Management of non-renewable resources : Market equilibrium, socio-economic impacts and potential channels of resource curse -An application to Phosphate Rock-

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Gestion des ressources naturelles non renouvelables:

Équilibre du marché, impacts socio-économiques et canaux potentiels de malédiction des ressources

— Une application au Phosphate —

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Management of non-renewable resources: Market equilibrium, socio-economic impacts and potential channels of resource curse

─ An application to Phosphate Rock ─

PhD Thesis

by

Jamal AZIZI

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Preface

This Ph.D. thesis entitled "Management of non-renewable resources: Market equilibrium, socio-economic impacts and potential channels of resource curse ─ An application to Phosphate Rock ─" has been prepared by Jamal AZIZI during the period from October 2014 to July 2018, at CERNA at Ecole des Mines (Mines ParisTech).

The Ph.D. project has been completed under the supervision of Professor Pierre Noël Giraud. I prepared this thesis in parallel with my work, which is a senior economist at mining sector.

The thesis is submitted as a partial fulfilment of the requirements for obtaining the Ph.D. degree at the PSL Research University.

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To my two daughters Doha and Rim.

Jamal AZIZI

Abstract

The purpose of this thesis is to examine the sustainable management of non-renewable resources in general and phosphate rock in particular.

The first chapter presents the current situation, future trends and geopolitical issues pertaining to the global phosphate market. The analysis shows a large deficit in world phosphate supply in the future, inciting producers with sufficient phosphate reserves to invest in new capacities.

The second chapter develops a multi-leader-multi-follower Stackelberg model, calibrated using real data from the phosphate market. This model derives the optimal future capacities for different producers according to their reserve levels and their development costs. The results show that the market would become more concentrated in 2100, with Morocco being the dominante country wich already holding three quarters of the world's reserves.

The third chapter presents and calculates the linkage effects generated by Morocco’s phosphates exploitation. Using the Input-Output model, the proposed empirical analysis compares the socio-economic impacts of extraction to those related to transformation or valorization. The results of this analysis show that phosphates transformation is more linked to the other sectors and generates higher socio-economic impacts in terms of added value, income and employement.

The last chapter contributes to the literature on the natural resources curse by linking agricultural performance and urbanization to the abundance of resources. The empirical study, based on a panel of African countries, shows a significant link between the abundance of mineral resources, the underdevelopment of the agricultural sector and urban explosion.

Résumé

Cette thèse a pour objet l'examen de la gestion durable des ressources non renouvelables en général et du phosphate naturel en particulier.

Le premier chapitre expose l'état, les perspectives et les enjeux économiques et géopolitiques du marché mondial des phosphates. Il s'attache à mettre en exergue de cette analyse un important déficit, à long terme, de l'offre mondiale par rapport à la demande incitant les producteurs des phosphates, qui ont suffisamment des réserves, à investir dans des nouvelles capacités.

Le deuxième chapitre développe un modèle Stackelberg à plusieurs joueurs, calibré sur des données effectives du marché des phosphates et permet de calculer les capacités optimales à mettre en place par les producteurs selon leurs niveaux de réserves et leurs coûts de développement. Les résultats de ce modèle montrent que le marché deviendrait plus concentré, en 2100, qu'il est aujourd'hui avec une dominance du Maroc, le pays qui détient les trois quarts des réserves mondiales.

Le troisième chapitre vise à évaluer les effets d'entraînement que le Maroc dégage de son exploitation des phosphates. En utilisant le modèle Input-Output, l'analyse empirique proposée compare les impacts socio-économiques de l'extraction à ceux liés à la valorisation ou à la transformation. Les résultats de cette analyse montrent que la transformation des phosphates est plus reliée en amont avec les autres branches de l'économie et génère plus de valeur ajoutée, de revenues et d'emplois.

Le dernier chapitre s'évertue à traiter à de nouveaux frais la question de la malédiction des ressources naturelles en reliant la performance agricole et l'urbanisation à l'abondance de ces ressources. L'étude empirique, basée sur un panel de pays africains, exhibe un lien significatif entre l'abondance de ressources minières, le sous-développement du secteur agricole et l'explosion urbaine.

