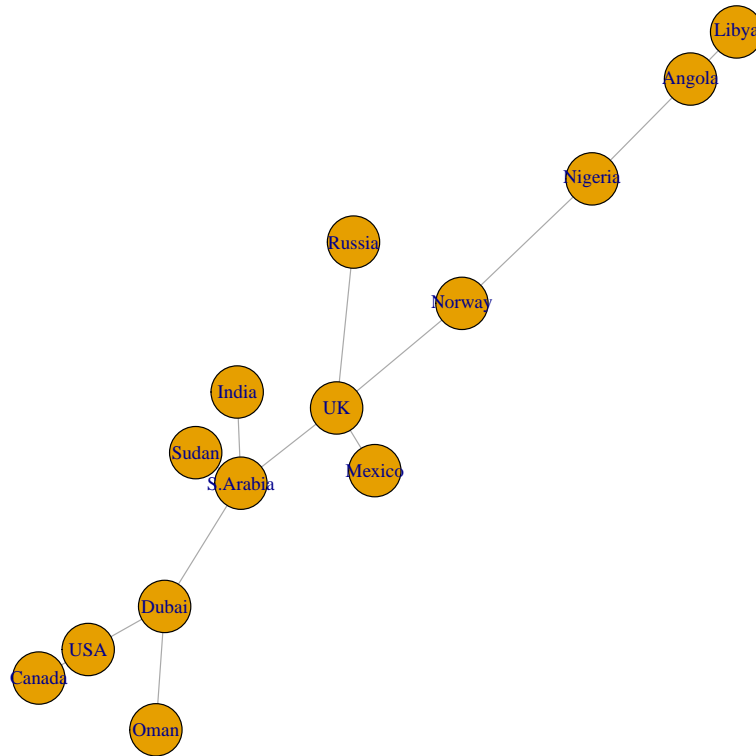


Then, we derive a Minimal Spanning Tree (MST), a subset of the edges of the former graph connecting all vertices together without any cycle and in which the sum of edge weights is as small as possible. The MST highlights the most important correlations and information of the graph. We choose to define the MST based on Prim (1957^[231])'s algorithm. It extracts only the shortest path covering all vertices of the graph:

We develop network analysis measures on the MST to study the relative importance of each market on the international one. First, we calculate the number of degrees connected to each market. Second, we present the betweenness centrality, then we focus on the fairness.

The betweenness centrality, $B_i(t)$, is a centrality measure we consider to capture the capacity for a country to be a key link between two other countries. A country acting as an intermediary platform between other countries will exhibit a high betweenness centrality.

Figure 4.2: Minimum spanning tree of the crude oil world market on 2009-2020



Sieczka and Holyst (2009^[248]) and Ji and Fan (2016^[157]) used it to measure market's centrality. Choi and Hwang (2014^[60]), referred to the betweenness centrality to identify intermediary countries in international trade and conclude they have a high bargaining power.

$$B_i = \frac{2}{N(N-1)} \sum_{j \neq k, j, k \neq i} \frac{\tau_{j,k}(i)}{\tau_{j,k}} \quad (4.28)$$

The betweenness centrality B_i of a country is the number of shortest paths $\tau_{j,k}(i)$ between j and k in G that pass through i while $\tau_{j,k}$ is the total number of shortest paths between j and k in the MST. In our case, we calculate the betweenness centrality in a MST, so $\frac{\tau_{j,k}(i)}{\tau_{j,k}} = 0$ if the path from j to k does not pass through the market i , and $\frac{\tau_{j,k}(i)}{\tau_{j,k}} = 1$ if it does. The higher value of B_i , the higher other markets relies on i , which raise its centrality.

The market farness is the sum of each market distances to all other markets (Sabidussi 1966).

$$Farness_i = \sum_{j \neq k, j, k \neq i} SD_{i,j} \quad (4.29)$$

Where $SP_{i,j}$ is the shortest distance from market i to market j in the MST. The smaller value of the market farness indicates that market i is ‘‘close’’ to others. It is a central market.

Table 4.2: Measures of crude oil markets

| Crude oil market | Degree | Betweenness centrality | Farness | Crude oil market | Degree | Betweenness centrality | Farness |
|------------------|--------|------------------------|---------|------------------|--------|------------------------|---------|
| United-Kingdom | 4 | 51 | 13.1462 | Angola | 2 | 12 | 17.1798 |
| United States | 2 | 12 | 21.9232 | Saudi Arabia | 4 | 51 | 13.1462 |
| Oman | 1 | 0 | 23.0054 | Libya | 1 | 0 | 24.4097 |
| Russia | 1 | 0 | 15.8473 | Norway | 2 | 30 | 14.3925 |
| India | 1 | 0 | 23.6212 | Sudan | 1 | 0 | 21.5485 |
| Dubai | 3 | 32 | 16.5143 | Mexico | 1 | 0 | 21.3484 |
| Nigeria | 2 | 22 | 15.4559 | Canada | 1 | 0 | 31.6901 |

Now that the MST is constructed, we can value the relative importance of each market into the international network. We see that half of the markets are connected to at least two edges in the MST and that only three are higher than 2. British and the Saudi Arabian markets show the highest correlation in the MST. Both seem to occupy a central place to influence other markets’ regional prices. The United Kingdom is found to be close to Norway, another North Sea oil producer and Russia, an European Market. The Mexican market is surprisingly found to be closer to the British one than the US one, which also explain that the US market is only connected to Canadian and Dubai prices. Saudi Arabia seems to exhibit a high influence on Indian prices, suggesting that Middle East price could be used as a benchmark for Asian prices. A similar comment can be made for Eastern African markets based on the high proximity with the Sudanese. Saudi Arabia is also close to Dubai which is consistent with the high similarity of their crudes. Dubai, usually defined as the benchmark market for Middle-East markets, has a lower centrality than Saudi Arabia, but is linked to other major oil producing market like Oman and the United States. Finally, Western and North African markets (Nigeria, Angola and

Libya) are also found to be close.

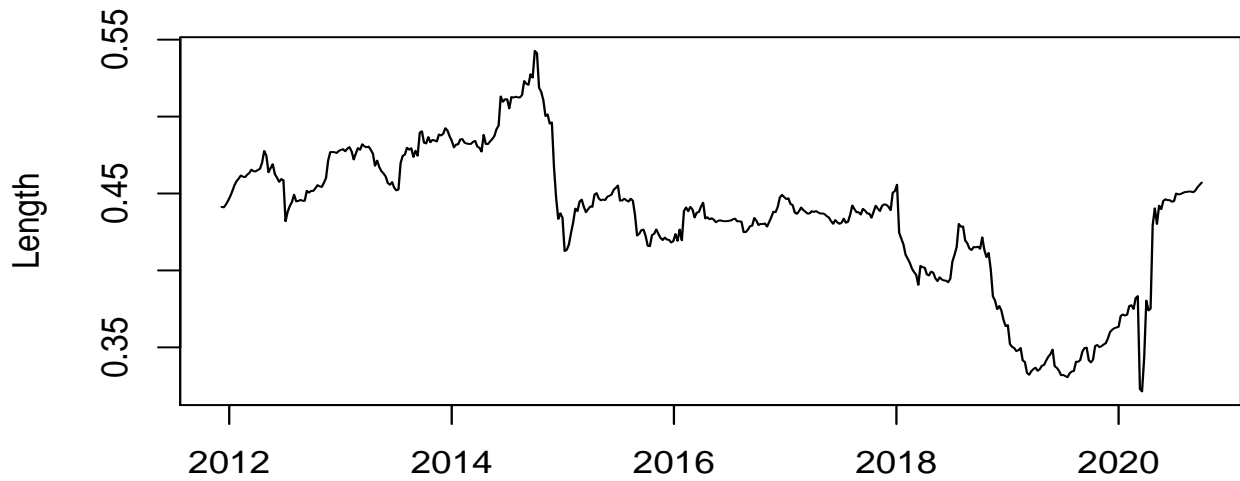
The market fairness also confirms the central role of Saudi Arabia, the United Kingdom and Russia into the international crude oil market. The relatively low centrality measures found for the United States can be explained by the relatively low number of American prices especially from the Colombian and Venezuelan markets where we can expect the WTI to be used as a benchmark. subsectionDynamic measure of the crude oil market integration We provided above static measures of the market organization on the full period 2009-2020. However, these do not give information on the stability of the market integration over time. To overpass this limit, we analyse the time-varying integration of the international crude oil market. We use rolling-time windows of 100 observations, which represent approximately 2 years of observations, for each MST with a 1 window step length. Based on the 564 weekly observation over 14 crude oil prices, we derive 464 MST.

The normalised tree length is the indicator of the market integration. The dynamic change of the market structure is derived from this measure (Onnela *et al.* 2003^[213]):

$$L(t) = \frac{1}{N-1} \sum_{e_{i,j} \in MST} e_{i,j} \quad (4.30)$$

$L(t)$ is the normalised tree length over the 100 past weeks at the date t , N the number of markets in this study, $e_{i,j}$ the edge from vertice i to vertice j . The length indicates the minimum distance linking all vertices of the MST. Decreasing $L(t)$ implies a higher market integration and deeper co-movements among crude prices of the MST.

Figure 4.3: Crude oil market integration using the normalised tree length



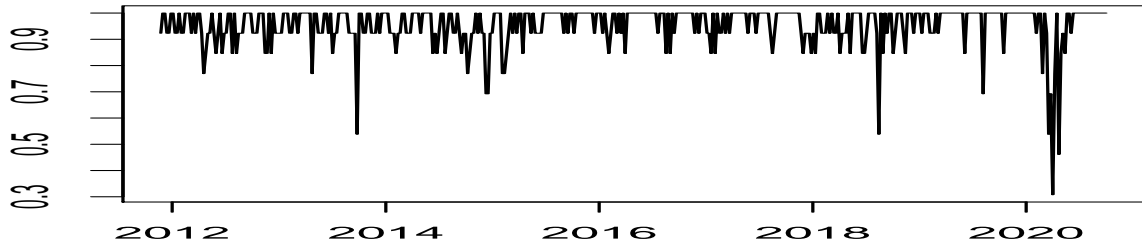
The multistep survival ratio of edges examines the stability of the oil market integration. We define it following Coelho *et al.* (2007^[64]):

$$Survival(t, k) = \frac{1}{N-1} |E(t) \cap E(t-1) \dots E(t-k+1) \cap E(E(t-k))| \quad (4.31)$$

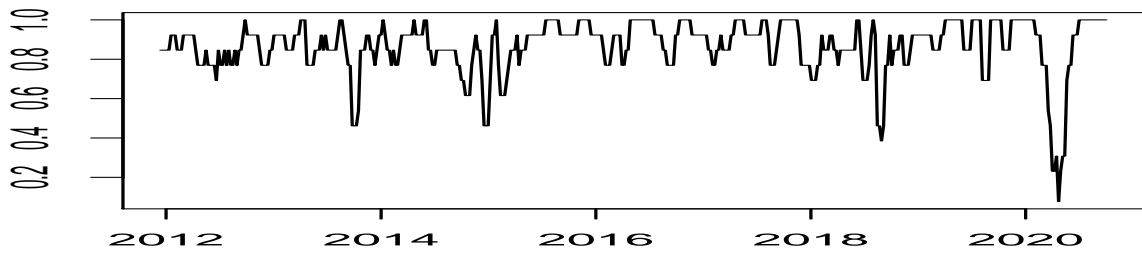
$Survival(t, k)$ is the k -step survival ratio of edges in the MST. $E(t)$ is the set of linkages in the MST at time t . k is the number of weeks over which we test the stability of the MST. It measures the robustness of edges between crude markets over time. The higher k the more accurate is the robustness measure. When the number of weeks increases, the survival ratio provide evidence of the robustness on a longer time period.

We compute five survival ratios, over 1, 4, 12, 24 and 48 weeks, to test the robustness of the model on multiple periods, from one week to approximately one year.

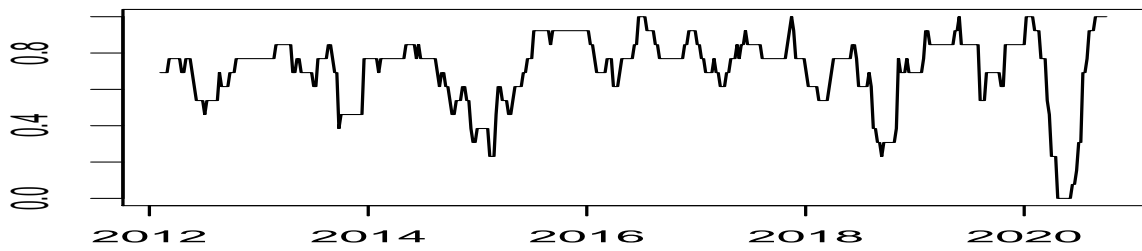
Figure 4.4: Survival Ratio



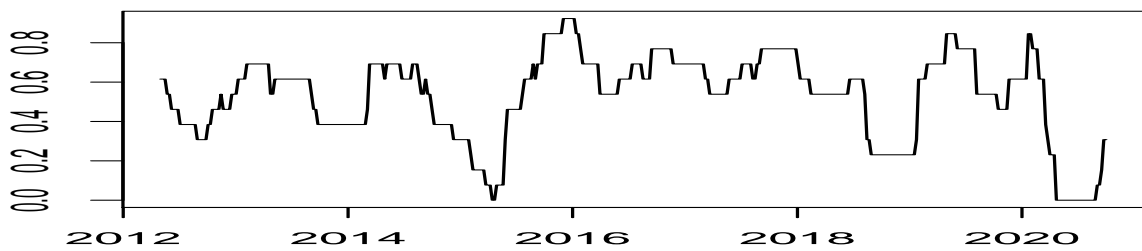
(a) 1 week, mean = 0.952752



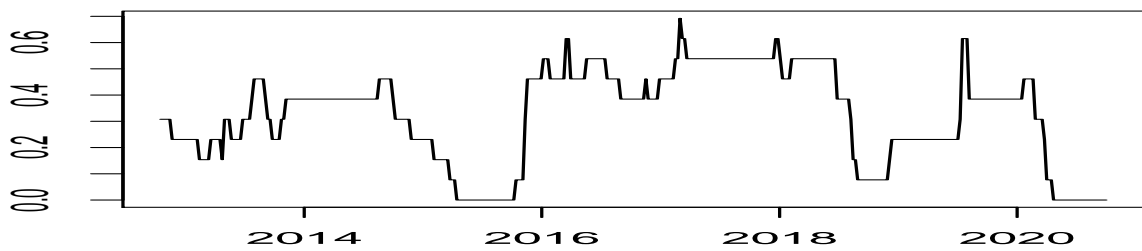
(b) 4 weeks, mean = 0.8623394



(c) 12 weeks, mean = 0.7072508



(d) 24 weeks, mean = 0.5290424



(e) 48 weeks, mean = 0.3241099

4.3.5 Comments

We find that the relationship between crude oil markets cannot be defined as linear or static. On the contrary, because each market exhibits some specificities, it makes the international market a complex network. Surprisingly, the normalized tree length seems to follow the oil price dynamic and low prices would raise the market integration while high prices would do the opposite. It indicates a global trend toward an increase in the world market integration starting 2014 to 2019. This result is coherent with Ji and Fan (2016) who concluded on a higher integration from 2002 to 2012. Nevertheless, based on our full data span it appears that the integration relationship varies. We distinguish three periods:

First, from 2012 to 2014 the market integration tends to decrease, which echoes Ji and Fan (2016^[157]) who found a decrease of the oil market integration starting 2011. It is confirmed by the analyse of the mean price correlation slightly increasing (figure 4.4) over the period. Two groups of markets emerge. Countries closely related to Saudi Arabia on the one hand, and countries closely related to the United Kingdom and Dubai on the other hand. However, the distance between both markets is found to be high, with only Nigeria as intermediate (see Appendix D). We find an increase of the regionalization of the market in the second half of 2014 corresponding to the large crude oil price drop starting in the summer. The latter can be seen as a consequence of the oversupplied market on the short run which led prices to respond to their local fundamental and the unbalance markets.

Second, from 2015 to 2019, we see a subsequent rise in the market integration. Markets appear to be less isolated from each other on the subperiod MST (Appendix D graph (b)). The MST seem to exhibit relatively similar clusters with the exception of the United Kingdom market which is isolated. This subperiod clearly highlight the relationship between low prices and the raise of the market integration. Indeed, on the medium-long run the oversupplied markets create opportunities for arbitrage between markets. This result

can be seen as the proof of commodity traders' contribution to the market. If we could expect price shocks and major unbalances to lead to higher regionalisation of the market, it is actually the optimal context to value commodity traders' skills. While commodity markets use to remain undersupplied in order to keep pressure on prices and support increasing trends (Marquet, 1992^[192]), oversupplied markets need optimized distribution networks to sell stocks. Hence the need for traders to arbitrate regional price spreads which is supposed to resorb unbalances. We see that the length measure stabilises to a lower value from 2014 to 2019.

Finally, the last period is characterized by large instability. No market clusters emerge from the subperiod MST (Appendix D graph (c)). New price drops in late 2018 and 2019 created new arbitrage opportunities for traders that contribute to a more integrated market observed from normalized tree length. Nevertheless, the uncertainty potentially coming from the Covid19 crisis can explain decrease of the integration since.

The multistep survival ratio presents the frequency of the links in MSTs. We see that the frequency is not always 1 meaning that MSTs are not perfectly stable. While, the average survival ratio is high for a 1 week and 4 weeks ratios, the robustness of market relationships clearly decline starting a 12 months step analysis. Our length measure is therefore a relevant indicator of the market integration on the short run but disparities appear on the long-run. Indeed, it seems that price drops starting the second semester 2014 and the one from 2019, plus the Covid19 pandemic crisis drastically changed the structure of the MSTs.

4.3.6 Final remarks

This analysis provides an extension of Ji and Fan (2016^[157])'s analysis of the crude oil market integration from 2010 to 2020. We constructed minimum spanning trees to highlight the market structure and the relative importance of each market in the international

crude oil network. In spite of regional specificities, our results confirm the integration of the oil market. The decreasing Euclidian distance between the price series indicates that prices tend to move together. It means that regional shocks can transmit to worldwide markets relatively fastly.

Our main contribution is to demonstrate that the integration is not linear. More specifically, we show the increase of the integration” in periods of oversupplied markets and decreasing prices. While previous studies explained the increase of the market integration in the decade 2000s as a result of the improvement of information technologies and trading techniques, we can hardly conclude that the same factors explain variations of the integration in the 2010s. However, we can link changes in the integration to crude oil price trends and market unbalances. We explain the role of commodity traders in arbitraging regional markets to justify the higher market integration during these periods. Nevertheless, perturbations derived from the actual Covid19 crisis widely stressed the market which distorted the market integration and raise uncertainty on the evolution of the integration even on the short-run.

4.4 Conclusion

This chapter highlighted the role of commodity traders into connecting local and regional markets to the global market. We developed a theoretical model to show that CTFs change trade flows in the industry by redirecting trade flows to the international market in case of higher international price volatility. This finding can sound counterintuitive; however, it characterises the main contribution of commodity traders. They offer to hedge risks for producers and connect producers to the international market. They also contribute to the oil price integration by benefiting from arbitrage opportunities to resorb local unbalances. Our network analysis even shows that the integration increases in oversupplied market with decreasing prices. This is the situation in which commodity traders are needed to ease international trade flows.

Appendix

Appendix A: Glossary

| | |
|------------------------|--|
| $P_t^{Cash(i,j)}$ | Price paid by the agent i to the agent j in period t |
| P_t^I | International price in period t |
| $P_{t,m}^F$ | Future price observed in period t for period m |
| $P_{t,m}^{F^{e(i,j)}}$ | Future currency price in period t for period m |
| \bar{Q} | Production available in period 1 |
| $Q_t^{i,j}$ | Production sold by i to j in period t |
| $q_t^{i,j}$ | Share of the production sold by i to j in period t |
| U | Producer's total utility |
| u_t | Producer's utility in period t |
| Y | Producer's total revenue |
| y_t | Producer's revenue in period t |
| Π^T | Trader's profit |
| α | Variable capturing both the physical trader profit margin and transportation costs on the buy side |
| β | Variable capturing both the physical trader profit margin and transportation costs on the sell side |
| θ | Parameter which hovers one |
| $e_t^{i,j}$ | Nominal exchange (direct quotation) between i 's currency and j 's currency |
| σ_P^2 | Price volatility in period t |
| σ_e^2 | Exchange rate volatility in period t |
| σ_β^2 | β volatility in period t |
| A_P | Producer's risk aversion |
| A_T | Physical trader's risk aversion |
| c_P | Producer's storage costs |
| c_T | Physical trader's storage costs |
| i | Interest rate |

$\hat{}$ indicates expected value

Appendix B: Proofs of stage one

Calculation of the quantity at equilibrium

$$\widehat{U}_2 = \widehat{y}_2 - \frac{1}{2}A_P \text{Var}(\widehat{y}_2)$$

Where A_P is the absolute risk aversion coefficient of the producer. It gives:

$$\widehat{U}_2 = \hat{q}_2^{P,EU} \theta \hat{P}_2^I + \hat{q}_2^{P,EU*} \hat{e} \hat{P}_2^I - \frac{1}{2}A_P \text{Var}(\widehat{y}_2)$$

With $\hat{q}_2^{P,EU}$, the share of the production that is sold to the national end-user by the producer, $\hat{q}_2^{P,EU*}$, the share of the production that is sold to the foreign end-user by the producer ($\hat{q}_2^{P,EU} + \hat{q}_2^{P,EU*} = 1$), \hat{e} , the nominal exchange rate, and \hat{P}_2^I the international price of the commodity (i.e. the futures price). We can see that:

$$\begin{aligned} \text{Var}(\widehat{y}_2) = & \left(\hat{q}_2^{P,EU} \right)^2 \theta^2 \hat{\sigma}_P^2 + \left(\hat{q}_2^{P,EU*} \right)^2 \left[\hat{e}^2 \hat{\sigma}_P^2 + \left(\hat{P}_2^I \right)^2 \hat{\sigma}_e^2 + \hat{\sigma}_e^2 \hat{\sigma}_P^2 \right] \\ & + 2 \hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \text{Cov}(\theta \hat{P}_2^I, \hat{e} \hat{P}_2^I) \end{aligned}$$

In fact we have:

$$\text{Cov}(\theta \hat{P}_2^I, \hat{e} \hat{P}_2^I) = \theta \text{Cov}(\hat{P}_2^I, \hat{e} \hat{P}_2^I) = \theta \left[E\left[\left(\hat{P}_2^I \right)^2 \hat{e} \right] - E[\hat{P}_2^I] E[\hat{e} \hat{P}_2^I] \right]$$

We assume that \hat{e} and \hat{P}_2^I are independent variables, so we get:

$$\begin{aligned} \text{Cov}(\theta \hat{P}_2^I, \hat{e} \hat{P}_2^I) &= \theta \left[E[\hat{e}] E\left[\left(\hat{P}_2^I \right)^2 \right] - E[\hat{e}] \left(E[\hat{P}_2^I] \right)^2 \right] = \theta E[\hat{e}] \left[E\left[\left(\hat{P}_2^I \right)^2 \right] - \left(E[\hat{P}_2^I] \right)^2 \right] \\ \text{Cov}(\theta \hat{P}_2^I, \hat{e} \hat{P}_2^I) &= \theta E[\hat{e}] \hat{\sigma}_P^2 = \theta \hat{e} \hat{\sigma}_P^2 \end{aligned}$$

As a consequence, we replace the latter equation in the utility function and obtain:

$$\widehat{U}_2 = \hat{q}_2^{P,EU} \theta \hat{P}_2^I + Q_2^I \hat{e} \hat{P}_2^I - \frac{1}{2} A_P \text{Var}((\hat{q}_2^{P,EU})^2 \theta^2 \hat{\sigma}_P^2 + (\hat{q}_2^{P,EU*})^2 \left[\hat{e}^2 \hat{\sigma}_P^2 + (\hat{P}_2^I)^2 \hat{\sigma}_e^2 + \hat{\sigma}_e^2 \hat{\sigma}_P^2 \right] + 2\hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e} \hat{\sigma}_P^2)$$

The producer maximizes its utility function. The first order condition (FOC) could be represented as:

$$\frac{\partial U_2}{\partial \hat{q}_2^{P,EU}} = 0$$

Let B be equal to:

$$B = e^2 \hat{\sigma}_P^2 + (\hat{P}_2^I)^2 \hat{\sigma}_e^2 + \hat{\sigma}_e^2 \hat{\sigma}_P^2$$

The FOC gives us:

$$\theta \hat{P}_2^I - \hat{e} \hat{P}_2^I - \frac{1}{2} A_P \left[2Q_2^N \hat{\sigma}_P^2 \theta^2 - 2(1 - \hat{q}_2^{P,EU})^2 B + 2\theta \hat{e} \hat{\sigma}_P^2 (1 - 2\hat{q}_2^{P,EU}) \right] = 0$$

It gives:

$$\hat{q}_2^{P,EU} = \frac{\theta \hat{P}_2^I - \hat{e} \hat{P}_2^I + A_P (B - \theta \hat{e} \hat{\sigma}_P^2)}{A_P (\hat{\sigma}_P^2 \theta^2 + B - 2\theta \hat{e} \hat{\sigma}_P^2)}$$

Computation of the first partial derivatives

$$\frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_e^2} = \frac{A_P \left[(\hat{P}_2^I)^2 + \sigma_P^2 \right] A_P \left[\hat{\sigma}_P^2 \theta^2 + B - 2\theta \hat{e} \hat{\sigma}_P^2 \right]}{A^2 [\cdot]^2} - \frac{A_P \left[\sigma_P^2 + (\hat{P}_2^I)^2 \right] \left\{ \left[\theta \hat{P}_2^I - \hat{e} \hat{P}_2^I \right] + A_P \left[B - \theta \hat{e} \hat{\sigma}_P^2 \right] \right\}}{A_P^2 [\cdot]^2}$$

For $e = \hat{e}$, we find that:

$$\frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_e^2} = \frac{A_P \left[\left(\hat{P}_2^I \right)^2 + \sigma_P^2 \right] (\theta - \hat{e}) \left(A_P \hat{\sigma}_P^2 \theta - \hat{P}_2^I \right)}{A_P^2 [\cdot]^2}$$

Note that the denominator of the latter equation is always positive. Thus, we only have to investigate the sign of the numerator. Using the fact that $Q_2^N + Q_2^I = 1$, we know that $Q_2^N \leq 1$, so we obtain:

$$\theta \hat{P}_2^I - e \hat{P}_2^I + A_P \left(B - \theta \hat{e} \hat{\sigma}_P^2 \right) \leq A_P \left(\hat{\sigma}_P^2 \theta^2 + B - 2\theta \hat{e} \hat{\sigma}_P^2 \right)$$

It gives:

$$(\theta - \hat{e}) \left(A_P \hat{\sigma}_P^2 \theta - \hat{P}_2^I \right) \geq 0$$

As a consequence, we obtain:

$$\frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_e^2} \geq 0$$

Computation of the second partial derivative

$$\begin{aligned} \frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_P^2} &= \frac{A_P \left[\hat{e}^2 + \hat{\sigma}_e^2 - \theta \hat{e} \right] A_P \left[\hat{\sigma}_P^2 \theta^2 + B - 2\theta \hat{e} \hat{\sigma}_P^2 \right]}{A_P^2 [\cdot]^2} \\ &\quad - \frac{\left\{ \theta \hat{P}_2^I - \hat{e} \hat{P}_2^I + A_P \left[B - \theta \hat{e} \hat{\sigma}_P^2 \right] \right\} A \left[\theta^2 + \hat{e}^2 \hat{\sigma}_e^2 - 2\theta \hat{e} \right]}{A_P^2 [\cdot]^2} \end{aligned}$$

It gives that:

$$\begin{aligned} \frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_P^2} &= \frac{- (\theta - \hat{e}) \hat{P}_2^I A_P \left\{ \left(\hat{e}^2 + \hat{\sigma}_e^2 \right) + \theta (\theta - 2\hat{e}) + A_P \left(\hat{P}_2^I \right)^2 \theta \hat{\sigma}_e^2 \right\}}{A_P^2 [\cdot]^2} \\ &\quad + \frac{A_P^2 \hat{\sigma}_P^2 \theta \left((2\theta \sqrt{\hat{e}} - \sqrt{\hat{e}^3})^2 + 4\theta (\hat{e}^2 - \hat{\sigma}_e^2) \right)}{A_P^2 [\cdot]^2} \end{aligned}$$

The right part of the equation is positive as long as $\hat{e}^2 > \hat{\sigma}_e^2$. The sign of the derivative only

depends on the numerator of the left-side element of the equation, which can be written as:

$$-(\theta - e) \hat{P}_2^I A_P \left\{ (\hat{e}^2 + \hat{\sigma}_e^2) + \theta^2 - 2\hat{e}\theta + A_P \left((\hat{P}_2^I)^2 \theta \hat{\sigma}_e^2 \right) \right\}$$

Therefore, we have:

$$-(\theta - e) \hat{P}_2^I A_P \left[(e - \theta)^2 + \hat{\sigma}_e^2 + A_P \left(\hat{P}_2^I \right)^2 \theta \hat{\sigma}_e^2 \right]$$

It is straightforward to see that $A_P \left[(\hat{e} - \theta)^2 + \hat{e}\hat{\sigma}_e^2 + A_P \left(\hat{P}_2^I \right)^2 \right] \geq 0$, so the sign of the relationship is only determined by $-(\theta - \hat{e})$, given the fact that $\hat{P}_2^I \geq 0$ and $A_P > 0$.

Thus, we have:

$$\begin{cases} \frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_P^2} \geq 0 \text{ for } \theta \leq \hat{e} \\ \frac{\partial \hat{q}_2^{P,EU}}{\partial \hat{\sigma}_P^2} \leq 0 \text{ for } \theta \geq \hat{e} \end{cases} \quad (4.32)$$

Appendix C: Proofs of stage two

$$\hat{U}_2 = \hat{Y} - \frac{1}{2} A_P \text{Var}(\hat{Y}) \quad (4.33)$$

$\hat{q}_2^{P,EU}$ and $\hat{q}_2^{P,EU*}$ being shares, we have $\hat{Q}_2^{P,EU} = \hat{q}_2^{P,EU}(\bar{Q} - Q_1^{P,T})$ and $\hat{Q}_2^{P,EU*} = \hat{q}_2^{P,EU*}(\bar{Q} - Q_1^{P,T})$. It gives:

$$\hat{U}_2 = Q_1^{P,T}(P_1^I - \alpha) + (\bar{Q} - Q_1^{P,T})(\hat{q}_2^{P,EU} \theta \hat{P}_2^I + \hat{q}_2^{P,EU*} \hat{e}_2) \hat{P}_2^I - (\bar{Q} - Q_1^{P,T}) c \frac{1}{2} A_P \text{Var}(\hat{Y}) \quad (4.34)$$

Where \bar{Q} is the whole production available in $t=1$, $Q_1^{P,T}$ is the production sold to the commodity trader. $Q_1^{P,T}(P_1^I - \alpha)$ is already known in $t=1$, and c is a constant, thus we can see that:

$$\begin{aligned} \text{Var}(\hat{Y}) = (\bar{Q} - Q_1^{P,T})^2 & \left((\hat{q}_2^{P,EU})^2 \theta^2 \hat{\sigma}_P^2 + (\hat{q}_2^I)^2 \left[\hat{e}^2 \hat{\sigma}_P^2 + (\hat{p}_2^I)^2 \hat{\sigma}_e^2 + \hat{\sigma}_e^2 \hat{\sigma}_P^2 \right] \right. \\ & \left. + 2\hat{q}_2^{P,EU} \hat{Q}_2^I \text{Cov}(\theta \hat{P}_2^I, \hat{e} \hat{P}_2^I) \right) \end{aligned} \quad (4.35)$$

Similarly to appendix A, we have:

$$Cov(\theta\hat{P}_2^I, \hat{e}\hat{P}_2^I) = \theta Cov(\hat{P}_2^I, \hat{e}\hat{P}_2^I) = \theta \left[E\left[\left(\hat{P}_2^I\right)^2 \hat{e}\right] - E[\hat{P}_2^I]E[\hat{e}\hat{P}_2^I] \right]$$

We assume that \hat{e} and \hat{P}_2^I are independent variables, we get:

$$\begin{aligned} \hat{U}_2 = Q_1^{P,T}(P_1^I - \alpha) + (\bar{Q} - Q_1^{P,T}) \left(q_2^{P,EU} \theta \hat{P}_2^I + q_2^{P,EU*} \hat{e} \hat{P}_2^I - c \right) - \frac{1}{2} A_P (\bar{Q} - Q_1^{P,T})^2 \\ \left(\left(\hat{q}_2^{P,EU} \right)^2 \theta^2 \hat{\sigma}_P^2 + \left(\hat{q}_2^{P,EU*} \right)^2 \left[\hat{e}^2 \hat{\sigma}_P^2 + \left(\hat{p}_2^I \right)^2 \hat{\sigma}_e^2 + \hat{\sigma}_e^2 \hat{\sigma}_P^2 \right] + 2 \hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e} \hat{\sigma}_P^2 \right) \end{aligned} \quad (4.36)$$

The producer maximizes its utility function. The first order condition (FOC) could be represented as:

$$\frac{\partial \hat{U}_2}{\partial Q_1^{P,T}} = 0$$

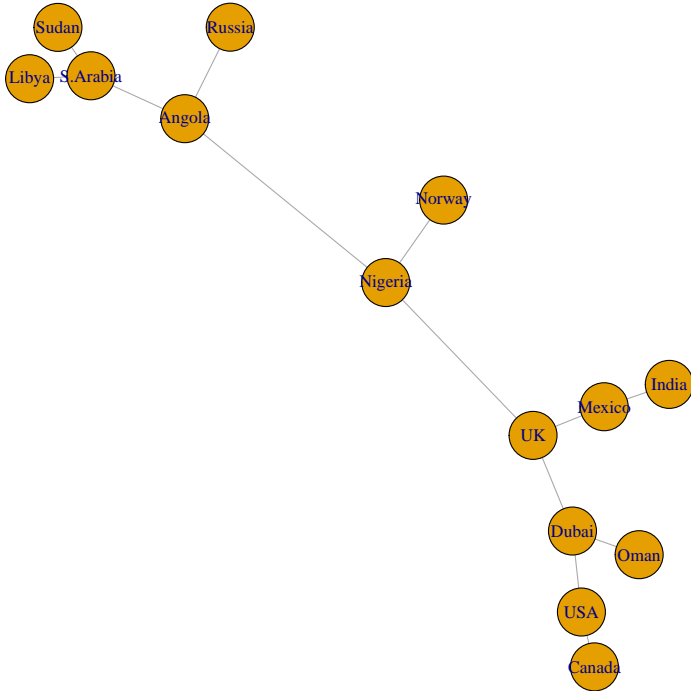
The FOC gives us:

$$Q_1^{P,T} = \bar{Q} - \frac{\theta \hat{P}_2^I q_2^{P,EU} + \hat{e} \hat{P}_2^I q_2^{P,EU*} - (P_1^I - \alpha) - c}{A_P \left(\left(\hat{q}_2^{P,EU} \right)^2 \theta^2 \hat{\sigma}_P^2 + \left(\hat{q}_2^{P,EU*} \right)^2 B + 2 \hat{q}_2^{P,EU} \hat{q}_2^{P,EU*} \theta \hat{e} \hat{\sigma}_P^2 \right)} \quad (4.37)$$

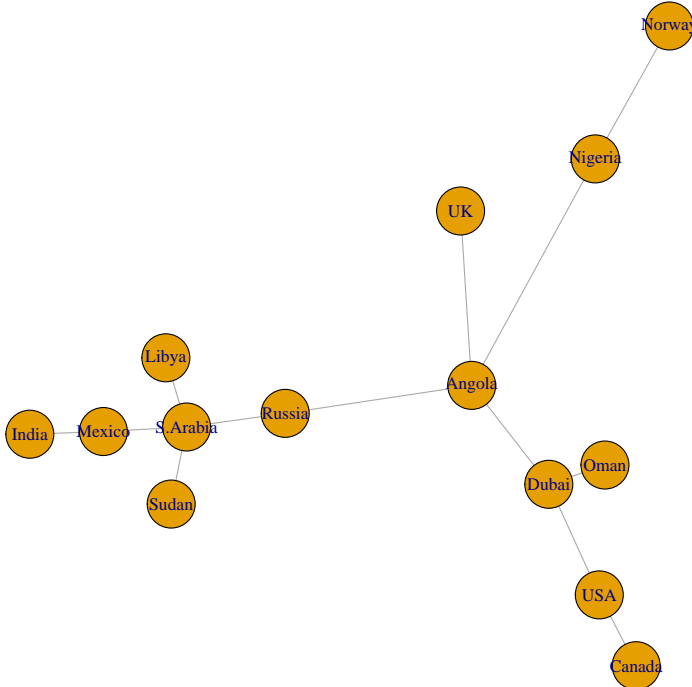
For $Q_1^{P,T} \leq \bar{Q}_1$.

Appendix D : Sub period MST

Figure 4.5: Minimum spanning trees on subperiods

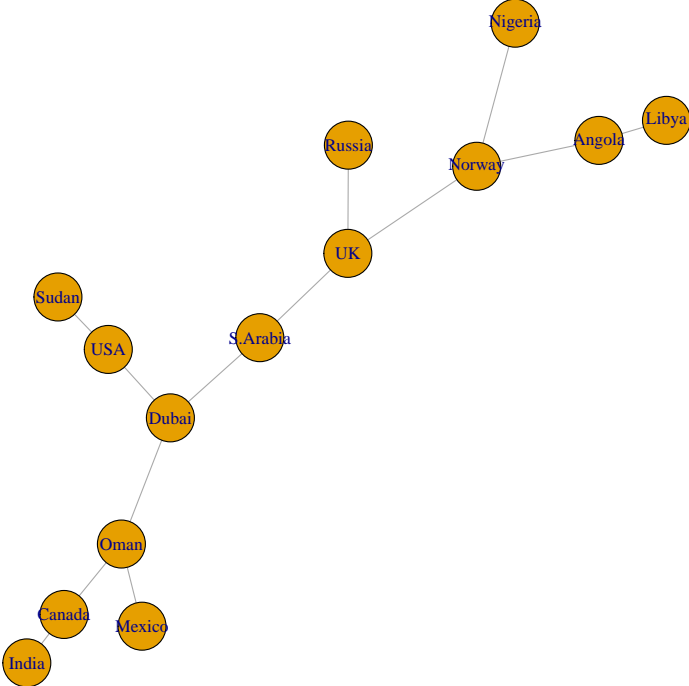


(a) 2010 - 2014



(b) 2015-2019

Figure 4.6: Minimum spanning trees on subperiods



(c) 2019-2020

Part III

Commodity traders change the
organization of the industry

Physical traders are essential agents in the commodity chain and their services enable the market to thrive. In the oil industry that is usually seen as fully vertically integrated, from extraction through refining to distribution, traders are opening up a new solution. Markets stressed by high volatility or excess supply to be sold can be managed by traders on the market. They offer flexibility to upstream producers to sell their supply rather than refining it themselves. Producers can benefit from high prices to raise their vertical integration and capture the highest fraction of the added value going through the industry, and turn to disintegration strategies when the integration becomes too costly. Because of physical traders, the organization of the industry is not rigid, but can react to price dynamics. This reconsiders the role of the market, and more precisely the use of short and long-term contracts in the oil industry.

Chapter 5

The sensitivity of the organization to price dynamics

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5.1 Introduction

So far, we have mainly dealt with the international organization of trades and the connection of producers and end-users thanks to physical trader. Nevertheless, we have not yet discussed the preponderant role of prices in trades. They obviously have a significant impact on market fundamentals of the sectors and on hedging strategies. The influence of prices in the contractual organization of the industry should also be discussed.

We presented in the first chapter that the management of transaction costs has become a dominant driver of the organization of the oil industry. Producers can trade on the market or transfer oil barrels within a vertically integrated firm. It is therefore necessary to make prices one of the essential components of the arbitrage between the market and the firm. In the segment that presents the choices of trade organizations available to producers, market trade and vertical integration are the two extremes bounds framing a plurality of options. Nevertheless, these two points have the advantage of opposing the main costs and risks associated with these organizations. Integration is costly and rigid, while the market exposes to price risk and opportunistic behaviors.

Contractual strategies are very sensitive to price dynamics, even if it is difficult to extract an unequivocal causal link from prices to the organization. Indeed, episodes of low prices are particularly relevant to analyze this phenomenon. On the one hand, they create opportunities for mergers and acquisitions since low prices weaken firms' revenue, making them more vulnerable to acquisition by major producers. Many examples are found in horizontal integration strategies. BP, in particular, has been able to carry out extensive acquisitions over the period 1998-2000. The producer merged with Amoco in 1998 and ARCO in 2000, making it the world's leading oil producer. The wave to mergers and acquisitions in the oil industry did not stop there, since Exxon and Mobil also merged in 1999. On the other hand, the same low prices can lead to opposite strategies when considering the vertical integration of the industry. Indeed, in times of great uncertainty,

producers are likely to reduce their investments in order to limit their price exposure (Bernanke 1988^[240], Kilian 2014^[169]). Moreover, it restores flexibility and allow producers to focus on their core business. Thus, the split off of ConocoPhillips into two separate entities, the historical crude oil producers and Phillips66 managing downstream assets, enabled both segments to outperform its competitors on the market. In the upstream segment, the company could benefit from greater flexibility during the period, while the downstream company clearly took advantage of low crude prices to benefit from high margins.

Nevertheless, as mentioned earlier, the economic theory which presents the determinants of the organization of the industry does not seem to give enough interest to price dynamics. In this chapter, we consider this is the main obstacle to the application of the incomplete contract theory to its application to commodity industries. This is all the more regrettable since the investment strategy and the hold-up risk, widely discussed in the incomplete contract theory, are themselves highly dependent on price levels. In this chapter, we defend the idea that long term contracts are weaker and provide less protection when prices are highly volatile. Therefore, producers must adapt the organization of the industry to fit with the state of the market. The relationship had already been discussed with regards to concessions between oil producing countries and international producers, mostly oil producing firms. Wälde (2008^[283]) explains that long term contracts negotiated in times of low prices were widely revised by host countries in the 2000s decade to adapt with high prices. He shows that price increases can lead producing countries to nationalize private ownership assets. On our side, we aim to show that vertical organization also adapt to price changes.

The remainder of this chapter is organized as follows. First, we first discuss the conclusion of the incomplete contract theory to highlight that the price dynamic directly impacts the hold-up risk. Second, we review the literature on the interrelationship between prices and the organization to show that both impact on each other. Finally, we present

some evidence of the impact of price dynamic on the trade structure of the oil industry.

5.2 The role of varying prices in the choice of the organization of industries

In the framework of the “make or buy” analysis, prices have a critical role to play. On the one hand because they directly influence opportunistic behaviors, and on the other hand, because the price and the organization impact each other.

5.2.1 The introduction of prices in the incomplete contract theory

The incomplete contract theory offers to explain the choice of the integration over the market in case of vertical relationships. It involves to analyze the implication of fixed-price long-term contracts on the management of the uncertainty, but also the impact of prices to determine the optimal contractual organization.

Prices in fixed-price long-term contracts

The incomplete contract theory, more precisely Hart and Moore (1988^[131])’s model of hold-up and renegotiation in long-term contract with mutually beneficial investments, has pointed out the role of prices in the organization. We have seen earlier that their model relies on a trade-off between prices fixed in a long-term contract for a transaction to be successful and prices in case transaction do not take place. However, prices described in their model are the result of negotiation between the two parties, the seller and the buyer. The reality of commodity markets would involve to consider the impact of external shocks on prices. Because prices are derived from international benchmarks, producers involved in the trade may not have any influence on the international price which creates a new game in the model. Producers, within the duration of their contract, may benefit from changes in the price dynamic at the detriment of their counterpart. The ag-

grieved producer is likely to have an opportunistic behavior to compensate losses on prices.

Furthermore, prices can also impact investment strategies, as shown by the incomplete contract theory. Since the decision to invest is taken unilaterally after a contract is signed but before the transaction takes place, any change of the fundamental of the market during this period affects producers' behavior. High prices are likely to provide an incentive to invest because the expected returns grow enough to cover the costs. Low prices, on the contrary, would bring producers to focus on private costs reduction, hence a decrease of the investment.

The determination of the optimal organization of the industry: the make or buy decision

The interconnection between prices and long-term contracts with no *ex ante* contract has been widely discussed by the Incomplete contract theory (Williamson, 1985^[275]; Klein, Crawford and Alchian, 1978^[173]; Hart, 1995^[128]). However, the determination of the optimal contractual organization induces the endogenous relationship with prices.

Grossman and Helpman (2002^[116]) developed an equilibrium model in which the organization of firms are endogenously determined. It allows them to conclude on the impact of the fundamental of a manufacturing industry on its organization. They aim to define the optimal organization between the vertical integration and outsourcing in the production of a differentiated product. Therefore, each downstream producer supplies a different product. Their definition of the framework and characteristics organization are derived from the transaction costs theory, mainly Williamson's models (1975^[273], 1985^[275]), and Grossman and Hart's conclusions on long-term contracts (1986^[117]). Vertical integration must deal with high costs of governance, while on the market, specialized producers face variable organizational costs because of research frictions and imperfect contracting on the market. They consider bilateral relationships in which upstream producers, providing the

input, and downstream firms, providing marketing services to distribute the final product to end-users, can integrate production capacities to process the intermediate good.

The main result of their model is to show the strong influence of the competition structure on the organization. They introduce to their model a matching process in which firms can find, or not, their partner with the intuition that an increase in the number of firms on each side of the industry – upstream as well as downstream – increases the probability to find a suitable partner. Higher competition reduces the hold-up risk since it provides other potential counterparts to buyers and sellers. They conclude on the following points:

- Highly competitive markets and cost advantage for specialized production can overcome the research friction resulting from imperfect contracts and reduce the hold-up problem. Producers can easily find counterparts. These market characteristics lead to an increasing use of outsourcing solutions.
- On the contrary, low competitive markets raises the incentive for integration.

With respect to our interest for the relationship between prices and organization, their study present one key contribution since final good prices are determined by bilateral negotiations. When the intermediate trade is realized on the market between specialized producers, the price of the final good depends on the distribution of the surplus and the demand elasticity, while in the case of a vertically integrated producer, the price is derived from the demand elasticity and the marginal cost function. Therefore, they show that greater demand elasticity raises operating profit for specialized firms. They also demonstrate that the intermediate asset's sensitivity to manufacturing costs is a critical argument inasmuch as it has a direct impact on the asset specificity as defined by Williamson. The higher it is, the more costly is incomplete contracting which create an incentive for integration.

Of course, the results of this model present some strong limits to our applications to

oil industries. Indeed, in commodity trading, there is no demand for differentiated demand and commodities are assumed to be homogenous. It is not the asset that is specific but the trading relationship that is due to quality requirements and timing issues that can impact preferences for different origins. Still, their model introduces key features like production costs function and demand elasticities as key determinant of the “take or buy” choice.

Prices and opportunism

The incompleteness arises because a long-term contract defining a price for a predetermined quality could induce producers to reduce costs and quality to increase their margins. Such a situation brings both the buyer and the seller to face a principal-agent problem. Producers have no choice but to find solution to reduce their exposure to hold-up risk. Indeed, in the event of a breach of contract, even the victim must pay court costs, especially since the legal proceeding can be lengthy and the decision remains uncertain (Masten and Crocker, 1985^[196]). Producers must find solutions to deal with contract incompleteness.

The transaction costs theory (Klein *et al.*, 1978^[173] and Hart, 1995^[128]) also shows that, once a production is specialized for a particular transaction without any contract exit, there is a hold-up problem. The buyer can threaten to refuse delivery of the asset if the price is too high. However, ex-post price negotiation may be useless for the seller whose manufactured costs are already paid, hence an incentive to underinvest and produce a lower quantity. Price uncertainty creates an incentive for producers to initiate the vertical integration strategies. In this scenario, the distortion coming from incomplete contracts has similarities with the Perry’s concept of “double marginalization” (1989^[219]). The seller uses its market power to impose a price above the marginal cost to downstream producers, who introduce its own market power to add another markup to prices for end-users. Hence a “double marginalization”, which can be multiplied again, for end-users. Double marginalization is used as an argument for vertical integration over markets with

perfect contracts.

Therefore, opportunistic behaviors can lead parties to negotiate specific-performance contracts and prepare for renegotiation in order to encourage or maintain specific investments (Aghion, Dewatripont and Rey 1994^[2]), or to agree on compensations (Maskin and Tirole, 1999^[195]). Of course, such relationships increase contractual costs. Nevertheless, it is by dealing with this issue that one can find the most dynamic area of academic research in the transaction cost theory on commodity industries.

5.2.2 Oil contractual clauses: “take-or-pay” provisions

In order to mitigate the effect of contract incompleteness, parties can agree on specific contractual clauses. In commodity trading, they usually stipulate an initial price in the contract that can be adjusted by a price pegged to an index, or a predetermined increasing or decreasing rate. But mostly, contracts introduce redeterminant clauses to renegotiate at predetermined periods. Such mechanisms are named the “take-or-pay” provisions and are essential to enable the contract to be coherent with the state of the market and reduce the hold-up problem.

The “take-or-pay” provision

Oil long-term contracts can link upstream and downstream producers for long periods of time depending on the operating periods of a specific site. Contracts can last more than 10 years, hence a high uncertainty derived from price cycles and volatility. The “take-or-pay” provision is an insurance for the parties in which the “take” component works as follows. The buyer can take the delivery of a quantity that is determined as a percentage of the crude oil production during the duration of the contract. Canes and Norman (1985^[47]) also explain that the amount to be traded can rely on a percentage of the production capacities in order to balance the seller’s bargaining power. Thus, the contract is ready to adapt to any supply fluctuations. The evaluation interval can be adjusted for seasonality

and can be operated annually, quarterly or monthly (Walls, 1998^[264]).

Most of the analysis of the “take-or-pay” provisions focus on natural gas trade. Indeed, these contracts link parties usually for 20 to 30 years (Creti, 2005^[71]). Moreover, the industry involved large specific investment both upstream and downstream, particularly with regards to the pipeline connections. The irreversibility of these investments is proven when considering that specific relationships decrease with the number of pipeline connections for both the seller and the buyer respectively. Nevertheless, we must notice that LNG trades revolutioned the industry over the past years and can reduce asset specificities if loading and unloading ports have invested in liquefaction and gasification units.. Nevertheless, we consider that oil trades are also specific for the same reason that pipelines and shipping lines link parties. Other analysis of these contracts can be found on coal trades (Carney, 1978^[48]; Joskow, 1987^[162]) and petroleum coke (Goldberg and Erickson, 1987^[111]).

Theoretical framework

The main framework to analyze “take-or-buy” provisions is provided in Masten and Crocker (1985^[196]) who discussed the limits of long-term contracting because of changes in supply and demand. They focus their analysis on natural gas trades and the specific relationship linking parties once specific investment has been made. They compare provisions to mechanisms creating appropriate incentives for the contract performance. That is why provisions must reduce hold-up incentive. The particularity of these provisions is that they do not need a court to verify the influence of exogenous events since terms are design in order to maximize joint-profits. Thus, a breach of contract can only happen if “alternative uses” are relevant, like selling commodities to another market if prices are higher or storing them and wait for higher prices. They conclude that “take-or-pay” provisions raise long-term contract efficiency because it brings buyers to “release investment to alternative uses only when it is efficient”. This result can be summarized in the three next relationships describing the bilateral trade between a producer and a pipeline:

The pipeline's profit is given by:

$$\Pi_P = \mu(\theta) - y \quad (5.1)$$

Where μ is a value of the well to the pipeline net of transmission costs and gross of payments to the producer and θ is the uncertainty. y is the payment made by the pipeline to the producer. Therefore, the well's profit is given by:

$$\Pi_W = y \quad (5.2)$$

Finally, the third relationship is an inequality highlighting the incentive to discontinue trade and breach the contract, which happen when the value of natural gas passing through pipeline is lower than its price:

$$s(\alpha) < \mu(\theta) \quad (5.3)$$

In this situation, the producer must search for the next highest value of its output, which is named " $s(\alpha)$ ", where α represent the information on the well. The breach of contract is considered to be efficient, since, as in Hart and Moore (1988^[132]), gas must be used in its highest value.

Nevertheless, a sufficient condition for a breach of contract by the pipeline is : $s(\alpha) < y$, that is when $s(\alpha) < \mu(\theta) < y$, the decision is not efficient. Therefore, a court could be needed to determine the penalty (δ) to be paid to the victim. A basic analysis could bring to set the penalty to the expected damages:

$$\delta = y - s(\alpha) \quad (5.4)$$

But because of costly court processes and the uncertainty on court results, the "take-or-pay" provisions offer to determine the penalty (γ) within the contract. Its advantage is to present it as:

$$\gamma = 1 - \frac{s(\alpha)}{y} \quad (5.5)$$

γ is always positive since $s(\alpha) \leq y$ to induce the seller to enter the contract. Moreover, $s(\alpha) = y$ only when the well owner is indifferent between selling to one counterpart or another.

Therefore, they concluded that the number of contracts including these requirements is negatively impacted by the number of pipelines linked to producers. Indeed, it increase the value of producers' alternative sale opportunities.

5.3 The interrelationship between the organization and market fundamentals

The contractual organization sets specificities of the market, but the reverse causality that is the consequence of a change in the organization does not benefit from the same research dynamic.

5.3.1 From the industry's fundamentals to the organization

As pointed out earlier, the state of the world, that is the overall set of information available on a market and an industry, can impact the organization and more precisely the hold-up risk. One of the most significant definition of the organization is given by Grossman and Hart (1986^[117]) who define it as the allocation of residual rights because firms engaged into a bilateral relationship take fundamentals of the industry into account when drafting their contracts. The framework enabled Legros and Newman (2008^[181]) to provide major contribution to this research field.

The allocation of residual ownership rights

Legros and Newman focus on the analysis of residual ownership rights to highlight the impacts of the scarcity of assets into the allocation of control inside the organization. Their model defined managers as the designated agent on which the choice of the organization is taken. Their goals echo with the firm performance since they aim to maximize

their payoff which depends on firms' productivity and private costs. Thus, managers' control right on production process is a major concern. The more assets he controls, the higher productivity the firm is supposed to show, while private costs are likely to increase.

They designed a two-sided model for producers whose contracts are specified through a competitive matching market. They do not include renegotiation process in order to focus on the effect of scarcity of assets, which can be heard as production units, in both sides of the industry. Assets have a large definition so that they can be assimilated to liquidity and technology in their model. They also specify that assets are scarce which make their control a strategic component of the industry.

The adequacy of Legros and Newman's model with the oil industry

The relevance of Legros and Newman's study to the oil industry is found in this definition. The scarcity of production units in the oil industry can be found in the location of these units. Oil reserves are not uniformly spread around the world, which make the ownership of productive asset in optimal locations is scarce.

What is more, the technology also have a critical role, as can show horizontal wells¹ which significantly raised the productivity and the output. Thus, we can imagine that the positive shock on productivity benefited to these producers which could give them the resources to launch integration strategies to acquire new assets.

The role of the market power

While the control of the scarce asset is usually defined by the organization, they rather conclude that the ownership control relies on firms market power. It is the relative scarcity

¹Horizontal wells is a horizontal drilling technology for oil and gas to enhance the well productivity. The devices appeared in 1980 and are now widely used by crude oil producers

of productive assets that allocate right control within the industry. Thus, any change in firms' endowments affects and modifies the welfare distribution and the fundamentals of the industry.

They also show that any event that impact the fundamentals of the industry always benefit to a party at the expense of the other, hence consequences on the organization. Integration is costly but enables a good coordination between managers within the same entity while nonintegration, on the contrary, is less costly but expose managers to changes in their welfare distribution. The authors extended their model to test the impact of liquidity, technology and demand shocks; The main remark to be done on their model is that the liquidity is defined as an instrument transferring surplus between producers engaged into a transaction, but does not consider liquidity for the acquisition of new assets. They show that changes in market fundamentals are twofold and divided into internal and external effects.

- First, a positive shock to firms' liquidity or productivity broadens the set of feasible payoffs for managers, which should lead to a reduction of contractual distortions.
- Second, a positive shock also gives more flexibility to pay a trade partner. That is the external effect: the firm that can take advantage of the shocks will easily find attractive terms of trade in the matching process in the market, while the others will have an incentive to reorganize their activity to fit with the new price.

A positive shock confers market power on the firm that does not need to increase its degree of integration. Therefore, the market should be less integrated. However, if, at the same time, prices rise sufficiently to overcome the liquidity increase, there could be an incentive to integrate.

The impact of interest rates on the organization

Another specificity of their model is the richness of the discussion toward further extensions. They discussed the role of interest rate and the design of the product market. Two

other key components that fits with the analysis of the oil industry.

The role of the interest rate

First, they extend the role of interest rates. Even if they define it as exogenous and unrelated neither to liquidity distribution neither to technology, it clearly impacts agents of the industry. The interest rate ensures a risk-free return for the firm and is, therefore, positively related to liquidity distribution. In their model, where liquidity is only used to transfer assets (there is on purchases of new assets), an increase in the interest rates is similar to a positive liquidity shock. Consequently, by focusing only on the role of liquidity as a surplus transfer and not on its capacity to acquire new assets, interest rates changes follow changes in liquidity and cannot increase the degree of vertical integration. As mentioned in their paper, the use of liquidity as an investing instrument could significantly change their results and would open the analysis of the interest rate for the investment purpose.

Extension of the model to commodity industries would involve to redefine the role of the interest rate. Indeed, investment in productive assets is negatively impacted by interest rate. Moreover, low interest rates reduce the cost of raising capital to finance integration strategy. It is worthy to notice that the decrease of interest rates since the 80s may have motivated this strategy.

The role of endogenous prices

Second, they discuss the influence of a competitive product market with endogenous prices. Thus, a positive shock on supplier's production would, as long as the demand remain the same, lead to a decrease in prices. They explain that competing firms are supposed to act similarly to a negative productivity shock, and the integration of the industry is likely to decrease.

5.3.2 From the organization to the industry's fundamentals

As specified by Legros and Newman (2004^[180], 2008^[181]), the choice of the organization can have consequences on the product market. In a competitive market, the integration is likely to raise output and decrease prices if demand remains the same. This idea is extended in their 2013^[182] study.

The choice of the organization impacts firms' revenue

They designed a perfectly competitive model of firm boundary decision derived from Hart and Holmström (2010^[129]) with a special focus on interactions between the organization and the market, composed of demand, technology, welfare distribution and prices. Two inputs, whose productions can be coordinated or not, are needed to supply the final product. Contrary to Hart and Holmström, who consider two firms, their key contribution is that the industry equilibrium can allow a mixed organization. Thus, both integrated and non-integrated firms can simultaneously co-exist within the same industry. As in their previous papers, the organization equilibrium is found when the welfare distribution and the manager's payoff are maximized. Managers can decide to coordinate and sell an input that is well-suited for downstream processes, or not. Each particular manager's decision, that we can see as an investment issue, is made to maximize the expected output, but without any consideration for the partner's utility. So, they both bear private non-contractible costs. Because of the lack of coordination, they the final producer may fail to generate output, what we can interpret as a failure from the upstream producers to provide inputs. On the contrary, an integrated organization ensures a good coordination but is costly.

In the model, the payoff distribution is affected by the product price, that is the price paid by consumers to acquire the final product. The authors define three equilibrium conditions that create endogenous links between the market and the organization:

- At the equilibrium, agents entered into coalition must ensure a *feasible payoff* given

the corresponding equilibrium price.

- There is a *stability* condition that implies that there is no other coalition providing a strictly higher feasible payoff.
- The *market clearing* condition ensures that supply meet demand.

Conclusions in times of low prices

Finally, they conclude on two opposite effects of the organization on the managerial welfare distribution. For any given price, the vertically integrated organization provide a constant welfare, while the non-integration involves to define a surplus division. They show that, for low prices, the integration's welfare is always lower than the non-integration one.

- Indeed, in the organization, if one of the manager's payoff is exogenous from the organization and does not have any interest in coordination, then its share of the welfare is null. It will not pay any costs. While it is the exact opposite for the counterpart who would need its production to fit with the other's.

Conclusions in times of high prices

On the contrary, high prices lead to the opposite conclusion.

- If the product price increases, the second player is likely to raise its costs and give concessions to the first one to guarantee the good process of the transaction. The second manager is, consequently, bearing large extra costs. The solution to this problem is the integration. This organization forces managers to collaborate, raising costs for the first manager described above, in exchange for a share of revenue from the sale of the product.

Therefore, the higher is the price and the lower is the relative cost of integration. For low prices, on the contrary, benefits from integration are not high enough and the manager has the incentive to focus on private cost reduction. Nevertheless, authors precise that if surplus distribution is close to equality, then managers are both concerned by the

revenue from the sale and need to dedicate a special focus to their private costs. As a consequence, managers are already likely to collaborate without facing costs of integration and the nonintegration always dominates.

Applications to commodity markets

In Legros and Newman 2013^[182] model, the final good sold to consumers is differentiated, while commodity producers, apart from variations in quality, sell homogenous goods. Thus, the downstream production process is relatively rigid and cooperation in the production process may not have the same role in the organization decision. Nevertheless, within the same industry, quality issues can impact trades and investment decisions on multiple segments of the industry. For example, quality and legal framework can lead producers to cooperate in order to control the fitness of inputs in the production process. Furthermore, investment in human capital to ease trade relationship between upstream and downstream agents can also impact coordination.

There is little empirical evidence of the effect of vertical integration on commodity markets, but the analysis of the cement market by Hortaçsu and Syverson (2007^[147]) reach to the same conclusions. They use plant-level microdata of the U.S. cement (upstream product) and ready-mixed concrete (downstream product) from Census of Manufactures which was published every five years between 1962 and 1997. The market is described as fairly competitive. The database gives information on plants activity and lets them identify changes of ownership plans over the years, to measure plant-level technology like factor productivity, capital-labor ratios and trade prices on local markets. Their results serve as new evidences to support the critic of the “naïve theory of foreclosure” which define integration as a way to raise entry barriers and to reduce competition in the market. Indeed, the “Chicago School”, carried by Allen (1971^[6]), Posner (1976^[229]) and Bork (1978^[37]), considered that an upstream monopolist do not raise its profit by acquiring and monopolizing its downstream assets. Nevertheless, we can regret they do not refer to the downstream asset’s price, the cement’s price, on the organization. Even if

they conclude that integration reduces prices, they support the idea that productivity is the key variable. Producers with a higher degree of vertical integration are generally more productive. Better performance raises quantity and lower prices from vertically integrated producers.

Market fundamentals and prices influence the organization

One of the most recent contributions to the study of the relationship between prices and vertical integration comes from Alfaro *et al.* (2014^[5]). Once again, the study does not focus on commodity trades, but it provides a critical contribution to our analysis. The novelty of their paper is to focus on the causality between prices and organization. Indeed, the influence of the vertical integration on prices has already been studied, notably in the foreclosure-related literature and benefits from empirical evidence. However, the reverse causality still remains isolated. To justify this idea, they use the *efficiency view*, that studies the impact of the integration of productivity, to justify the hypothesis they test. This framework considers that integration reduces transaction costs and opportunity (Williamson, 1975^[273]; Grossman and Hart, 1986^[117]), creates multitasking incentives and improved coordination (Holmström and Milgrom, 1991^[144]). Integration dominates when the increase of profitability overcomes the costs of integration. It follows that high prices raise profitability while low prices reduce it. Thus, this allows them to test the hypothesis that vertical integration is positively correlated to prices. This mechanism has the advantage to run under any competition game, while the foreclosure theory underlies imperfect competition.

The authors design a model in which Most Favoured-Nation tariffs on the output are used to ensure that price variations are exogenous to the choice of the vertical integration. An increase in the tariff is expected to raise product prices in the domestic market, thus increasing vertical integration strategies for firms trading in that market. Their main results are based on a cross-section analysis of multi-country firm-level, especially manufacturing companies, both public and private, in 2004. They find that high import tariffs

encourage firm to integrate vertically. This result seems to confirm the initial idea that prices have a significant effect on firm boundaries. They even find larger elasticities for firms operating in market where the mean ad-valorem import tariffs are around 5 percent. Tariff elasticities of vertical integration are estimated to be between 0.4 to 2.1 percent, compared with 0.02 to 0.09 for the full sample estimation. They also find that, for highly competitive markets, the elasticity is even higher. Finally, in order to test for time varying effect of tariff changes, they use the Chinese liberalization who entered into the WTO in 2001. Firm-level data from 1999 to 2007 are used in a PPML model is used to show that sectors which experienced large tariff cut on the period are also the one where vertical integration decreased the most.

5.4 An organization dynamic?

The recent interest in the literature on the role of prices on the organization lead us to discuss new questions about vertical integration movements. The oil industry is known to deal with volatile and cycling prices. If we have theoretical and empirical evidences that organization is impacted by prices, then we might expect that, commodity organization cycles are derived from commodity price cycles or, at least, that there is a dynamic following this idea. Moreover, it should be emphasized the that price level is not the only component of the price dynamic that we would like to study here. Price volatilities are as important and constitute key variables of price risk management. Consequently, it should not be surprising to see the organization adapt its specificities to the price volatility.

5.4.1 Commodity price dynamics

Commodity prices are known to volatile and following a price dynamic for a long time. Price studies were first been linked to development economics to construct economic policies to commodity producers. Deaton and Laroque (1992^[?]) made a major contribution to the analysis of price dynamic by rethinking the theory of production including compet-

itive storage and the foundations of the storage theory. They derived their hypothesis and model from Gustafson (1958^{[120],[121]}) and Williams and Wright's model (1991^[271]). They show that commodity prices can experience sharp rises and peaks in just few months, as their description of sugar prices seems to presuppose in the second part of the 20th century. But they also explain that these volatile prices can impact the revenue of commodity producers and countries whose gross national product (GNP) relies strongly on commodity production. They conclude that the myopia on supply and demand sides as well as speculators owning competitive storages can explain the asymmetry of price changes and episodes of "violent" price increases. On the contrary, prices can remain "in the doldrums" on longer periods.

Asymmetric price changes are highlighted in Cashin *et al.* (2002^[50]). They show that price slumps are found to be larger and takes more time to rebound, by almost a year, than price booms. However, the price growth rate in booms is higher than the price decreasing rate in "regular" times. Those large variations seem to imply that price volatility is not linear and experiences sharp rises. Cashin *et al.* (2000^[49]) had already shown that shocks on commodity prices are long in first-order autoregressive models. In 2001, they use methodology from the study of cycles in real economic activity with a cycle-dating algorithm derived from Bry and Boaschan (1971^[42]), Watson (1994^[265]) and Harding and Pagan (2002^[127]). The advantage of this technique is that it establishes the turning point of the cycles. It leads them to conclude that there is no relationship between slumps and its duration, as us the case for booms concerning most of the commodities studied.

The commodity price supercycle

The sharp increase in commodity prices between 2003 and 2008, when energy and metal prices more than doubled, led Erten and Ocampo (2013^[91]) to identify commodity supercycles from the mid-1800s. They distinguish super-cycles from short-term fluctuations by their origins and components. Super-cycles do not seem to rely on microeconomic

factors and are decades-long. Heap (2005^[135]), from the *Citigroup*, explains that these factors create to long-periods price raises. Metal prices cycle in the 2000s is explained by the growing Chinese demand for building and industrial sectors. Cuddington and Jerrett (2008^[73], IMF) identify three main super-cycles over the past 150 years for six LME metal prices and the signs that a fourth one started in the 2000s. Usually, two cycles are identified until 2000s. The first one is due to the US growth late in 1800s and the second coincides with the reconstruction in Europe and the Japanese fast growth (1945-1975). However, Cuddington and Jerrett divided the second in two subperiods: from 1930 to 1951 and from 1962 to 1977. They also show high correlations between the six metal price cycles. Their findings appear to validate Heap's intuition as they found that cycles begin with prolonged expansions in demand.

Erten and Ocampo (2013^[91]) highlight the relationship with central policies in commodity dependent developing countries to explain price movements. Furthermore, the lag between productive investment and the moment when producers actually change their production capacities can exacerbate price cycles² because of the pro-cyclicality between prices and supply. They also point out the use of commodity products as hedging instruments in portfolio management and commodity indices that feed demand for commodity assets. Following Christiano and Fitzgerald (2003^[62]), they use the band-pass filter approach and identify four super-cycles from late in the 1800s to 2012. They conclude that non-oil commodities show decreasing-mean prices during their supercycles³, as it is observed for metal prices in the 2000s. Oil and metal prices, on the contrary, show a long-term upward trend. Their cointegration analysis, designed through a VECM, confirms that the acceleration of global production is one of the main drivers of commodity prices.

²That is why Erten and Ocampo (2013^[91]) recommend to look at midterm prices when defining the production capacities.

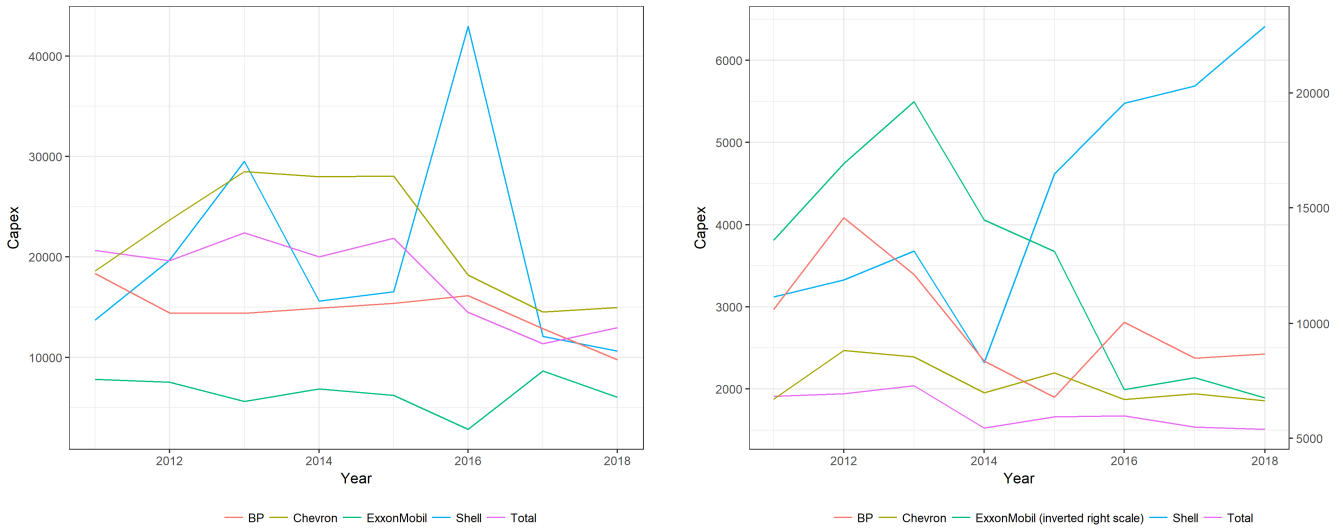
³This result supports the Prebisch-Singer hypothesis, which is used as a regular framework for the study of commodity prices (Ocampo and Parra, 2003^[211]). The Prebisch-Singer hypothesis assumes that the price of commodities – produced in emerging countries – relatively to manufactured products – produced in industrialised countries – declines over time.

Another part of the literature on the analysis of commodity price dynamics and cycles focuses on price volatilities. The study of commodity price volatilities is essential for commodity investments and the hedging strategies (Baillie and Myers, 1991^[20]; Chang, McAleer and Tansuchat, 2011^[56]). GARCH-class models are widely used to model commodity price conditional variances, they are found to outperform other models (Kang *et al.*, 2009^[164], Mohammadi and Su, 2010^[203]) and used for forecasting (Wei Wang and Huang, 2010^[266]). Another benefit from these models is that their extension to dynamic conditional correlation models enable them to identify volatility spillovers between commodities and stock markets (Creti *et al.*, 2013^[72]) even if many empirical papers do not conclude on clear results (Vivian and Wohar, 2012^[263]). DCC-GARCH models also have the particularity to look at the correlation between different commodities, that is to say commodity co-movements, as an extension to cointegration analysis of commodity prices. Luo and Ji (2018^[188]) highlight spillovers from the US crude oil market to Chinese's agricultural commodity markets. Their results support the cross-correlation analysis of GARCH estimation on US oil and agricultural products provided by Nazlioglu *et al.*(2012^[205]).

5.4.2 Price cycle and investment strategies in the oil industry

In addition to the analysis of specific investments provided by the incomplete contract theory we should also take into account productive investments. However, more than specific relationships, productive investments are highly sensitive to the price dynamic. Indeed, increasing price trends create an incentive to raise production in order to benefit from high prices, while decreasing trends reduce producers' investment to minimize their costs. Evidences can be found in oil producers' segmental financial reports (see figure 5.1).

Figure 5.1: Capital expenditures in major oil producers, millions of USD



(a) Upstream segment

(b) Downstream segment

Source: Annual financial reports

Both charts, on upstream and downstream segments, seem to validate the fact that capital expenditures follow the price dynamics. From 2011 to 2013, we see that investments are high in both sides, supported by high costs to finance them. Changes are observed in the downstream side starting 2013. Crude oil sky-high prices maintained investment level upstream, but led to a decrease downstream. Indeed, higher crude prices reduce margins causing producers to orientate their finance to the most valuable segment of the industry: upstream.

Nevertheless, the first chart indicates a significant slowdown or decrease in capital expenditures in the upstream segment of the supply chain from 2015 to 2018, with the exception of ExxonMobil whose expenditure increased in 2017. The crude oil price drop, coming from an oversupplied market, influenced producers to reduce unbalances. Moreover, the financing of investments is no more backed by the strong price trend. On downstream segments, capital expenditures remained relatively similar with the exception of Shell and BP from 2015 to 2018. Both increased, strongly for Shell and moderately for BP, their investment. The segment benefited from low crude prices to restore their refining margins. It also explains the allocation of finances from upstream to downstream capital expenditures.

These results also raise concerns about the procyclicality of productive investment in commodity industries. The previous figure shows us that investments respond to prices but also expose producers to over-invest in the industry. While high prices can maintain returns, price downturns can have exacerbated effect in the industry. Because of the rigidity of the crude oil production process, it takes time to adjust capacities. Thus, in case of the turnaround in price supercycles, like the one observed in the summer of 2014, producers keep feeding the oversupplied market in spite of unattractive returns due to the low prices.

5.4.3 Changes in oil producers' segmental activities

Many commodity price trends seem to be governed by super-cycles which clearly impact organizational structure. Thus, one would expect that price dynamics would lead to an organization dynamic. Indeed, the tight interrelationship between them brings us to assume that the organization must systematically adapt to the price dynamic. Following basic results from industrial economics, we can assume organization to be more vertically integrated to compensate the high fixed costs when revenue and prices are increasing. Moreover, integration gives the opportunity to capture a higher part of the value added of a high-revenue industry. While low and decreasing prices would lead to a more dis-integrated industry to restore flexibility and reduce organizational costs. Moreover, if volatilities are considered in the organization design of the industry, we can also expect producers to adapt their contract to commodity volatilities in order to reduce their risk exposure if needed. In that case, the use of short-term contract appears to be optimal to avoid tied-hands by producers in long-term contracts.

Regardless of the extend of the results on the relationship between organization and price dynamics, the failure to take price levels into account is a major concern. Compared with manufacturing industries, the mining, metallurgical and energy sectors are

characterized as price-takers. While some producer groups, companies or countries, such as OPEC, may well have an influence on prices, it appears that they do not determine them, not even in the short term (Wirl and Kujundzic, 2004^[277]; Brunetti *et al.*, 2013^[41]). In a context of traditionally low margins, prices are therefore an important determinant of the profitability of operators in the sector and, consequently, a driving force of their commercial, industrial and investment strategies.

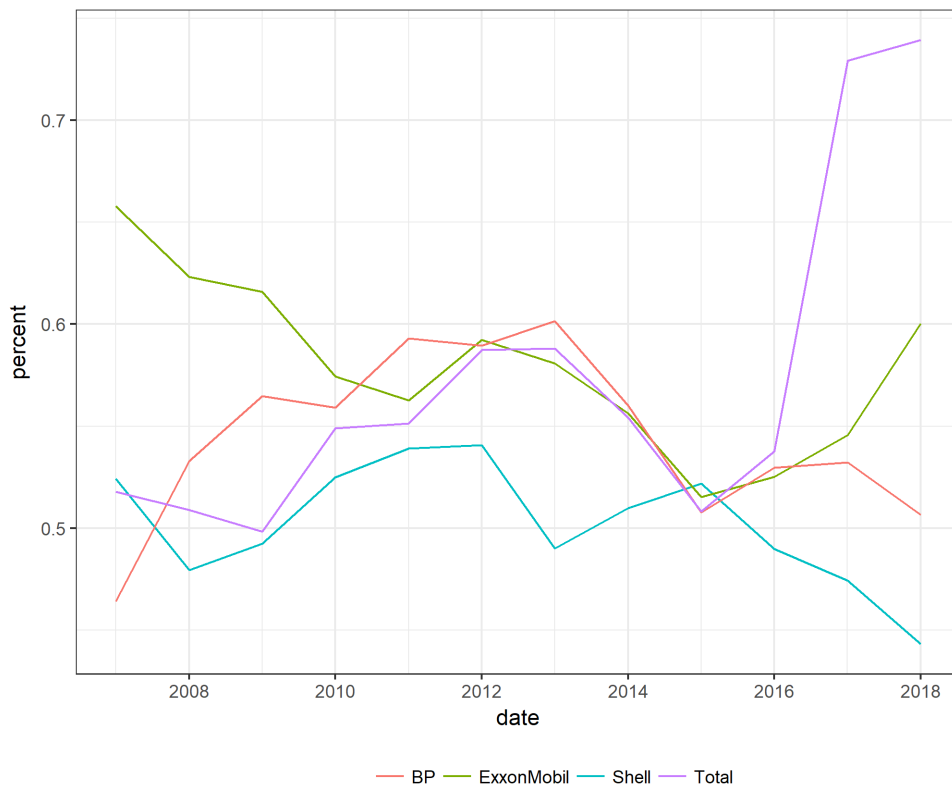
We have already established that the oil industry has experienced several periods where the productive apparatus has been vertically integrated. Even after the opening of the markets in the 1970s, which opened up the strategies of disintegration, most companies maintained operations in multiple segments. Moreover, this is consistent with the common belief that oil industries, being visible, large, and established long-term companies, are necessarily vertically integrated. Nevertheless, they remain largely sensitive to changes in segment margins.

In the oil industry, producers benefited from high price because of the so-called commodity supercycle which has given them the financial support to bear the cost of vertical integration strategies. But, as crude oil prices were hitting new records, ConocoPhillips took the opposite position in 2012. Instead, they rather observed that high crude prices stressed refining activities and largely decreased margins. For this reason, it decided spin off its refining and market assets into a new separated company: Philipps 66. The disinvestment allowed ConocoPhillips to focus on its core business that is the upstream segment. The real impact of this operation appeared with the end of the so-called commodity price supercycle described above. The sharp drop in oil prices did not allow producers to bear their high costs of integration, and most of them exhibited a need for flexibility and a new focus on their core activity. ConocoPhillips, on the contrary, had previously launched its disintegration strategy and went through the crisis relatively better than its main competitors did.

Because of the pression coming from the reversing trend of the commodity supercycle,

costs of the vertical integration became relatively too high and producers were more likely to divest in order to restore flexibility. Disintegration strategies allowed producers to focus on their core business to ensure returns. Based on the figure 5.2 on intersegment sales in major oil producers, we can see that the share of internal transfers decreased significantly starting 2014.

Figure 5.2: Intersegment sales in upstream sales of major oil producers



Source: Firms' annual financial report

Whereas high prices between 2007 and 2012 led to an increase in the share of intersegment trades in total upstream sales for four major oil producers (BP, Chevron, ExxonMobil, Total) the opposite occurred in subsequent years (see figure 5.2). Indeed, the years 2014 and 2015 marked a noteworthy decline in the percentage of internal trades for three out of four producers (BP, ExxonMobil and Total). This raises the question of why this major shift occurred. If the sharp increase in Total intersegment sales in 2016 and 2017, can look surprising it actually results from a redefinition of upstream and

downstream segments in their financial report. These observations appear to validate the assertion that the fall in prices has led producers to reduce internal transfers, *i.e.* to reduce their degree of vertical integration, in favor of external trades on the market. It is coherent with theoretical and empirical findings. Chen (2005^[57]) shows that vertical disintegration is beneficial when it increases the economies of scales and when the upstream producers can charge a competitive price. Applied to commodity industries, Barrera-Rey (1995^[26]) tests the usual hypothesis of a correlation between vertical integration, size and performance of oil companies. A cost-benefit analysis indicates that integration leads to diseconomies of diversification which have to be compared to the decrease in the price risk exposure.

5.5 Conclusion

In the market, the analysis of commodity industries differs from traditional studies on the contract incompleteness for differentiated manufactured goods. Commodities trading deals with homogenous products and opportunism does not necessarily arise from specific relationships or specific investments. Prices changes always create a winner and a loser once producers are locked into a long-term fixed-price contract. Changes in the market fundamentals, both from the supply and the demand sides, also create incentives to opportunism. That is why, the contract incompleteness imposes producers to set contractual clauses.

In this chapter we have highlighted the impact of varying prices on the hold-up risk and productive investment strategies. The analysis of the oil industry shows that upstream and downstream investments are sensitive to price changes. In this chapter we have highlighted the impact of price variations on the hold-up risk and productive investment strategies to show the impact of commodity price dynamic. High prices allow producers to support the investment cost of a vertically integrated organization. However, a segmental analysis indicates that prices can also have an asymmetric impact. High prices can squeeze

refining margins and direct investment to upstream units. This is likely to lead producers to disintegrate low value-added segments of the business. While, low prices have the opposite effect.

Chapter 6

Optimal organization in the oil industries

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6.1 Introduction

Now that the particular and critical role of commodity traders in the industry has been established, we can study their influence on the organization of the oil industry. Indeed, given that the organization aims to reduce producers' risk exposure and maximize their profits, the introduction of players whose role is specifically to manage risks must have consequences. The transfer of crude oil barrels to downstream segments can take multiple forms. We have presented that integration and long-term fixed-price contract are the two organizations that benefits from the highest attention in the academic literature. However, both have certain limitations. The first entails high organization costs, while the second exposes to the hold-up risk.

In this last chapter, we aim to show that commodity traders bring another viable organization to the industry. They can manage the price risk exposure inherent to short-term price contracts. Thus, they make short-term contract a credible solution for commodity trades. In this chapter, considering the short-term contract leads to a spot trade, a spot contract is assumed to similar to a short-term contract. Of course, in reality producers have more than these three solutions (the integration, the long-term fixed-price contract and the short-term contract) to trade commodities. The market and the integration can be seen as the two boundaries of a segment whereas producers can trade through numerous hybrid organizations like joint-ventures. However, the opposition between market trades and internal transfers through the integration allow to discuss the consequences of price and hold-up risks. We must also note that the long-term fixed-price contract is a very specific case since trading prices are rather anchored on a reference price and periodically renegotiated instead of being totally fixed. However, this does not mean producers do not face opportunism on price indices variations and do not pay high renegotiation costs. Therefore, these three organizations define a relatively large scope of trading contracts on which hybrid solution can be associated to each of them.

Our purpose is to determine the optimal contractual organization to transfer crude oil from upstream to downstream producers through a theoretical approach. We develop a partial equilibrium model of the crude oil industry with competitive storage like Broussard and Mitra (2011). Moreover, we include into our model that the presence of commodity trader to allow producers to trade crude oil through short-term contracts. We show that the optimal organization depends on the state of the world and more precisely on the price dynamic. Our results indicate that there are price conditions for each of the three organizations to be optimal. Prices must be high to enable producers to finance the organization costs of a vertically integrated firm. Short-term contracts are preferred when prices are low because they allow flexibility to be restored. Finally, long-term contracts can only be a credible solution for producers when the price volatility is low. Consequently, finding the right organization is a matter of timing and producers must take decisions based on their expectation on the future state of the market.

The second ambition of the model is to demonstrate the interrelation between the choice of the organization and crude oil prices. Cyclical effects can emerge and exacerbate price variations. High prices triggered by an undersupplied market can lay the foundations for vertical integration processes. Moreover, this is likely to increase production capacities in order to raise profits and cover organizational costs. Nevertheless, this strategy is only attractive if prices remain high and the market undersupplied on the long run. Therefore, producers must face with the risk that the market may switch from undersupply to oversupply, with a consequent price decrease. Indeed, oversupplied commodity markets discovered in summer 2014 led to major reversal in price trend. For this reason, we conclude that, in addition to cyclical prices, the pattern of crude oil trade organization relies on cyclical vertical integration processes.

The reminder of this chapter is organized as follows. In a first part, we present a theoretical model of the oil industry. In a second part, we test the results of our model to identify the optimal organization of the oil industry for upstream producers.

6.2 Modelling the oil industry

We model a partial equilibrium model with competitive storage and commodity traders based on the oil industry. We aim to identify the optimal organization for an upstream producer to trade crude oil to downstream assets, either through a vertically integrated firm or through the market. Therefore, in this first section, we present the main characteristics and assumption of our model.

6.2.1 Actors of the model

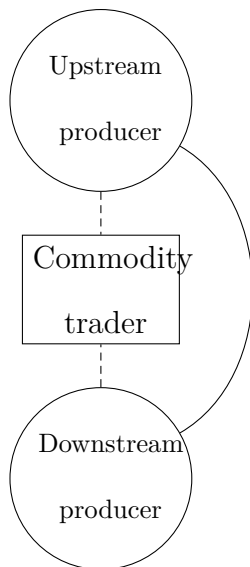


Figure 6.1: Industry organization

We consider three agents: a buyer, a seller and a commodity trader. The upstream stage is composed of crude oil producers selling barrels to downstream buyers (refiners). There are three organizations in the industry. Producers can trade directly with each other in the market through the long-term fixed-price contract (straight line) or the spot contract (dotted line). In the second case, they are use an intermediary, the commodity trader, in order to manage the price risk. They can also trade within a vertically integrated firm. Thus, there is no more trades on the market and producers are under the same authority organizing trades between its segments. An internal transfer price substitutes the market price, cancelling the price risk. For simplicity, we consider that, downstream, the refiner sells a finished product to the demand, either for consumption, either for storage.

We assume that commodity traders are pure third parties in the industry, which means that they can only be intermediaries not involved in the production process. They are independent actors reconciling in time and in geographical space, supply and demand for a commodity. We assume that these midstream companies are the only one with access to financial markets to manage the price risk for producers.

Of course, nowadays, major producers and refiners own trading facilities to manage those risks, but independent commodity traders subsist in the industry thanks to their network and their capacity to lever large amount of money and ease trades (Pirrong 2014^[228]). The presence of independent third actors contrasts with some conclusions of the Incomplete contract theory and notably Hart and Moore (1987) who explained that “large potential efficiency from the inclusion of a third party is limited by the collusion by two of the agents against the third”¹ what is not verified in the oil industry considering the role played by traders like Glencore, Vitol or Gunvor in the oil industry as demonstrated in Chapter 2.

6.2.2 The timing of the organization strategy

Producers use the organization that best suits the state of the world. We define the state of the world as the whole set of information available on the market *i.e.* supply, demand, prices, expectations, and the behaviors of both parties of the trade. As in Hart and Moore (1988), there is always a time mismatch between the date when producers agree on the organization in t_0 , and when the transaction occurs, in t_1 . In t_0 producers take a decision based on their expectations on the future state of the world in t_1 . Supply responds to price incentives that may or may not materialize (Hamilton 2008^[122] and Smith (2009^[254]). The supply is too rigid to be adapted simultaneously to any change in the state of the world.

The figure 1 represents the life of a contract based on Hart and Moore^[130]. The organization is rigid until the transaction happens, with the exception of the long-term contract in which producers can defect in t_{1-k} , where k is the minimum time required to deal a spot transaction. Thus, t_{1-k} is a date close to the physical trade t_1 and the corresponding state of the world is already known by both of the parties.

¹Hart, O., and Moore, J. Incomplete contracts and renegotiation. *Econometrica: Journal of the Econometric Society* (1988) footnote 20 p. 774

Figure 6.2: Contract lifetime



Here is an example. In t_0 , a drilling company decides on its organization to sell crude oil barrels in t_1 . If it chooses to set a spot transaction, then it waits for the date t_{1-k} to deal at the t_1 price. If it chooses the vertical integration in t_0 , then the transaction will be achieved internally in t_1 , and there is no way to change the organization before the end of the period. But if it chooses to exchange through a long-term contract, the producer or its counterpart can defect in t_{1-k} when the state of the world in t_1 is known, this is the counterpart risk. Then producers have just enough time to deal a spot contract for a transaction in t_1 .

6.2.3 The model

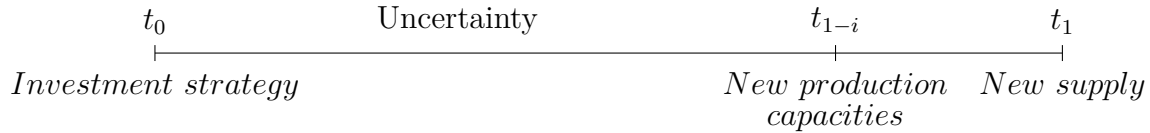
We consider a representative price-taking crude oil producer U producing Q_t crude oil barrels priced on the spot market P_t . The producer chooses between three possible organizations i : the spot contract sc , the long-term fixed-price contract lt and the vertically integrated firm f . The organization determines productive investments I_t^i . The impact of the price dynamic on the organization can be summarized in two main features: high prices create incentive to increase productions and transaction costs partly depend on prices.

As presented in the previous section, there is a time lag between the choose of the organization and its application on trades. Consequently, risk-neutral producers define their expected profit Π_t^e , here modelled in the simplest way as in Alfaro *et al.* (2016^[5]):

$$\Pi_t^e = P_t^e Q_t^{cap}(I_t) - PC(I_t) - \Phi(I_t) \quad (6.1)$$

Production is derived from capacities fixed by producers in the previous period when they decide on their investment strategy. Producers define their new production capacities Q_t^{cap} as the expected production for the next period. Again, we assume a lag of one period between the time they choose their investment strategy and the time supply is affected:

Figure 6.3: Investment strategy



$Q_t^{cap}(I_t)$ is an increasing function of the investment I_t through the positive parameter λ which is the number of barrels produced by “unit of investment”. Because of the rigidity of the organization, we assume that producers cannot radically change their strategy. Considering we are dealing with a strategic asset, we have a minimum production capacities Q_{min} :

$$Q_t^{cap^i} = Q_{min} + \lambda I_t \quad (6.2)$$

$PC(Q_t^{cap}, I_t)$ is the cost of producing Q_t^{cap} barrels. It is an increasing function of the production capacities and of the investment:

$$PC_t = A_{MC}Q_t^{cap^i} + \eta I_t \quad (6.3)$$

Where A_{MC} is a positive parameter representing the minimum marginal cost of crude oil barrels and η is the unit cost of investment.

Φ is the organizational cost which can take three different forms depending on the organization (the spot contract, the long-term fixed-price contract or the firm). As in Alfaro *et al.* (2016^[5]), when it is an integration cost, it is independent of production (Q_t^{cap}, I_t) and the price P_t^e .

Investing is risky for producers, they cannot afford to invest and increase the capacities

if the expected demand is not high enough. The optimal investment in t is obtained by maximizing the expected utility from investment I_t in the second period $t + 1$. The expected outcome sensitive to the investment strategy Y_t^e is:

$$Y_t^e = \lambda I_t P_t^e \quad (6.4)$$

Starting from this point, we assume that producers are risk averse when deciding on their investment strategy. Therefore, we define their expected welfare derived from their investment decision, W_t^e , net of risk by the mean-variance equation :

$$\begin{aligned} W_t^e &= Y_t^e - \frac{1}{2} A_i \text{Var}(Y_t^e) \\ W_t^e &= \lambda I_t P_t^e - \frac{1}{2} A_i \lambda^2 I_t^2 (\sigma_t^e)^2 \end{aligned} \quad (6.5)$$

Where A_i is the risk aversion parameter, that is the sensibility of the investment to price risk, and σ_t^e the expected price volatility, we assume: $\sigma_t^e = \sigma_t$.

At equilibrium, the marginal welfare gain of investing equals the expected marginal cost of investing $\frac{\partial W_t^e}{\partial I_t} = \frac{\partial PC_t}{\partial I_t}$:

$$\frac{\partial W_t^e}{\partial I_t} = \lambda P_t^e - A_i \lambda^2 I_t (\sigma_t^e)^2$$

Production capacities are set as the production target $Q_t^{S^e}$ for the next period. Hence, we have $Q_t^{cap^e} = Q_t^{S^e}$ and:

$$\frac{\partial PC_t}{\partial I_t} = \lambda A_{MC} + \eta$$

We have :

$$\begin{aligned} \frac{\partial W_t^e}{\partial I_t} = \frac{\partial PC_t}{\partial I_t} &\Leftrightarrow \lambda P_t^e - A_i \lambda^2 I_t (\sigma_t^e)^2 = \lambda A_{MC} + \eta \\ I_t &= \frac{\lambda P_t^e - \lambda A_{MC} - \eta}{A_i \lambda^2 (\sigma_t^e)^2} \end{aligned} \quad (6.6)$$

Proposition 1 : Investments increases with prices

$$\frac{\partial I_t}{\partial P_t^e} = \frac{\lambda P_t^e}{A_i \lambda^2 (\sigma_t^e)^2}$$

$$\text{Hence, } \frac{\partial I_t}{\partial P_t^e} > 0 \text{ for } \lambda > 0 \quad (6.7)$$

High prices provide an incentive to invest and expand production capacities. Producers can only afford increasing marginal costs if the selling price is high enough. On the contrary, low prices do not create opportunities for extra production, they must lead to divestment. Furthermore, they are frequently linked to excess supply, hence the need to restructure production by reducing supply similarly to our observation on the price fall starting 2014.

Proposition 2 : Price volatility decreases investments

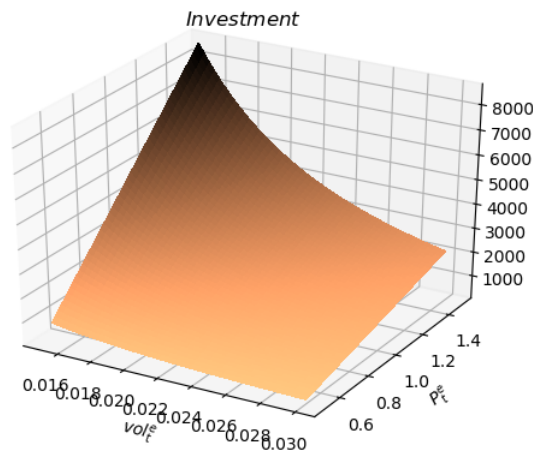
$$\frac{\partial I_t}{\partial \sigma_t^e} = \frac{2(\lambda A_{MC} + \eta - \lambda P_t^e)}{A_i \lambda^2 (\sigma_t^e)^3} \quad (6.8)$$

Then, $\frac{\partial I_t}{\partial \sigma_t^e} < 0$ for $\lambda A_{MC} + \eta < \lambda P_t^e$ in which $\lambda A_{MC} + \eta$ the marginal cost of investment and λP_t^e is the marginal welfare by unit of investment. We can assume that there is investment only if the marginal welfare is superior or equal to the marginal cost, otherwise $I_t = 0$, hence a negative relationship between investments and price volatility.

Producers reduce their investment if the selling price is uncertain. On the contrary, low volatility decreases producers' overall risk exposure which includes both price and investment risk.

Figure 5 is a three-dimensions representation summarizing the last two propositions. When prices are high and the volatility is low, the slope of the plan is sharply increasing in the red part of the surface.

Figure 6.4: Productive investment and expected price and volatility



$$A_i = 3, \lambda = 0.0083, \eta = 0.0059.$$

The three organizations

We define a contract as a set of commercial commitments to which both of the parties comply with to trade an asset. We only talk about “commitments” because the involvement may not sufficient to guarantee the trade. A contract can be broken by one of the actors. We consider three organizations.

Spot contract

The short-term or spot contract *sc* only deals with the short term, there is no commitment out of the one-shot transaction². The spot price is based on a reference price, usually a future price³. The contract does not ensure the trade flows and it exposes to price risks. As a consequence, the price risk management is transferred to the commodity traders (Johnson 1960^[160]).

The commodity trader carries the price risk for the upstream producer by buying the barrel with a discount to remunerate his activity. We describe the discount as a positive convex function of the spot price because the producer is more likely to accept a bigger discount when prices are high enough to cover his margins. Whereas, with low prices,

²We notice that the spot transaction cannot be set instantaneously as there is always a time mismatch. However, it is relatively small. It depends on the traded commodity, that is why it is difficult to quantify the short term in commodity economics

³Indeed, unlike the spot market, the financial markets give publicly traded price.

the producer negotiates low discounts, but the trader can charge a higher premium when they carry the risk for the downstream producer. We assume premium π_t and discount δ_t functions follow inverted movements:

$$\pi_t = A_{pr} \frac{1}{P_t^2} \quad (6.9)$$

$$\delta_t = A_d P_t^2 \quad (6.10)$$

A_{pr} and A_d are two parameters representing the sensitivity of commissions δ_t and π_t to price levels.

The commissions δ_t and π_t are the transaction costs Φ_t on the spot market.

Long-term fixed-price contract

In the model we refer to long-term contracts *lt* as long-term fixed-price contracts in which firms decide to trade a good at a date and a price settled in advance. This contract removes price risks. In accordance with the transaction cost theory, we can distinguish *ex-ante* from *ex-post* costs (Williamson 1981). *ex-ante* costs are pre-contractual charges paid to organize the transaction and conclude the contract, while *ex-post* costs are post-transaction charges. In this chapter, we assume *ex-post* costs arise because of counterpart risk. Indeed, the delay between the signature and the trade exposes to a counterpart risk because one can go bankrupt, experiences logistical problems or decides to break the contract. In the model, we restrict this risk to opportunism and, unlike conventional studies from economics of the institutions, we support the idea that it is, at least partly, derived from the price dynamic. Indeed, the price fixed in the contract is based on a reference price, most of the time it is the future price for the same maturity, at the date of the signature. So, until the date of trade, prices can sharply change creating a winner and a loser. A seller, upstream, could benefit from a price increase at the expense of the buyer, downstream. He could turn to a spot trade with another buyer to benefit from a higher

price. And vice versa if prices go down, the buyer would be seeking for the lowest price.

ex-post costs: the counterpart risk exposure

Our measure of the *ex-post* costs for producers on the long-term contracts is the counterpart risk. To value it, we propose a new methodology describing opportunism in long-term relationships, inspired by Hart and Moore (1988^[131]), based on the price dynamic. As explained above, the spread between the price fixed in the previous period and the current spot price creates an incentive to break the contract. This is why there are contractual clauses dealing with penalties when the trade is not as stated initially (MacDonald *et al.* 2004^[189]). The clauses, also close to the definition of the “take-or-pay” provisions, are negotiated to reduce the incentive to have an opportunistic behavior. We assume producers agree on exit costs that are paid to the counterpart in compensation for a breach of contract. Exit costs are similar to cushions reducing the counterpart risk by absorbing part of the spread. Parties can impose different exit costs to each other, that we defined as ec_t^b and ec_t^s respectively to the buyer and the seller. Maximum exit costs ($ec_t^{b^{max}}$; $ec_t^{s^{max}}$) is a fraction of the price fixed in the contract:

$$ec_t^{b^{max}} = \theta_t^b P_t^{LT} \quad (6.11)$$

$$ec_t^{s^{max}} = \theta_t^s P_t^{LT} \quad (6.12)$$

Exit costs ec_t^b and ec_t^s are determined within the respective intervals $[0, ec_t^{b^{max}}]$ and $[0, ec_t^{s^{max}}]$ after negotiations when producers enter into the contract. θ_t^j is a positive variable linked to the volatility for $j = b, s$. The more uncertainty increases, the more exit costs increase to reduce the counterpart risk. Hence:

$$\theta_t^j = 1 - \exp(-\mu^j vol_t^e) \quad (6.13)$$

Where μ^j is a positive parameter.

We notice that exit costs and the price fixed in the contract P_t^{LT} are determined at the

date of signature in t_0 , but these variables are compared to the spot price P_t at the date of transaction in $t = 1$ (in accordance with the figure 3).

Nevertheless, exit costs are not necessarily deterrent. Indeed, the potential profits from trading with another party on the spot market can exceed these costs. The transaction costs of the long-term contract are derived from the counterpart risk. The former is defined as the probability to see that the trade does not happen ($Q = 0$). In other cases, there is no price change or the exit costs balance the spread, then the transaction happens ($Q = 1$). We have the following propositions:

- *If $P_{t-1}^{LT} = P_t$, then $Q = 1$.*

Both of the producers have made good price expectation and the predetermined price is still coherent at the date of transaction. None of the producers is willing to break the contract.

- *For $P_{t-1}^{LT} - P_t < 0$, if $P_{t-1}^{LT} - P_t < ec_{t-1}^b$ then $Q = 1$.
For $P_t - P_{t-1}^{LT} < 0$, if $P_t - P_{t-1}^{LT} < ec_{t-1}^s$ then $Q = 1$.*

Even if one of the counterparts could trade at a better price on the spot market, the benefit from the breach of contract is not high enough to overtake the exit costs.

- *For $P_{t-1}^{LT} - P_t < 0$, if $P_{t-1}^{LT} - P_t > ec_{t-1}^s$ then $Q = 0$.*

The downstream producer on the buy side can benefit from a breach of contract because he can buy the barrel cheaper on the spot market and his gains exceed the exit costs. The upstream producer is the victim.

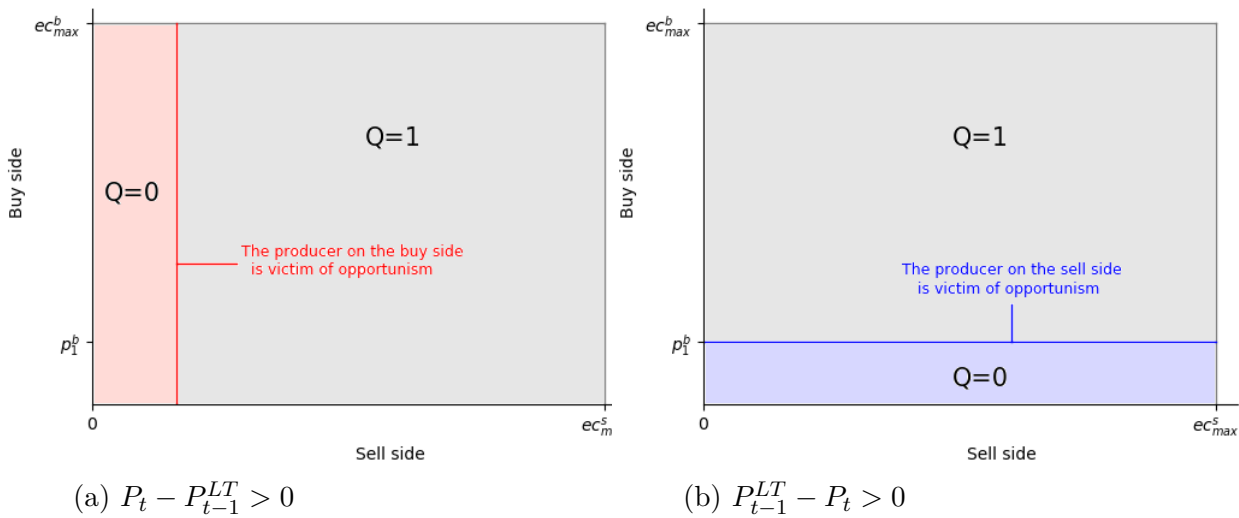
- *For $P_t - P_{t-1}^{LT} < 0$, if $P_t - P_{t-1}^{LT} > ec_{t-1}^b$ then $Q = 0$.*

The upstream producer on the buy side can benefit from a breach of contract because he can sell the barrel more expensive on the spot market and his gains exceed the exit costs. The downstream producer is the victim.

The counterpart risk is the probability that the last two scenarios occur. We define $p_1^b = P_{t-1}^{LT} - P_t$ and $p_1^s = P_t - P_{t-1}^{LT}$ as the price differentials benefiting respectively the buyer

and the seller. ec_{t-1}^s and ec_{t-1}^b are the maximum exit costs the producers negotiate for their respective counterpart. The figure 2 illustrates the counterpart risk in the long-term contract:

Figure 6.5: Counterpart risk in the long-term contract



We assume the grey area represents the set of possible exit costs the producers agree on at the date of the signature. On the figure 6 (a), if the seller's exit costs are within the red area, the producer on the buy side is a victim of opportunism because the exit costs are not high enough to cover the price increase, $Q = 0$. But out of the red rectangle, the breach of contract is not profitable for the producer on the sell side $Q = 1$. Symmetrically, in the second figure 6 (b), the buyer has an incentive to break the contract if $p_1^b > ec_t^b$ (within the blue rectangle).

The counterpart risk is the probability CR_t that the trade does not happen. When dealing a long-term contract, producers expect to agree on a price that avoids any counterpart risk. They do not want to be a victim either to initiate the breach of contract, because they cannot know if the price change would be at their benefit or at their expense. By assuming a uniform distribution of the couples of exit costs $\{ec_t^B; ec_t^S\}$, the counterpart

risk is the ratio of the red or the blue area on the grey area:

$$CR_t = \text{Max} \left(\frac{p_1^s ec_t^{s^{max}}}{ec_t^{s^{max}} ec_t^{b^{max}}}, \frac{p_1^b ec_t^{b^{max}}}{ec_t^{s^{max}} ec_t^{b^{max}}} \right)$$

$$CR_t = \text{Max} \left(\frac{p_1^s}{ec_t^{b^{max}}}, \frac{p_1^b}{ec_t^{s^{max}}} \right)$$

We assume the expected counterpart risk: $CR_t^e = CR_t$, hence:

$$CR_t^e = \text{Max} \left(\frac{p_1^s}{ec_t^{b^{max}}}, \frac{p_1^b}{ec_t^{s^{max}}} \right) \quad (6.14)$$

If $CR_t^e > 1$, because $p_e^s > ec_t^{s^{max}}$ or $p_e^b > ec_t^{b^{max}}$, then the counterpart risk is assumed to be 1. Whatever the exit costs decided at the date of signature, one of the producers would defect.

For simplicity, in the model, we assume $ec_t^{b^{max}} = ec_t^{s^{max}}$ meaning that:

$$CR_t^e = \text{Max} \left(\frac{p_1^s}{ec_t^{max}}, \frac{p_1^b}{ec_t^{max}} \right) \quad (6.15)$$

As the errors of estimates are preponderant variables to determine the counterpart risk, we have: $P_t^{LT} = P_t^e$.

ex-ante costs

Agreeing on exit costs can be costly for the firm, the more uncertain is the future price and the higher are the *ex-ante* costs. Otherwise, producers would be likely to fix $\theta_t = 1$ cancelling the counterpart risk. We define eac_t as the *ex-ante* costs:

$$eac_t = \rho \theta_t \quad (6.16)$$

Where ρ is a positive parameter traducing that a full hedging by the exit costs is costly.

Vertically integrated firm

In a firm, there is no property right transfer (Coase 1937^[63]), meaning that outlets and supplies are guaranteed. Opportunism disappears and the market price is substituted by an internal transfer price. The firm can benefit from economies of scale and greater efficiency. The firm is costly and exposes to heavy transaction costs paid at each period to keep the firm vertically integrated. We define these costs by OC , a high and fixed parameter. They are paid to achieve vertical integration and are usually financed by debt, hence the importance of the interest rate, and/or by mobilizing shareholders⁴. They can also be seen as the costs of maintaining the authority of the firm on multiple stages. Aghion and Tirole, 1997^[3] distinguish formal from real authority — that is how well the information is diffused within the firm — showed the importance of these costs. Uncertainty does not totally disappear because the firm still needs to sell the commodity to end users. Refined products remain highly correlated to crude prices.

The specificities of the three organizations are summarized in the following table:

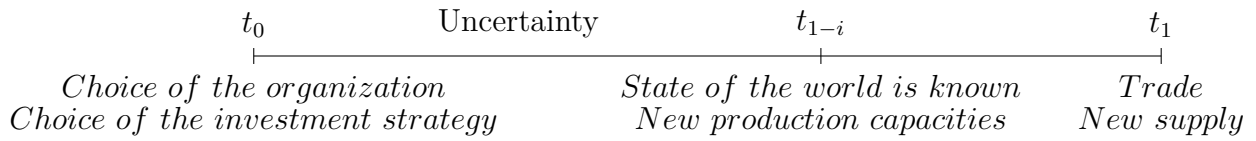
Table 6.1: Summary of the transaction costs:

| Market | | Firm |
|---|---|--|
| Spot contract | Long-term contract | |
| Price risk No counterpart risk The transaction cost is the commission paid to the commodity trader hedging the price risk | No price risk Counterpart risk The transaction cost is the <i>ex-ante</i> costs, plus the potential losses in case the producer is a victim of opportunistic behavior | No price risk No counterpart risk The transaction cost is a high fixed cost paid to keep the company vertically integrated |

At each period, producers choose the organization fitting with their investment strategy and the expected state of the world:

⁴It exposes the strategy to the shareholders' support. Extending the vertical integration of a company can be in conflict with the shareholder's portfolio investment strategy. An investor looking for a crude exposure might not welcome a redirection of the activity on the refining activities as a good opportunity.

Figure 6.6: Timing of the contract



The optimal organization

We can now determine the optimal organization by maximizing the producer's investments and comparing their resulting expected profits Π_t^{ie} , with i the organization. Profit functions are derived from the sales revenue, the production and investment costs from equation 1. Unlike section 2.3, we introduce organizational costs in the optimization program, meaning that, now, we deal with total costs functions TC_t . It is the cost of producing and selling Q_t^{cap} oil barrels.

$$TC_t = A_{MC}Q_t^{cap^i} + \eta I_t + \Phi(I_t) \quad (6.17)$$

$$\text{where } \Phi(I_t) = \begin{cases} \delta Q_t^{cap} & \text{for the spot contract} \\ (1-CR_t^e)P_t^e Q_t^{cap} & \text{for the fixed-price contract} \\ OC & \text{for the integration} \end{cases}$$

Then we remove the production cost function by the above equation in the optimization program equation (7). Each organization exhibits distinct transaction costs which are introduced in the total cost function when deciding on their investment strategy. This is why we have three profit functions:

- In the spot contract, the organizational cost is the discount δ_t charged by the commodity trader to hedge the price risk for the upstream producer. The total cost function is:

$$TC_t^{sc} = A_{MC}(Q_{min} + \lambda I_t^{sc}) + \eta I_t^{sc} + \delta(Q_{min} + \lambda I_t^{sc})$$

Which gives the following investment profile:

$$I_t^{sc} = \frac{\lambda(P_t^e - \delta) - \lambda A_{MC} - \eta}{A_i \lambda^2 (\sigma_t^e)^2}$$

Thus, the profit for the seller is:

$$\Pi_t^{ct^e} = (P_t^e - \delta_t) Q_t^{cap^{ct}}(I_t^{sc}) - (A_{MC}(Q_{min} + \lambda I_t^{sc}) + \eta I_t^{sc} + \delta(Q_{min} + \lambda I_t^{sc})) \quad (6.18)$$

- In the long-term contract, producers' hands are tied, this is why the main risk exposure is the counterpart risk. There are two organizational costs, the *ex-ante* cost eac_t and the *ex-post* cost in case the producer is the victim of a breach of contract. The drilling company is left with barrels for which it needs to quickly find a new buyer. The total cost function is:

$$TC_t^{lt} = A_{MC}(Q_{min} + \lambda I_t^{lt}) + \eta I_t^{sc} + CR_t^e P_t^e (Q_{min} + \lambda I_t^{lt}) + eac_t(Q_{min} + \lambda I_t^{lt})$$

Which gives the following investment profile:

$$I_t^{lt} = \frac{\lambda P_t^e (1 - CR_t^e) - \lambda A_{MC} - \eta}{A_i \lambda^2 (\sigma_t^e)^2}$$

Thus, the profit for the seller is:

$$\Pi_t^{lt^e} = P_t^e Q_t^{cap^{lt}}(I_t^{lt}) - (A_{MC}(Q_{min} + \lambda I_t^{lt}) + \eta I_t^{sc} + CR_t^e P_t^e (Q_{min} + \lambda I_t^{lt}) + eac_t(Q_{min} + \lambda I_t^{lt})) \quad (6.19)$$

- In the vertically integrated firm, there is no price risk, neither a counterpart risk. The organizational cost OC is a high and fixed parameter. It is paid by the firm at each period for being vertically integrated. As in Alfaro *et al.* 2016^[5], the integration cost is independent of the expected price P_t^e and the capacities $Q_t^{cap^v}$. It proves the rigidity of the organization, because whatever the prices in level or volatility are, it remains unchanged. The firm need a favourable state of the world, with high prices,

to overtake the total cost function:

$$TC_t^v = A_{MC}(Q_{min} + \lambda I_t^v) + \eta I_t^v + OC$$

Which gives the following investment profile:

$$I_t^v = \frac{\lambda P_t^e - \lambda A_{MC} - \eta}{A_i \lambda^2 (\sigma_t^e)^2}$$

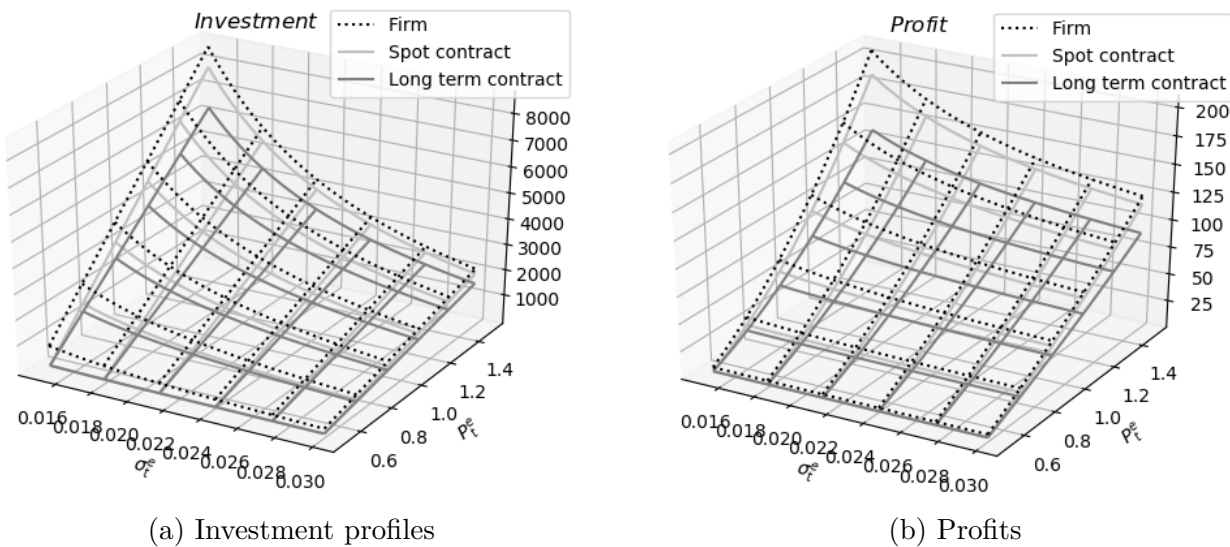
This expression is similar to equation (7) because the organizational cost is independent of the production. Thus, the profit for the seller is:

$$\Pi_t^{v^e} = P_t^e Q_t^{cap^v}(I_t^v) - (A_{MC}(Q_{min} + \lambda I_t^v) + \eta I_t^v + OC) \tag{6.20}$$

The optimal organization for the upstream producer maximizes the expected profit:

$$Q_t^{cap} = Max(\Pi_t^{ct^e}, \Pi_t^{lt^e}, \Pi_t^{v^e}) \tag{6.21}$$

Figure 6.7: Impact of the price dynamic on the organizations



For $Q_{min} = 90$, $\lambda = 0.0114468017027981$, $A_i = 50$, $A_{MC} = 0.363780016159399$, $\eta = 0.000261035$, $P^e = 1^5$, $OC = 6.37533463792033$, $CR^e = 0.2$, $delta = 0.1^6$

Figure 8 (b) indicates that profits are maximized when the price is high and the volatil-

ity is low, which are conditions to raise productive investments. It also shows that, for high prices, the vertical integration is maximizing the profit, whereas at low prices, the spot contract does. Integration is optimal only when $OC < \delta \left(Q_{min} + \lambda \frac{P_t^e - \lambda A_{MC} - \eta}{A_i vol_t^e \lambda^2} \right)$, the total transaction cost for the spot contract, and when $OC < (1 - CR_t^e) P_t^e \left(Q_{min} + \lambda \frac{P_t^e - \lambda A_{MC} - \eta}{A_i vol_t^e \lambda^2} \right)$, the total transaction cost for the long-term fixed-price contract.

Proposition 3: Vertically integrated firms exhibit the highest investment profile.

On the market, organizational costs decrease investments: $\frac{\partial I_t^{sc}}{\delta_t} < 0$, $\frac{\partial I_t^l}{CR_t^e} < 0$ and $\frac{\partial I_t^l}{eac_t} < 0$. On the contrary, the marginal cost function of the vertically integrated firm is independent of OC . Consequently, for the same parameters and states of the world, the firm invests more than the market whatever the discount and the counterpart risk are (see figure 8 b).

Figures 8a and 8b show the risk of overinvestment in the vertically integrated firm. If conditions are met (high price), the firm is willing to invest more than the market would which could significantly increase the supply. But in case of a price downturn, especially if the price decrease has not been anticipated, as observed in 2014, overinvestment increases the gap between supply and demand bringing to an exacerbated price drop. Supply readjustment has to be done by a strong decrease of investments as shown in table 5.1.

A partial equilibrium model

We develop a demand-driven model in which production reacts to demand shocks. We derived demand and supply functions from Pirrong's storage model in Commodity Price Dynamics, (2011^[227]). The flow of demand for a commodity at a date t is denoted by $P_t = D(Q_t^{D^{tot}}, Z_t)$ where P_t is the current price in t , $Q_t^{D^{tot}}$ is the daily demand for crude oil barrels at t , and Z_t is a vector of random variables representing the demand shocks. In our model, the flow of demand is a constant elasticity function:

$$P_t = \varphi \exp(Z_t + Y_t) (Q_t^{D^{tot}})^{\frac{1}{\beta}} \quad (6.22)$$

β is the constant demand elasticity of barrels for the consumers, and ϕ is a parameter. We deal with the overall demand $Q_t^{D^{tot}}$ because the consumption Q_t^D is not sufficient as storage demand matters.

Supply is given by a marginal cost function. It is increasing with the output gap between outputs Q_t^S and production capacities Q_{t-1}^{cap} defined with a one-period lag. Indeed, the extension of production capacities involves costly methods of extraction such as offshore plants or the extraction of light tight oil.

In accordance with the production cost function (equation 2)⁷, the marginal cost function gives the production costs:

$$MC_t = A_{MC} + \frac{\nu}{(Q_{t-1}^{cap} - Q_t^S)^\psi} \quad (6.23)$$

$$Q_t^S \leq Q_{max} \quad (6.24)$$

ψ is the constant supply elasticity of the commodity for the consumers, and ν a positive parameter. Producers are supposed to operate on a competitive industry, as a consequence, the marginal cost equals the current spot price. So, $MC_t = P_t$.

This equation also shows that production is a matter of timing because investments launched in t only impact the production capacities in $t+1$. It takes time for a project to exhibit results: producers need to look for a land, acquire it, install the drilling instruments until the completion of the well. Thus, bad price estimation creates pro-cyclicality

⁷The primitive of equation (24) is:

$$PC_t = A_{MC}Q_t^S - \frac{\nu(Q_{t-1}^{cap} - Q_t^S)^{1-\psi}}{1-\psi} + \eta I_t$$

The production costs also include the investment strategy, where I_t is the investment and η is the unit cost of the investment.

In equation (2), the producer is estimating the expected net profit, hence the expected production cost:

$$PC_t^e = A_{MC}Q_t^{S^e} - \frac{\nu(Q_t^{cap} - Q_t^{S^e})^{1-\psi}}{1-\psi} + \eta I_t$$

Considering, producers expect the capacities to be the next period production, we have $Q_t^{S^e} = Q_t^{cap}$. Thus the expected production cost:

$$PC_t^e = A_{MC}Q_t^{cap} + \eta I_t$$

of investment strategies in commodity industries.

The role of expected price

The model being demand-driven, producers make estimations on the next period demand shocks to derive the future price. Because of the uncertainty on the evolution of stocks, the storage demand is assumed to be constant. We focus on the expected consumption demand $Q_t^{D^e}$:

We deal with exogenous expected consumption demand shock: Z^e :

$$Q_t^{D^e} = Q_t^D \exp(Z^e) \quad (6.25)$$

Like the spot price, the expected price is determined by a demand function similarly to equation (22) by removing Q_t^D by $Q_t^{D^e}$:

$$P_t^e = \varphi \exp(z_t^e) (Q_t^{D^e} + S_t^{spec} + S_t^{co})^{\frac{1}{\beta}} \quad (6.26)$$

The expected volatility σ_t^e is a proxy for the price risk. We assume that $\sigma_t^e = vol_t$ which is defined as the historical volatility:

$$\sigma_t^e = \sqrt{\frac{\sum_{n=0}^m (\Delta p_{t-n} - \overline{\Delta p_t})^2}{m+1}} \quad (6.27)$$

Where Δp_{t-n} is the one-period price variation of the crude oil barrel, $\overline{\Delta p_t}$ the mean price variation on $m+1$ periods.

The role of the storage demand to determine the price dynamic

The storage demand is part of the total demand, that is why it is important to clearly quantify it when defining the price. A large body of literature proposes to model price and quantity changes in a sector (Pindick 1990^[224], Newbery and Stiglitz 1979^[209]) and major contributions from Deaton and Laroque (1992^[?], 1996^[79]) and Wright and Williams (1982^[281]) demonstrated the role of competitive storage in the commodity prices.

In the model, producers or commodity traders, can have storage capacities. We can distinguish different storage behavior in the industry: commodities can be held with the intention of making a benefit and others to absorb excess demand or supply. One contribution of this chapter is to show that stocks impact the price dynamic.

Residual stocks

Stocks are known to fill the gap between supply and demand. We define residual stocks S_t^{res} as follows:

$$S_t^{res} = Q_t^{D^{tot}} - Q_t^S \quad (6.28)$$

They are not assumed to have an impact on the spot price as they already reflect gaps between supply and demand. An increase of the residual stocks should coincide with an excess demand and a price increase, whereas a decrease should be observed in case of excess supply and price decrease.

Unlike traditional studies on the topic, we consider the storage cost per barrel sc_t is not a parameter but an increasing function of the overall stocks S_t :

$$sc_t = sc_{min} + \iota S_t \quad (6.29)$$

Speculative stocks

Agents can build strategies to remunerate the stock ownership. First, we define speculative stocks S_t^{spec} when the return from selling barrels later can make a profit:

$$S_t^{spec} = Max(A_{spec} (P_t^e - P_t - sc_t), 0) \quad (6.30)$$

Where A_{spec} is the sensibility of the stock held for speculative purpose to the expected price change. We use a maximum function because if agents expect prices to go down, there is no negative speculative stock, the variable remains to zero.

Contango stocks

Commodity economics involve dealing with financial markets and future prices, which bring us to another storage behavior: “the contango stocks”. They depend on the carrying conditions that are interest rates, insurance and storage for holding the commodity. In a contango market, future prices exceed spot prices. The future price is converging to the spot price when the contract is close to maturity. As a consequence, inventory holders can store commodities and register almost a risk-free profit by selling it forward. We determine the future price Fut_t for a one period maturity based on the cost-of-carry model (Brennan 1958^[38], Fama and French 1988^[96]):

$$Fut_t = P_t \exp(rf + sc_t - cy_t)^n \quad (6.31)$$

Where rf is the exogenous interest rate and cy_t the convenience yield which describes how much the ownership of the asset is valued (Kaldor 1939^[163], Working 1949^[280]). The benefit from holding the commodity is negatively correlated with stocks (Fama and French 1988^[96], Ng and Pirrong 1994^[210]), which is empirically documented (Deaton and Laroque 1992^[7] and 1996^[79], Routledge *et al.* 2000^[238], Gorton *et al.* 2012^[112]). It is a convex function because the marginal benefit from owning the commodity is supposed to be unbounded:

$$cy_t = \frac{\kappa}{(S_t^{tot})^\alpha} \quad (6.32)$$

α is the elasticity of the convenience yield relatively to the stocks and κ a parameter. It shows how sharply the convenience yield increases when stocks decrease.

We can then determine the carry-over stocks S_t^{co} :

$$S_t^{co} = \text{Max}(A_{co} (Fut_t - P_t), 0) \quad (6.33)$$

Where A_{co} is a parameter. Just like the speculative stocks, the carry-over stocks cannot be negative. However, if the spot price exceeds the future price, there is no interest in holding barrels for this motive.

The relationship between the inventories and the contango stocks is documented in Appendix A.

The total level of stock S_t is the sum of every stock held during the period. Stocks are cumulative over periods as soon as they remain below the maximum storage capacities S_{max} . Moreover, by considering oil as a strategic asset, we assume it is more realistic to introduce minimum stocks S_{min} .

$$S_t^{tot} = S_t^{res} + S_t^{spec} + S_t^{co} \quad (6.34)$$

$$S_t^{tot} \leq S_{max} \quad (6.35)$$

$$S_t^{tot} \geq S_{min} \quad (6.36)$$

6.3 A simulation of the oil industry when the price dynamic change

6.3.1 Calibration

The model uses data from the second semester of 2017.

Flows of production and consumption in barrels per day (current and expected) used in the model are from the U.S. Energy Information Administration (EIA)⁸. The elasticities, $\beta = \frac{1}{0.26}$ and $\psi = \frac{1}{0.27}$, come from Baumeister and Peersmman (2013^[31]) who use a Bayesian VAR model with time-varying parameters and stochastic volatility framework between 1974 and 2010.

Our reference price is the WTI. We set the spot price to 1 and scale every price on this base. The expected spot price is derived from the expected demand. There are no world data on most parts of our variables because of the specificities of each drilling sites. The production capacities also come from the EIA, as there is no world data, we use the

⁸EIA Short term energy outlook January and July 2016, 2017 and 2018

OPEC usage rate in January 2018. We suppose the spot price equals the future price at the initial period.

The total amount of stocks in the world is unknown, however, based on the EIA requirements, the members must stock at least 90 days of daily imports. This measure concerns both crude and refined oil products but we assume 2/3 of the stocks concern crude oil, which represents 6,037 million barrels. The minimum and maximum storage are also fixed to 4 and 13 weeks of consumption respectively. We can hardly state on how much of the inventories are held for speculative, contango or residual purposes. The initialised values are subjective, we consider that the speculative stocks represent 3.125% of the total stocks, which means that 1% of the total daily demand is stored for both of these storage purposes. Contango stocks are null in the initial period, so for simplicity we have $A_{co} = A_{spec}$. They are assumed to be positive, starting with 6,450 barrels stocked (see Appendix A). The storage cost per barrel and the minimum storage cost are initialised to 0.05 and 0.005 respectively. The convenience yield cy_t is derived from equation 9. Parameters α and κ from equation (36) are solved with respect for positive contango stocks when stocks exceed 6,450 units.

A common measure of the investment I_t in the drilling sector, for both academic (Smith 2009^[254]) and operational actors, is the number of oil rig counts, given by Baker Hughes. It is the number of active oil rigs at a certain location⁹. The unit cost of investment η is derived from the average capital expenditure of the upstream segment of five major oil producers (BP, ExxonMobil, Shell, Total and Chevron), expressed in daily data (see appendix C for the methodology). Data are extracted from their 2018 financial investment annual report.

⁹The number of rig counts is one of the primary measures of exploratory activity and, hence, a good indicator for investment in production capacities. We agree that this choice may be controversial as the innovation in the drilling activity (drilling companies are substituting traditional vertical drilling by horizontal drilling technics) and the well-site cost cuts make the rig count a less relevant indicator of the holes in activity. In a single site, multiple wells can be drilled. Wells could be a better indicator but, because of the lack of data, the consensus on the use of rig counts and the difficulty to value the productivity, we deal with the rig counts.

To calibrate organizational costs, we assume that, in the first period, the upstream producer is indifferent between spot contract, long-term contract and vertical integration. In the model the discount and the premium δ_t and π_t are initially set to a 5% fee on the transaction to hedge the price risk for the seller. The *ex-ante* cost eac_t is arbitrarily fixed to 0.005 for the initial period. The counterpart risk and the firm's organizational costs are then calibrated from profit equations (31 to 33) verifying $\Pi_{t_0}^{sc} = \Pi_{t_0}^{lt} = \Pi_{t_0}^v$. The investment risk aversion A_i is set to 55 in order to test the model on multiple scenarios without challenging the boarders and to deal with a coherent minimum marginal cost A_{MC} which is calibrated to 0.3638. The later induces that the minimum barrel price is 21,99 USD.

All initial data are summarized in the appendix B.

6.3.2 Simulation analysis

We run the model on 7 different scenarios after an initial period in which producers expect demand to increase by 2% in T_2 . Running the model on 7 scenarios allows us to study the impact of estimation errors on the organization and the state of the world in the next following period. The first three scenarios (S_1 , S_2 and S_3) determine the optimal organization when the demand actually to decrease by 3%, 2% and 1% respectively. We test the model when there is no change in demand (S_4). Then we estimate the impact of underestimated increase (S_5 , with a 1% increase), good estimation of the demand increase (S_6 , with a 2% increase) and overestimation (S_7 , with a 3% increase). Results are presented in the table 2 below.

Then, in a second simulation (table 3), we run the model on 3 consecutive periods with cumulative effects starting from the initial period (T_1). The second period cumulates a new demand increase (by 1%) so as the expected demand (by 1%) which would lead producers to choose the integration as the best organization. The third period exhibits

a non-anticipated demand decrease (by 2%). Finally, we run three different scenarios for this third period. First, we assume that producers had chosen in the previous period (T_2) to trade through spot contract, second, that they had chosen long-term fixed-price contract, and third, that they had launched vertical integration. In this section, we expect to see the impact of the organization on the industry. Our intuition is that if the firm overinvests or chooses an organization that does not fit with the $t + 1$ state of the world, investment is disconnected from the demand which exacerbates the demand or supply gap. This phenomenon is assumed to be similar to the excess supply observed in 2014 when producers turned to disintegration strategies.

Table 6.2: Results of the simulation analysis

| | T_1 | | | | T_2 | | | |
|------------------|------------------|-----------------------------|-----------------------------|-----------------------------|---------------------|---------------------------|---------------------------|---------------------------|
| | $z = 0.017$ | S_1 | S_2 | S_3 | S_4 | S_5 | S_6 | S_7 |
| | $ze = 0.02$ | $z = -0.03$ $ze = -0.03$ | $z = -0.02$ $ze = -0.02$ | $z = -0.01$ $ze = -0.01$ | $z = 0$ $ze = 0$ | $z = 0.01$ $ze = 0.01$ | $z = 0.02$ $ze = 0.02$ | $z = 0.03$ $ze = 0.03$ |
| Q_t^D | 98.9600 | 96.0353 | 97.0005 | 97.9753 | 98.9600 | 99.9546 | 100.9591 | 101.9738 |
| $Q_t^{D^{tot}}$ | 99.2899 | 96.0370 | 97.0016 | 97.9753 | 98.9600 | 100.1105 | 101.3173 | 102.5603 |
| $Q_t^{D^e}$ | 100.9591 | 93.1970 | 95.0797 | 97.0005 | 98.9600 | 100.9591 | 102.9986 | 105.0793 |
| Q_t^S | 98.6400 | 100.3617 | 100.4931 | 100.6191 | 100.7403 | 100.8747 | 101.0083 | 101.1387 |
| Q_{t-1}^{cap} | 105.9120 | 108.0516 | 108.0516 | 108.0516 | 108.0516 | 108.0516 | 108.0516 | 108.0516 |
| P_t | 1.0000 | 0.8798 | 0.9142 | 0.9500 | 0.9873 | 1.0322 | 1.0808 | 1.1327 |
| P_t^e | 1.0797 | 0.7839 | 0.8465 | 0.9142 | 0.9873 | 1.0726 | 1.1670 | 1.2705 |
| σ_t | 0.0267 | 0.0902 | 0.0746 | 0.0588 | 0.0432 | 0.0278 | 0.0245 | 0.0397 |
| Fut_t | 1.0000 | 0.8857 | 0.9199 | 0.9552 | 0.9916 | 1.0350 | 1.0810 | 1.1284 |
| S_t^{tot} | 6036.5600 | 6828.2914 | 6675.7106 | 6520.3612 | 6362.3464 | 6204.9508 | 6045.5655 | 5883.7478 |
| S_t^{spec} | 0.3299 | 0 | 0 | 0 | 0 | 0.1559 | 0.3582 | 0.5865 |
| S_t^{co} | 0 | 0.0017 | 0.0011 | 0 | 0 | 0 | 0 | 0 |
| S_t^{res} | -0.6499 | 4.3247 | 3.4915 | 2.6437 | 1.7803 | 0.7642 | -0.3090 | -1.4216 |
| sc_t | 0.0050 | 0.0055 | 0.0054 | 0.0053 | 0.0052 | 0.0051 | 0.0050 | 0.0048 |
| cy_t | 0.0150 | 0.0021 | 0.0030 | 0.0044 | 0.0065 | 0.0097 | 0.0146 | 0.0225 |
| π_t | 0.0500 | 0.0646 | 0.0598 | 0.0554 | 0.0513 | 0.0469 | 0.0428 | 0.0390 |
| δ_t | 0.0500 | 0.0387 | 0.0418 | 0.0451 | 0.0487 | 0.0533 | 0.0584 | 0.0642 |
| EC_t | 0.9067 | 0.7823 | 0.8415 | 0.8980 | 0.9364 | 0.9137 | 0.9498 | 1.1870 |
| ea_{ct} | 0.0050 | 0.0059 | 0.0059 | 0.0058 | 0.0056 | 0.0051 | 0.0048 | 0.0056 |
| CR_t | 0.0417 | 0.2205 | 0.1825 | 0.1430 | 0.1019 | 0.0524 | 0.0013 | 0.0585 |
| σ_t^{SC} | 1577.0000 | 77.0535 | 131.3162 | 243.8848 | 516.0630 | 1426.4723 | 2099.5486 | 909.2821 |
| Q_t^{cap,sc^e} | 108.0516 | 90.8820 | 91.5032 | 92.7917 | 95.9073 | 106.3285 | 114.0331 | 100.4084 |
| Π_t^{sc} | 72.1766 | 35.2786 | 40.9518 | 47.4580 | 55.6256 | 69.9646 | 85.0160 | 84.9952 |
| σ_t^{LT} | 1577.0000 | 46.9489 | 94.0672 | 197.6570 | 462.2737 | 1408.3868 | 2250.9751 | 891.8032 |
| Q_t^{cap,lt^e} | 108.0516 | 90.5374 | 91.0768 | 92.2625 | 95.2916 | 106.1215 | 115.7665 | 100.2083 |
| Π_t^{lt} | 72.1766 | 22.4705 | 29.9704 | 38.7651 | 49.8036 | 68.9824 | 92.2954 | 83.2522 |
| σ_t^v | 1699.6089 | 85.3688 | 144.4397 | 266.6965 | 561.6295 | 1546.5657 | 2269.4164 | 980.4473 |
| Q_t^{cap,v^e} | 109.4551 | 90.9772 | 91.6534 | 93.0528 | 96.4289 | 107.7032 | 115.9776 | 101.2230 |
| Π_t^v | 72.1766 | 32.4581 | 38.4695 | 45.4079 | 54.2378 | 70.1963 | 86.8189 | 85.7817 |

Maximum profits and corresponding production capacities and investments are in bold.

Table 6.3: The impact of the organization dynamic

| | | | T_3 | | |
|------------------|----------------------------|---------------------------|-----------------------------|-----------------------------|-----------------------------|
| | T_1 | T_2 | Spot contract | Fixed-price contract | Integrated firm |
| | | | in T_2 | in T_2 | in T_2 |
| | $z = 0.017$ $ze = 0.02$ | $z = 0.01$ $ze = 0.01$ | $z = -0.02$ $ze = -0.02$ | $z = -0.02$ $ze = -0.02$ | $z = -0.02$ $ze = -0.02$ |
| Q_t^D | 98.9600 | 99.9546 | 97.9753 | 97.9753 | 97.9753 |
| $Q_t^{D^{tot}}$ | 99.2899 | 100.1105 | 97.9753 | 97.9753 | 97.9767 |
| $Q_t^{D^e}$ | 100.9591 | 100.9591 | 96.0353 | 96.0353 | 96.0353 |
| Q_t^S | 98.6400 | 100.8758 | 98.8960 | 98.6890 | 100.2709 |
| Q_{t-1}^{cap} | 105.9120 | 108.0516 | 106.3285 | 106.1215 | 107.7032 |
| P_t | 1.0000 | 1.0322 | 0.9500 | 0.9500 | 0.9501 |
| P_t^e | 1.0797 | 1.0726 | 0.8797 | 0.8797 | 0.8797 |
| σ_t | 0.0267 | 0.0278 | 0.0536 | 0.0536 | 0.0536 |
| Fut_t | 1.0000 | 1.0350 | 0.9543 | 0.9540 | 0.9558 |
| S_t^{tot} | 6036.5600 | 6205.1383 | 6373.4318 | 6335.5470 | 6625.0313 |
| S_t^{spec} | 0.3299 | 0.1559 | 0 | 0 | 0 |
| S_t^{co} | 0 | 0 | 0 | 0 | 0.0014 |
| S_t^{res} | -0.6499 | 0.7653 | 0.9207 | 0.7136 | 2.2941 |
| sc_t | 0.0050 | 0.0051 | 0.0052 | 0.0052 | 0.0054 |
| cy_t | 0.0150 | 0.0097 | 0.0063 | 0.0069 | 0.0034 |
| π_t | 0.0500 | 0.0469 | 0.0554 | 0.0554 | 0.0554 |
| δ_t | 0.0500 | 0.0533 | 0.0451 | 0.0451 | 0.0451 |
| ect | 0.9067 | 0.9137 | 0.8574 | 0.8574 | 0.8575 |
| $eact$ | 0.0050 | 0.0051 | 0.0058 | 0.0058 | 0.0058 |
| CR_t | 0.0417 | 0.0524 | 0.1341 | 0.1341 | 0.1341 |
| σ_t^{SC} | 1577.0000 | 1426.4716 | 272.3164 | 272.3164 | 272.5824 |
| Q_t^{cap,sc^e} | 108.0516 | 106.3285 | 93.1172 | 93.1172 | 93.1202 |
| Π_t^{sc} | 71.5405 | 69.3285 | 44.4031 | 44.4031 | 44.4085 |
| σ_t^{LT} | 1577.0000 | 1408.3861 | 224.5016 | 224.5016 | 224.7549 |
| Q_t^{cap,lt^e} | 108.0516 | 106.1215 | 92.5698 | 92.5698 | 92.5727 |
| Π_t^{lt} | 71.5405 | 68.3462 | 36.8765 | 36.8765 | 36.8860 |
| σ_t^v | 1699.6089 | 1546.5650 | 299.7486 | 299.7486 | 300.0417 |
| Q_t^{cap,v^e} | 109.4551 | 107.7032 | 93.4312 | 93.4312 | 93.4345 |
| Π_t^v | 71.5405 | 69.5601 | 42.3848 | 42.3848 | 42.3910 |

6.3.3 Results and Interpretation

Results confirm that the upstream producer needs to reassess the organization at each period of transaction, hence a possible contractual dynamic. The model being set on an initial period where $P_t = 1$, we consider as low every price lower than 1 and high every

price higher than 1.

The optimal organization for the upstream producer

The decision to vertically integrate is highly dependent on price levels.

First, producers' investment profiles are driven by their risk management strategies. They are willing to establish investment strategies only if they have guarantees on selling prices. The model indicates that there are price conditions for the vertically integrated firm to be competitive: P_t must be greater than 1, otherwise the profit from the spot contract is always higher. Therefore, the firm does not outperform the market in all scenarios. We agree that the firm leads to higher investment at a lower marginal cost of investment, but it does so at a cost. At low prices, the additional output has little value relative to the high and fixed costs of vertical integration. The firm is profitable when prices are high enough (see S_5 and S_7). Low prices lead producers to choose spot contracts (S_1 to S_4). High prices lead producers to turn to vertical integration strategies, while low prices lead them to divestment strategies.

Price volatility directly affects the counterparty risk exposure in the long-term contract.

Second, price volatility determines the optimality of long-term fixed price contracts. The profit of this organization depends on the accuracy of the prediction and the volatility because estimation errors create uncertainty increasing the expected counterparty risk. Indeed, even if prices are relatively high, if counterparty risk is low (S_6), producers have no reason to pay the vertically integrated firm's high fixed costs and the cost of no risk may exceed the cost of exposure to counterparty risk. Therefore, the fixed price contract is the optimal organization.

Storage behaviors, specific to the commodity industries, modify the market fundamentals.

Third, we showed that both speculation and contango market influence the overall demand. They have a particularly acute impact in case of trend overturns. In S_1 , S_2 and S_3 , demand is twice affected, first because of the consumption decrease, and secondly because of stocks. In the initial period, 0.3299 million barrels are stocked every day for speculation purpose but it falls to zero when the price is expected to decrease or to remain unchanged (S_4). Contango stocks can also modify the overall demand when stock movements are large enough to modify the sign of the basis and impact the carry-over conditions (S_1 and S_2). The excess supply feeds the stock level and impacts the future prices through low convenience yields. This could explain the contango market from the second semester 2014 to 2017.

Productive investments create pro-cyclical effects.

Fourth, Table 3 shows us the pro-cyclicality of the organization when unanticipated demand decreases, indicating that the organization has an impact on supply. Even though from period T_2 onward, the vertically integrated firm is the optimal organization for T_3 , it is the organization that has the highest excess supply when demand actually decreases. Indeed, this organization has led to overinvestment in this period. As a result, the gap between supply and demand is 2.2923 million barrels per day for the firm while it is 0.9188 and 0.7118 mill. barrels per day for the spot and fixed price contracts respectively. This is explained by a larger overinvestment in T_2 where the firm presented 1,546.5650 mill. units of productive investments against 1,426.4716 mill. units for the spot contract and 1,408.3861 mill. for the fixed price contract. This explains the sharp increase in stocks regardless of the agency used in T_2 , leading the industry to turn to a contango market in T_3 . But only excess supply from vertical integration led to a large enough base to create contango stock opportunities. Contango stocks explain why prices are slightly higher in the latter case.

In a similar state of the world, the vertical integration of the oil industry seems to

have created an oversupply that was highlighted from July 2014 with unanticipated low prices and high volatility. Producers turned to the market with an increasing reliance on spot contracts, which seems to confirm the causality of the organization to the investment and supply of the oil industry. Thus, the choice of vertical integration can be seen as one of the roots of overinvestment and lower prices.

What can we expect for the commodity trader?

The role of the commodity trader is highly sensitive to the price dynamic.

In times of low prices and high volatility, price risk management is necessary. Uncertainty about the future price is likely to reduce profits. For example, without the commodity trader's expertise, transaction costs would be too high for spot contracts. Therefore, there would be no spot market.

In addition, unlike producers, the commodity trader can benefit from decreasing prices, as his profit depends on fees. This may even be the best "state of the world" for him. First, thanks to its inventory capabilities, the commodity trader can offer time transformation of the commodity. Thus, when the need for risk management increases, the volume of his transactions increases. Second, even if the discount he pays to upstream agent is decreasing ($\delta_{t-1} > \delta_t$), in t , he can sell barrels previously purchased at the discount δ_{t-n} while collecting the increasing premium pi_t . As a result, the unit margin on the stored barrels increases ($\delta(\delta_{t-n} + \pi_t) \geq 0$).

6.3.4 Robustness check

In this section, we check the sensitivity of the model to changes in risk aversion A_i and the demand elasticity β on the sixth scenario of the simulation analysis in section 4.2, in which producers achieved a good estimate of demand growth. We test the sensitivity of these two parameters since they are core component of the model that are not determined during the model calibration. The risk aversion was set arbitrarily, while the demand elasticity was taken from the literature (Baumeister and Peersmman (2013^[31])).

The sixth scenario is chosen because it leads to situation similar to the one observed in T_1 . The results of the robustness checks are presented in Appendix E, Tables 5 and 6.

On the one hand, we check the impacts of variations of the risk aversion by running the model for $A_i = 10$, a smaller risk aversion, and for $A_i = 77.7337$ which is the maximum risk aversion allowed by the model¹⁰. The changes in risk aversion do not change the conclusion of the model for scenario 6, as the long-term fixed price contract is still the organization that offers the most benefits. However, the investment profiles change significantly. Risk aversion has a negative impact on investment, and in both cases the vertically integrated firm is the organization with the largest changes. Indeed, when considering organizational costs in its investment function, it is more sensitive to changes in A_i . Its investments increase by 70% (to 3,774.8220 mill. units) when $A_i = 10$ compared to $A_i = 50$ against 44% for the spot contract (to 3,017.2520 mill. units) and 68% for the fixed-price contract (at 3,774.8220 mill.), and decrease by 6.3% (to 2,126.9447 mill.) when $A_i = 77.7337$ compared to 3.9% (at 2,017.6842 mill. units) and 6% (at 2,115.0784 mill. units).

On the other hand, we check the sensibility of the model to the demand elasticity. As the model is demand driven, changes of the supply elasticity ψ does not impact results. However, the demand elasticity β could change our conclusions. We check the results for higher and lower elasticities: $\beta = (\frac{1}{0.252538}, \frac{1}{0.5}, 1^{11})$.

The results are coherent with our conclusions. For lower demand elasticities ($\beta = \frac{1}{0.5}$ and $\beta = 1$), the model is less sensitive to price changes, this is why volatility is lower and the counterpart risk is small. Thus, fixed-price contract profit compared to the two other organizations becomes proportionally higher for those elasticities. In the benchmark situation, the profit is 8.5% and 6.3% higher than the spot contract and the firm, respectively, while we find 27,6% and 20.4% for $\beta = \frac{1}{0.5}$ and even 85.6% and 54% for $\beta = 1$.

¹⁰The minimum marginal cost A_{MC} is calibrated based on equation 19, yet A_{MC} must be lower than 1 which is the initial spot price. Otherwise, the oil barrel spot price would be fixed. Thus, for $A_{MC} < 1$ we must have $A_i < 77.7338$.

¹¹Based on our initial variables and the calibration, 0.252538 is the lowest elasticity the model can allow. Indeed, the parameter μ is derived from $\mu = \frac{-\ln(1-\theta)}{vol_t^2}$. To keep the parameter $\theta < 1$ the model must verify $\beta < \frac{1}{0.252538}$.

For a higher elasticity $\beta = \frac{1}{0.252538}$, we find a higher volatility which raises the counterpart risk exposure. As a consequence, the fixed-price contract profit relatively to the other organization is lower, it is now 8.1% and 6.3% higher than the spot contract and the firm respectively.

6.4 Conclusion

Dans ce chapitre, nous étudions le lien entre la dynamique des prix du pétrole et l'organisation des transactions dans l'industrie pétrolière. Nous avons modélisé une industrie pétrolière simplifiée avec un stockage concurrentiel et des négociants en matières premières afin de déterminer les stratégies d'investissement et les coûts de transaction associés à trois organisations contractuelles : le contrat spot, le contrat à long terme à prix fixe et l'entreprise verticalement intégrée. Dans une perspective de gestion du risque, chaque organisation est efficace pour faire face à un état particulier du monde. L'optimalité est trouvée pour l'organisation réduisant l'exposition au risque et les coûts organisationnels. Le modèle montre que même si l'intégration verticale annule les risques liés au commerce et garantit des investissements plus élevés, l'organisation ne maximise pas nécessairement son profit. L'intégration est intéressante lorsque les prix sont suffisamment élevés pour couvrir les coûts organisationnels. Dans d'autres cas, elles choisissent le contrat au comptant lorsque les prix sont bas et les contrats à long terme à prix fixe lorsque la volatilité est modérée. Ces résultats sont cohérents avec le mouvement global vers l'intégration verticale observé jusqu'à la chute des prix en 2014 et les stratégies de désintégration et la volonté de réduire les capacités excédentaires observées par la suite.

We report on the pro-cyclicality of investments in the oil industry, which is highly correlated with the organization. Due to its rigidity, producers cannot react instantly to any change in price dynamics, therefore their production capacities depend on the investments of previous periods. Thus, if producers do not correctly estimate future prices and

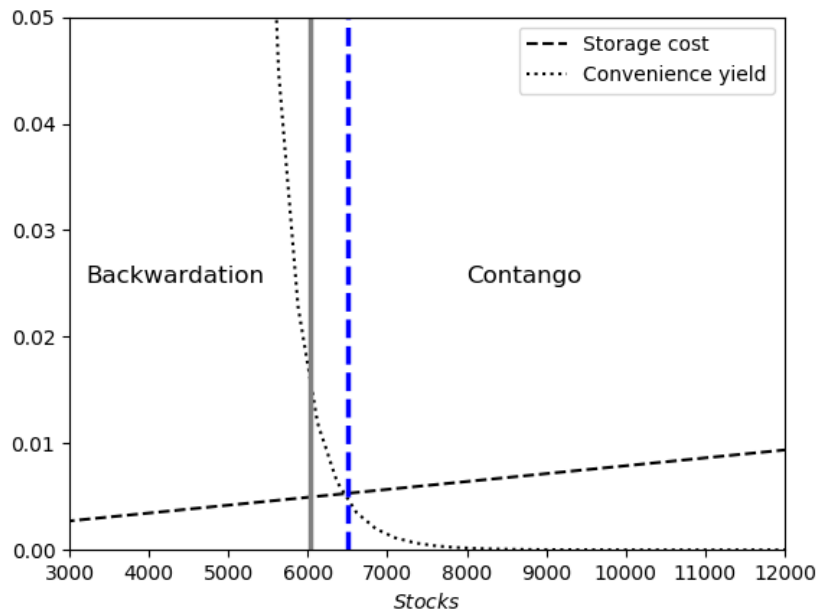
future risks, they create imbalances between supply and demand and exacerbate the price decline. Our simulation showed that this phenomenon is more acute when the industry moves from integration to disintegration. This finding indicates that organizations evolve over time and need to be re-evaluated in each period to adapt to the changing state of the world.

We also analyze the response of inventories to the organization and role played by commodity traders within the oil industry. These results lead us to fill a gap in the industrial organization literature by concluding that the oil industry, and more generally commodity industries, deserve a particular analysis when it comes to market organization.

Appendix

Appendix A : Contango - Backwardation

Figure 6.8: Relationship between stocks and carry-over conditions



Convenience yield is a convex and decreasing function (the dotted curve). It equals the storage cost for a level of stock equivalent to 61 days of oil consumption¹², that is to say for 6,036 barrels stored, the vertical grey line. Parameters α and κ are solved in respect with this condition. Convenience yield exceeds the storage cost when the inventories are relatively low, the market value the storage ownership. In our simplified model, it can bring the spot price to exceed the future price, in this case we are in a backwardation market. In the other case, the higher the inventories are, the less the market values the stocks and the inventory holders call for increasing storage costs. The market shifts to contango in the model.

Contango markets are not sufficient to have contango stocks. We need $Fut_t - P_t > sc_t$ to register a risk-free return associated to storage holding. Thus, there are contango stocks starting the blue dotted line (for stocks $> 6,450$).

¹²The EIA members must stock an equivalent of 90 days of daily imports. But this concern both crude and refined oil. We assume countries' stock around 2/3 of crude oil and 1/3 of refined products.

Appendix B : Initial values

Table 3: Initial Values

| cycle 1 | T_0 | Lag variables | T_0 | Parameters | |
|------------------|---------|---------------------|---------|------------|------------------------|
| Q_t^D | 98.96 | P_{t-1} | 0.9652 | A_{MC} | 0.3567 |
| $Q_t^{D^{tot}}$ | 99.29 | Q_{t-1}^D | 98.05 | A_i | 50 |
| $Q_t^{D^e}$ | 100.96 | Q_{t-2}^D | 95.8 | A_{co} | 4.4145 |
| Q_t^S | 98.64 | Q_{t-3}^D | 94.9 | A_{spec} | 4.4145 |
| Q_{t-1}^{cap} | 105.91 | $Q_{t-1}^{D^{tot}}$ | 96.7036 | A_δ | 0.05 |
| P_t | 1.00 | | | A_π | 0.05 |
| P_t^e | 1.0797 | | | | |
| σ_t^e | 0.0267 | | | β | 0.26 |
| Fut_t | 1.00 | | | ψ | 0.27 |
| S_t^{tot} | 6036.56 | | | | |
| S_t^{spec} | 0.3299 | | | α | 15.8907 |
| S_t^{co} | 0 | | | η_t | $3.5194 \cdot 10^{-4}$ |
| S_t^{res} | -0.6499 | | | ι | $7.3979 \cdot 10^{-7}$ |
| sc_t | 0.0050 | | | φ | $2.0874 \cdot 10^{-8}$ |
| cy_t | 0.0150 | | | κ | $1.7959 \cdot 10^{58}$ |
| | | | | λ | 0.0114 |
| π_t | 0.05 | | | μ | 68.5944 |
| δ_t | 0.05 | | | ρ | 0.0060 |
| ec_t^{mac} | 0.9067 | | | ν | 999.37 |
| ea_t | 0.0050 | | | OC | 6.3753 |
| θ_t | 0.8397 | | | | |
| CR_t | 0.0417 | | | rf | 0.01 |
| | | | | Q_{max} | 120.0 |
| $Q_t^{cap^{ct}}$ | 108.05 | | | Q_{min} | 90.0 |
| σ_t^{ct} | 1577 | | | S_{max} | 9005.36 |
| Π_t^{ct} | 72.17 | | | S_{min} | 2770.88 |
| $Q_t^{cap^{lt}}$ | 108.05 | | | sc_{min} | 0.0005 |
| σ_t^{lt} | 1577 | | | | |
| Π_t^{lt} | 72.17 | | | | |
| $Q_t^{cap^v}$ | 109.46 | | | | |
| σ_t^v | 1699.61 | | | | |
| Π_t^v | 72.17 | | | | |

Appendix C: Unit investment cost

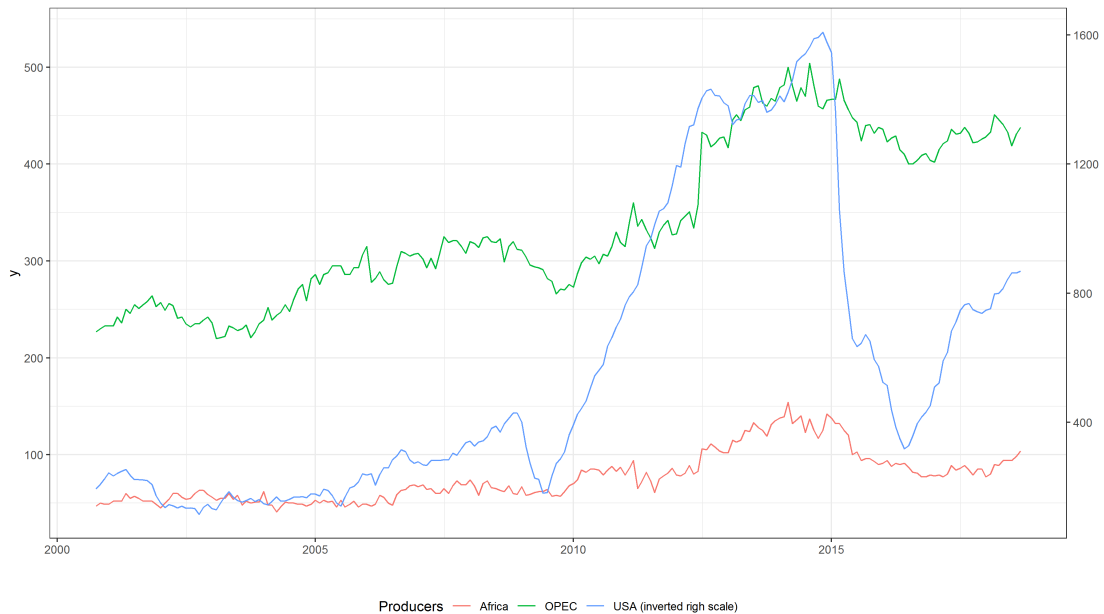
Table 6.4: Determination of the unit investment cost η

| (millions of USD) | BP | Shell | ExxonMobil | Total | Chevron | Average |
|---|------------------------|------------------------|------------------------|-----------------------|------------------------|--|
| Capital expenditure (Capex) | 14,500.22 | 13,647.67 | 9,761.54 | 12,801.88 | 16,388.03 | 13,419.87 |
| Capex per day | 35.2274 | 33.1562 | 23.7151 | 31.1014 | 39.8137 | 32.6027 |
| Daily Capex per unit of investment $\$I_{\{0\}} = 1577\$$ | 0.0223 | 0.0210 | 0.0150 | 0.0197 | 0.0252 | 0.0207 |
| Daily Capex per unit of investment normalised to spot price (60.46 USD) | $3.6947 \cdot 10^{-4}$ | $3.4775 \cdot 10^{-4}$ | $2.4873 \cdot 10^{-4}$ | $3.262 \cdot 10^{-4}$ | $4.1757 \cdot 10^{-4}$ | $3.4194 \cdot 10^{-4}$ |

Hence $\eta = 3.4194 \cdot 10^{-4}$

Appendix D : Investments in the oil industry

Figure 6.9: Oil rig counts



Source: Backer Hughes

Appendix E : Robustness check

Table 6.5: Risk aversion A_i

| | Reference values | | $A_i = 10$ | | $A_i = 77.7337$ | |
|------------------|------------------|------------------|------------|------------------|-----------------|------------------|
| | T_1 | T_2 | T_1 | T_2 | T_1 | T_2 |
| Q_t^D | 98.9600 | 100.9591 | 98.9600 | 100.9591 | 98.9600 | 100.9591 |
| $Q_t^{D^{tot}}$ | 99.2899 | 101.3173 | 99.2899 | 101.3169 | 99.2899 | 101.3174 |
| $Q_t^{D^e}$ | 100.9591 | 102.9986 | 100.9591 | 102.9986 | 100.9591 | 102.9986 |
| Q_t^S | 98.6400 | 101.0083 | 98.6400 | 101.6757 | 98.6400 | 100.9306 |
| Q_{t-1}^{cap} | 105.9120 | 108.0516 | 105.9120 | 108.0516063 | 105.9120 | 108.0516063 |
| P_t | 1.0000 | 1.0808 | 1.0000 | 1.0808 | 1.0000 | 1.0808 |
| P_t^e | 1.0797 | 1.1670 | 1.0797 | 1.1669 | 1.0797 | 1.1670 |
| σ_t | 0.0267 | 0.0245 | 0.0267 | 0.0245 | 0.0267 | 0.0245 |
| Fut_t | 1.0000 | 1.0810 | 1.0000 | 1.0832 | 1.0000 | 1.0807 |
| S_t^{tot} | 6036.5600 | 6045.5655 | 6036.5600 | 6167.6906 | 6036.56 | 6031.3450 |
| S_t^{spec} | 0.3299 | 0.3582 | 0.3299 | 0.3578 | 0.3299 | 0.3582 |
| S_t^{co} | 0 | 0 | 0 | 0 | 0 | 0 |
| S_t^{res} | -0.6499 | -0.3090 | -0.6499 | 0.3588 | -0.6499 | -0.3867 |
| sc_t | 0.0050 | 0.0050 | 0.0050 | 0.0051 | 0.0050 | 0.0050 |
| cy_t | 0.0150 | 0.0146 | 0.0150 | 0.0106 | 0.0150 | 0.0152 |
| π_t | 0.0500 | 0.0428 | 0.0500 | 0.0428 | 0.0500 | 0.0428 |
| δ_t | 0.0500 | 0.0584 | 0.0500 | 0.0584 | 0.0500 | 0.0584 |
| EC_t | 0.9067 | 0.9498 | 0.9067 | 0.9497 | 0.9067 | 0.9498 |
| EAC_t | 0.0050 | 0.0048 | 0.0050 | 0.0048 | 0.0050 | 0.0048 |
| CR_t | 0.0417 | 0.0013 | 0.0417 | 0.0013 | 0.0417 | 0.0013 |
| σ_t^{SC} | 1577.0000 | 2099.5486 | 1577.0000 | 3017.2520 | 1577.000 | 2017.6842 |
| Q_t^{cap,sc^e} | 108.0516 | 114.0331 | 108.0516 | 124.5379 | 108.0516 | 113.0960 |
| Π_t^{sc} | 72.1766 | 85.0160 | 16.5861 | 28.5256 | 110.7200 | 124.6823 |
| σ_t^{LT} | 1577.0000 | 2250.9751 | 1577.0000 | 3774.8220 | 1577.000 | 2115.0784 |
| Q_t^{cap,lt^e} | 108.0516 | 115.7665 | 108.0516 | 133.2096 | 108.0516 | 114.2109 |
| Π_t^{lt} | 72.1766 | 92.2954 | 16.5861 | 37.2636 | 110.7200 | 131.8316 |
| σ_t^v | 1699.6089 | 2269.4164 | 2190.0447 | 3866.7343 | 1655.8647 | 2126.9447 |
| Q_t^{cap,v^e} | 109.4551 | 115.9776 | 115.0690 | 134.2617 | 108.9544 | 114.3467 |
| Π_t^v | 72.1766 | 86.8189 | 16.5861 | 31.7291 | 110.7200 | 126.3603 |

Maximum profits and corresponding production capacities and investments are in bold.

Table 6.6: Changes in the demand elasticity

| | Reference values | | $\beta = 0.252538$ | | $\beta = 0.5$ | | $\beta = 1$ | |
|------------------|------------------|------------------|--------------------|------------------|---------------|------------------|-------------|------------------|
| | T_1 | T_2 | T_1 | T_2 | T_1 | T_2 | T_1 | T_2 |
| Q_t^D | 98.9600 | 100.9591 | 98.9600 | 100.9591 | 98.9600 | 100.9591 | 98.9600 | 100.9591 |
| $Q_t^{D^{tot}}$ | 99.2899 | 101.3173 | 99.2899 | 101.3181 | 99.2899 | 101.3041 | 99.2899 | 101.2973 |
| $Q_t^{D^e}$ | 100.9591 | 102.9986 | 100.9591 | 102.9986 | 100.9591 | 102.9986 | 100.9591 | 102.9986 |
| Q_t^S | 98.6400 | 101.0083 | 98.6400 | 101.0025 | 98.6400 | 101.1319 | 98.6400 | 101.1343 |
| Q_{t-1}^{cap} | 0.0267 | 108.0516 | 0.0306 | 0.0336 | 0.0135 | 0.0146 | 0.0066 | 0.0072 |
| P_t | 1.0000 | 1.0808 | 1.0000 | 1.0834 | 1.0000 | 1.0410 | 1.0000 | 1.0202 |
| P_t^e | 1.0797 | 1.1670 | 1.0821 | 1.1723 | 1.0407 | 1.0833 | 1.0201 | 1.0408 |
| σ_t | 0.0267 | 0.0245 | 0.0275 | 0.0253 | 0.0135 | 0.0123 | 0.0066 | 0.0061 |
| Fut_t | 1.0000 | 1.0810 | 1.0000 | 1.0835 | 1.0000 | 1.0416 | 1.0000 | 1.0208 |
| S_t^{tot} | 6036.5600 | 6045.5655 | 6036.5600 | 6044.5044 | 6036.5600 | 6068.1773 | 6036.5600 | 6068.6106 |
| S_t^{spec} | 0.3299 | 0.3582 | 0.3299 | 0.3590 | 0.3299 | 0.3450 | 0.3299 | 0.3382 |
| S_t^{co} | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| S_t^{res} | -0.6499 | -0.3090 | -0.6499 | -0.3156 | -0.6499 | -0.1722 | -0.6499 | -0.1631 |
| sc_t | 0.0050 | 0.0050 | 0.0050 | 0.0050 | 0.0050 | 0.0050 | 0.0050 | 0.0050 |
| cy_t | 0.0150 | 0.0146 | 0.0150 | 0.0147 | 0.0150 | 0.0138 | 0.0150 | 0.0139 |
| π_t | 0.0500 | 0.0428 | 0.0500 | 0.0426 | 0.0500 | 0.0461 | 0.0500 | 0.0480 |
| δ_t | 0.0500 | 0.0584 | 0.0500 | 0.0587 | 0.0500 | 0.0542 | 0.0500 | 0.0520 |
| EC_t | 0.9067 | 0.9498 | 1.0819 | 1.1719 | 0.3057 | 0.2956 | 0.1345 | 0.1263 |
| EAC_t | 0.0050 | 0.0048 | 0.0050 | 0.0050 | 0.0050 | 0.0046 | 0.0050 | 0.0046 |
| CR_t | 0.0417 | 0.0013 | 0.0416 | 0.0011 | 0.0432 | 0.0010 | 0.0441 | 0.0006 |
| σ_t^{SC} | 1577.0000 | 2099.5486 | 1577.0000 | 2092.3768 | 1577.0000 | 2320.5526 | 1577.0000 | 2766.7662 |
| Q_t^{cap,sc^e} | 108.0516 | 114.0331 | 108.0516 | 113.9510 | 108.0516 | 116.5629 | 108.0516 | 121.6706 |
| Π_t^{sc} | 72.1766 | 85.0160 | 76.6169 | 89.9415 | 20.3828 | 26.2603 | 6.9707 | 9.7713 |
| σ_t^{LT} | 1577.0000 | 2250.9751 | 1577.0000 | 2235.4240 | 1577.0000 | 2876.3559 | 1577.0000 | 4990.6674 |
| Q_t^{cap,lt^e} | 108.0516 | 115.7665 | 108.0516 | 115.5885 | 108.0516 | 122.9251 | 108.0516 | 147.1272 |
| Π_t^{lt} | 72.1766 | 92.2954 | 76.6169 | 97.2462 | 20.3828 | 33.5008 | 6.9707 | 18.1375 |
| σ_t^v | 1699.6089 | 2269.4164 | 1692.2449 | 2252.7383 | 2058.5040 | 2942.3060 | 3566.6159 | 5240.2320 |
| Q_t^{cap,v^e} | 109.4551 | 115.9776 | 109.3708 | 115.7866 | 113.5633 | 123.6800 | 130.8263 | 149.9839 |
| Π_t^v | 72.1766 | 86.8189 | 76.6169 | 91.7708 | 20.3828 | 27.8201 | 6.9707 | 11.7812 |

Maximum profits and corresponding production capacities and investments are in bold.

General Conclusion

The strategic position occupied by physical traders in commodity industries leads us to reconsider their treatment in economic theory and more particularly in industrial economics. Their contribution to managing price risks (Marquet, 1992^[192]; Pirrong, 2011^[227]) is already established, but their ability to link producers in different segments of the industry remains relatively unknown if not little discussed in the academic literature. Their contribution is thus fundamental in any activity related, closely or remotely, to international trades. In reality, it seems that their role has been either omitted or too limited. Therefore, the idea of the present thesis was to offer an analysis of the oil industry by repositioning physical traders at its center.

If the need to refocus attention on physical traders has emerged, it is because the large price variations observed in recent years have put their contribution at the center of attention. They are the agents capable of filling various mismatches inherent in commodity trading. They have the storage capacity to manage time shifts between supply and demand, they are located in the main ports of international trade to transfer commodities in areas where they are the most valued. Above all, they are mostly known for their access to financial derivatives markets to manage price risks. Under these conditions, it becomes essential to properly describe and explain the role of these agents in industries. On the basis of these different contributions, it becomes important to widen the industrial analysis to no longer present trades and organization as an allocation of assets only between two producers positioned next in the supply chain, but as a meeting in which physical traders can be an intermediary agent. From then on, they cease to be exogenous third parties and become the key agents for the smooth functioning of the market. They provide liquidity and consistency to ensure the market integration and are the missing link that allow a supply to find a demand and conversely.

Thus, this thesis aimed to be part of this effort to transcribe the contribution of physical traders to the organization of the international trade. Of course, several writings have already dealt with the organization of trade, including for commodities, but few have

discussed the specificities of these industries in terms of price dynamic and the impact of traders. We have thus set our objectives of contributing to fill the gap in the literature on this issue. Given the breadth of presentation of physical traders and their contribution, as varied as it may be, we focused our efforts on their ability to allow supply to transfer their output downstream in the market. In this way, we were led to develop our research framework in three main parts. In a first instance, we have presented the emergence of individual oil traders to highlight the conditions that created the need for third parties managing trade-related risks. Then, we have offered to focus on oil traders' contribution to enable the market to exist and to match supply and demand. Finally, once their presence justified in the two previous parts, we analyzed the consequences of taking traders into account in the choice of industrial organization of the industry's producers.

Main results

The main thread of the thesis has been to follow the role of the physical trader in the oil industry in order to justify his presence, then highlight his contribution to international trades and finally to look at the consequences of his presence on the organization of the industry.

The first part of this thesis dealt with the emergence and growth of the oil industry. We aimed to demonstrate how physical traders have emerged to become the key players we know nowadays. Our line of the analysis have led us to make the management of international trades the key component of the distribution of market power in the industry. This part follows the evolution of the agents that control midstream, and more precisely transport, infrastructures.

The first chapter have addressed the question of the main paradigms used to analyze the oil industry. Therefore, the first line of study have reviewed the major historical events that explain the evolution of the theoretical framework of the industry. Thus, we could

highlight three main periods. The first one focuses on the growth of the Standard Oil company starting 1870. The company is the first “big” oil producer. It initiated vertical integration strategies to establish and extend its market power in the industry, especially on transport companies since the main issue was to connect crude oil producers to refiners at a competitive cost. The dominant position derived from the monopolistic competition allowed Standard Oil to benefit from lower shipping rates than its competitors. Moreover, it enabled to impose the posted-price system. Despite antitrust laws that dismantled the company in 1914, the legacy of the imperfect competition and the price system went to the Seven Sisters until the oil peaks in the 1970s. Many similarities can be found between the two periods. The oligopolistic competition, or even the cartel organization, has kept market powers of a small group of companies. Vertical integration of oil producers has emerged as the norm to maintain market power in the industry. Internal trades within the same firm circumvented any attempt to create an integrated market that would have allowed prices to be determined by both supply and demand. On the contrary, the dynamism of horizontal integration, to extend market power to any area, has reinforced their position. The proof is that the spot market remained underdeveloped with regard to the place of crude oil in international trades until the 1970s.

Therefore, these two periods share the same dominant framework to analyze changes in the industry: the foreclosure theory. The strategy that use vertical integration to “raise rivals’ costs” (Ordover *et al.*, 1990^[214]) or denying rivals’ access to some key segments and services of the industry (Rey and Tirole, 2007^[233]; Klein, 2011^[172]) is used to justify the development of antitrusts laws to limit the influence of the Standard Oil. Despite the “As-in Agreement” which aimed to prevent counterproductive moves between the Seven Sisters, the “run” to horizontal integration and the vertical integration has maintained the foreclosure theory as the dominant framework.

The formation of the OPEC in the 1970s, to rebalance the distribution of revenue between producing companies and host countries, and the emergence of a liquid and open spot market has led to a major change in the organizational framework of the oil industry. Producers are no longer constrained to extract the amount of crude they refine. Upstream

segments can sell crude oil to independent downstream segments on the market. It has made the boundaries of oil firms more visible. They can divest when the market is a better option than the vertical integration. The oil industry could become a field of application of the theory of the transaction costs economics (Coase, 1937^[63]; Williamson, 1971^[273]). However, it has also revealed the contract incompleteness. The trade-off between the vertical integration and the market relies strongly on the design of contract to reduce the risk exposure. Nevertheless, and this the main critic we can make these frameworks, the literature do not really consider the role of third parties and other midstream agents in the organization. Yet, commodity traders are an essential part of the organization of international trades.

It is quite naturally that the second chapter of this thesis focused on the emergence of crude oil producers. Our objective was to present the contribution of commodity traders to al enable producers to trade in the oil international market. We reject the presentation of traders as mere agents to move crude oil barrels from one point to another. In line with Marquet (1992^[192]) and Pirrong (2011^[227]), our work intended to highlight the multiple barriers that producers may face on the international oil market and how commodity traders help to circumvent any mismatch between the two parts of international trades. We contribute to the analysis of the price risk management by studying the main drivers of energy price volatility. The main empirical challenge here is to account for the strong connectivity of energy prices to equity markets, without neglecting the role that can be played by commodity-specific variables. That is why we have used traditional GARCH-class models with two specifications. A EGARCH model analyzes drivers of price volatility on a daily frequency and, following Engle *et al.* (2013) a mixed-frequency GARCH model enables to study the driver of the long-term component of the price volatilities and, thus, to include low frequency variables. Indeed, it seemed to us essential to also take into account demand and supply variables that are essential to explain the role of market unbalances on price volatility. The so-called “commodity super-cycle” that ended in 2014, with a sharp price decrease and a subsequent surge in price volatility,

justifies the analysis of the volatility long-term component. Thus, we have been able to demonstrate that increasing financialization of commodities since the 2008 crisis (Creti *et al.* (2013) modifies the relationship between volatilities and equity returns. Furthermore, the mixed-frequency GRACH model has highlighted the impact of supply and demand changes, which are both positively correlated with energy price volatility. Therefore, it seems that financial variable could explain high-frequency volatility while commodity-specific variables influence the trend of energy price volatility.

In a second part, we offered to focus on commodity traders' contribution to link producers and end-users. This mission went through a two-step analysis. First, we determine countries exhibiting a high oil trading activity and how they change trade oil patterns. Second, we highlighted commodity traders' contribution to link regional markets

In chapter 3, we aimed to contribute to the literature on crude and refined oil international trade by introducing the particular role of "commodity trading countries" in the framework. Our ambition was twofold. On the one hand, we wanted to highlight the key role of commodity reexporting countries, which can import large volumes of oil from commodity producing countries and re-export them to a large variety of destination in smaller amount. On the other hand, we have extended gravity model by introducing measures from the graph theory. Indeed, the gravity model is the reference to explain international trade patterns. However, in an industry that needs intermediaries to link producers and consumers, we have stated that the analysis of bilateral trades must incorporate a special treatment for re-exporting countries in which commodity traders can be found. Therefore, we have computed centrality measures to identify oil trading countries. We have also introduced some of the centrality measures in order to quantify their capacity to link markets. We have concluded that the actual gravity effect is found in countries that we defined as oil traders. Their capacity to be the missing link between producing and consuming countries that do not have many trade partners is highly valued. We could also show that the pattern of trade is different between crude and refined oil.

We have dedicated the chapter 4 to the ability of commodity traders to link producers to the international oil market. Indeed, the most basic barrier to the development of an international market is simply to allow its producers to take part in it. Yet, the risk exposure on the international market raises the uncertainty on producers' revenue who could rather focus on their domestic market. This chapter is divided into two main areas of study. First, we have built a two-step theoretical model of a commodity industry in which producers can trade on local market or trade with commodity traders in order to access to the international market. We have found other proofs that physical traders change commodity trade flows. As can be expected, an increase in commodity prices creates an incentive to trade on the international market. However, the main contribution of the model is to show that higher uncertainty on commodity prices increase international trades, which could be counter-intuitive. Indeed, it leads producers to use commodity traders' price hedging services, thus to trade on the international market.

Second, in order to control if the action of commodity traders really contribute to link producers from multiple regional markets, we have offered to verify the existence of a global oil market. To verify the oil market integration, we stood out from traditional analysis using cointegration analysis and VECMs. The later has already proved to be performing to demonstrate the integration of the oil market (Bachmeier and Griffin, 2006) and changes in the cointegration relationship (Kuck and Schweikert, 2016). In our case, we have chosen to value the evolution of the oil market integration through time, considering 14 oil prices from 2011 to 2019. We have used the graph theory and constructed minimum spanning tree, following Ji and Fan (2014). We could develop time varying indicators of the integration and show that periods of high volatility, in 2015 and 2019, led to a rise of the market integration. The causal link is certainly too weak to attribute to traders the sole responsibility for the increasing integration over these periods, just as our theoretical model is too simplistic to be a perfect representation of market reality. Nevertheless, consistent with both of our results of the chapter, we can assume that an increase in uncertainty raises trades with physical traders. As a consequence, a higher volume of oil

barrels traded on the international market must contribute to market integration.

In the third part of the thesis, we have continued our analysis of the role played by physical traders in organizing trades in the industry. Having established that traders provide essential services to link producers and end-users in the industry and contribute to the management of risks inherent to international trade, it seems essential to focus on their inclusion in the contractual organization of producers. Indeed, both the organization and traders aimed to minimize transaction costs and the risk exposure. Thus, the last essay of this thesis have aimed at verifying the inclusion of these agents in the choice of trading on the market or to vertically integrate.

In chapter 5, we have reviewed the literature on the incomplete contract theory to determine the optimal contractual design of oil trades. Indeed, most theoretical studies aim to define the contract that would be able to protect producers from price variations and opportunism. Actually, we support the idea that both risks balance each other. Indeed, fixed-price contracts raise opportunism since price variations create incentives to renegotiate or even break contracts when trading outside the contract become attractive. On the contrary, varying prices do not lock producers on prices and reduce the hold-up risk. In the case of commodity trading, contractual clauses and “take-or-pay” provisions can reduce exposure to opportunism. Therefore, our perception of the literature on the organization has made us think that the price dynamic must systemically include in the analysis. Furthermore, a segmental balance sheets of big oil producers has confirmed us that the allocation of investments is sensitive to the price dynamics. It seems to indicate that vertical integration strategies also follow a dynamic. High prices encourage producers to extend their activity to capture the higher part of the added value of the industry, while disintegration rather leads to disintegration strategies.

The final chapter has provided a theoretical model to verify our assumption from the analysis of the literature on the organization. We built a two-period partial equilibrium

model with competitive storage and commodity traders. Rather than comparing the market and the firm as solutions to transfer crude oil barrels to downstream units, we have split the market in two in order to get closer to the stakes of the oil trades. We have considered fixed-price long-term contracts but also short-term contracts which are only possible because of the presence of agents hedging price risk: the commodity traders. In this way, we have learnt the following lessons. Commodity traders modify the trade organization of the industry by making spot and price varying contracts credible contracts for producers. Results show that we can determine an organization dynamic since high prices can finance the costs of the vertical integration, while lower prices bring producers to restore flexibility. Moreover, we could highlight the pro-cyclicality of productive investments because of the delay between the investment decision and the changes in productive capacities.

The perspective, both theoretical and empirical, proposed by this essay on the role of physical traders on the oil industry may have revealed the need to take them into account in the literature on transaction costs economics. Oil traders modify trades in the industry on several levels. They change international oil trades flows to connect local producers to the international market and directly impact the organization of the industry.

Thus, the role of physical traders remains largely unknown, which, in the end, is also partly due to the relative opacity of these actors. Yet this is a field of literature that will continue to gain in interest in the coming years. The limited reserves of a number of raw materials make agents organizing commodity trades strategic actors. Furthermore, transparency of physical traders is increasing, notably carried by physical traders choosing to go public. This new flow of information should be able to create a new momentum in the economic literature on the subject. Thus, this thesis aims to contribute to this new momentum.

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La théorie des coûts de transaction et le rôle du trader physique dans l'organisation de la filière de matière première: un essai théorique

Résumé : Les fortes variations des prix des matières premières et la chute des prix observée en 2014 pour beaucoup d'entre elles ont, plus que jamais, mis en évidence la contribution des commerçants physiques dans les secteurs. En se concentrant sur le secteur pétrolier, cette thèse vise à rendre compte du rôle joué par les négociants internationaux dans l'organisation du commerce international. Tout d'abord, nous émettons l'idée que ce sont les stratégies de désintégration verticale et l'ouverture des marchés qui ont permis l'émergence de négociants indépendants. Ils occupent un rôle clé dans la transformation temporelle et spatiale de la marchandise, mais aussi dans la gestion des risques inhérents au commerce international. À cette fin, nous montrons que la volatilité des prix du pétrole brut est de plus en plus sensible aux rendements boursiers et que les facteurs de l'offre et de la demande de pétrole influencent directement la composante à long terme de la volatilité des prix. Par la suite, à l'aide d'un modèle cobweb simple, nous analysons la capacité des négociants physiques à favoriser l'intégration du marché pétrolier. Nous montrons que les hausses de prix, tant en niveau qu'en volatilité, encouragent les producteurs à faire appel à des négociants pour se connecter au marché international. En utilisant la théorie des graphes, nous mettons également en évidence l'utilité des traders pour maintenir l'intégration du marché pétrolier, en cas de baisse des prix et de forte volatilité. En outre, il apparaît que les pays qui accueillent des négociants internationaux font preuve d'un effet de gravité en important d'importants volumes de barils de pétrole des pays producteurs pour réorienter ces flux vers les marchés de la demande. Enfin, nous soutenons que la théorie des contrats incomplets doit intégrer la variabilité des prix afin de faire face aux comportements opportunistes dans les chaînes d'approvisionnement en matières premières. Ce postulat et l'inclusion des négociants dans l'industrie des matières premières nous amènent à considérer les contrats à court terme et les contrats à prix fixe comme deux organisations qui s'inscrivent dans les stratégies de désintégration verticale des producteurs. En utilisant un modèle d'équilibre partiel avec comportement de stockage stratégique, nous concluons que la dynamique de l'intégration verticale dans l'industrie pétrolière est influencée par les prix du pétrole brut. Notre travail défend donc l'idée qu'il n'y aurait pas de marché sans l'action des négociants physiques.

Mots-clés : Matières premières, Théorie des coûts de transaction, Négoce international, Industrie pétrolière, Commerce International

Transaction costs economics and the role of the commodity trader in the organization of the industry: a theoretical approach

Abstract: Large variations in commodity prices and the price drop observed in 2014 for many of them have, more than ever, highlighted the contribution of physical traders in the sectors. By focusing on the oil sector, this thesis aims to account for the role played by traders in the organization of international trade. First of all, we state that vertical disintegration strategies and the market openness have allowed independent traders to emerge. They have a key role in providing time and spatial transformation of the commodity, but also in managing the risks inherent in international trade. To this end, we show that the volatility of crude oil prices is increasingly sensitive to stock market returns and that oil supply and demand factors directly influence the long-term component of price volatility. Subsequently, using a simple cobweb model, we analyze the ability of physical traders to foster the oil market integration. We show that price rises, both in level and volatility, encourage producers to use traders in order to connect to the international market. Using graph theory, we also highlight the usefulness of traders in maintaining the oil market integrated, in the event of decreasing prices and high volatility. Furthermore, it appears that countries hosting international traders demonstrate a gravity effect by importing large volumes from producing countries to redirect these flows to demand markets. Finally, we argue that the theory of incomplete contracts needs to integrate price variability in order to deal with opportunistic behavior in commodity supply chains. This postulate and the inclusion of traders in the commodity industry lead us to consider short-term contracts and fixed price contracts as two organizations that fit into producers' vertical disintegration strategies. Using a partial equilibrium model with strategic storage behavior, we conclude that the dynamics of vertical integration in the oil industry are influenced by crude oil prices. Our work therefore defends the idea that there would be no market without the action of physical traders.

Keywords: Commodity, Transaction Cost Theory, Commodity trading, Oil industry, International trade