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General introduction

The relationship between natural resources and economic growth is, in essence, controversial. In theory, an abundance of natural resources will boost economic growth. A rising natural resources output would increase public revenues, enabling governments to increase investments in physical and human capital, while private returns on resource production would boost both private domestic and foreign investments. However, many resource-rich developing countries fail to realize the full development potential of their natural resources. This is the case in many countries in the Sub-Saharan Africa (SSA) region, especially when it comes to non-renewable resources (also called finite or exhaustible resources) such as oil, gas and minerals. A large body of literature has highlighted the causes and the mechanisms of this underperformance—often referred to as the "resource curse"— reliving a complex and often-ambiguous set of associations.

World demand for non-renewable resources grows continuously. If efficiently produced and traded and sustainably managed, those resources can generate important revenues for governments. Those revenues can in turn be invested in education, health, and infrastructures which are indeed critical to development and poverty reduction.

Geologically speaking, most of the non-renewable resources are unevenly distributed throughout the world and this may leads to an oligopolistic market structure.

In this research, three major economic questions are raised in relation with the production and management of non-renewable natural resources. The first question is : How producers of non-renewable natural resources, facing a growing demand, make their investment decisions in order to meet their optimal market share? The seconde question is: How do non-renewable natural resources affect the economic and social development of a producing country? The third question is: How can non-renewable natural resource-rich developing countries, especialy in the SSA region, avoid or escape the resource curse?

The present research is mainly focused on **phosphate rock** (PR) for four reasons. First, PR is a non-renewable resource. Second, this resource plays a key role in global food production and to this date, there are no agricultural alternatives for it. It is then directly linked to food security. Third, global PR reserves are unevenly distributed and highly concentrated. Worldwide reserves are estimated to 68 billion tons, with almost 85% of total reserves located in five countries: Morocco, China, Algeria, Syria and South Africa. Morocco alone holds 75% of the world's highest-quality reserves. Fourth, PR has for a long time been a commodity with low and stable prices. But since 2008, when prices jumped up dramatically by 900% and then dropped to around twice the pre 2008 level, PR has exhibited significant price volatility rising therefore questions about future availability and prices. Before 2011, numerous articles concerning a looming scarcity of PR had argued that global reserves might be depleted in 50–100 years and a peak of world production had been predicted to occur around the mid-21s centry.

Given the large number of studies on non-renewable resource management, this research does not pretend distinguishing itself by absolute novelty; yet, the way of approaching the subject is an innovative one, representing a distinctive element regarding the study of this topic.

Given the nature of the subject, the methodology adopted for this research is based on both theoretical and practical frameworks. The research strategy is a deductive one performed using a combination of qualitative and quantitative approaches (empirically – by using real data, econometric estimation and game theory models), thus providing a strong support for the conclusions.

0.1 Objectives of the thesis

Sustainable management of phosphate rock represents a major challenge for policy-makers, scientists and the civil society. The current economic context requires more rationality and optimality at both production and consumption levels. From this perspective, the first objective of this research is to get a better economic understanding of the global phosphate market (Chapter 1) and the second objective is to develop an equilibrium model for future competition in order to help producers reach optimality in terms of investment decisions (Chapter 2).

Mining and mineral processing can generate several types of positive externalities. The third objective of this research is to gain a better understanding of the socioeconomic impact of resource extraction and transformation on the national economy. The study considers the case of phosphate mining and processing in Morocco and identifies three broad channels through which the national economy may be potentially affected by extractive activities and through links that exists with other economic sectors. These three channels are production, income and employment (Chapter 3).

However, natural resource extraction can also generate negative externalities. The theoretical explanations for the resource curse can be grouped into four broad categories: Dutch Disease, volatility in commodity prices, rent seeking/corruption and institutional quality. The fourth objective of this research is to highlight the resource curse explanations and to test two potential channels for African countries: First, can mineral resources abundance explain the poor agricultural performance? Second, is there a relationship between natural resources abundance and urbanization trends? (Chapter 4).

0.2 Outline of the thesis and main results

The PhD thesis entitled "Management of non-renewable resources: Market equilibrium, socio-economic impacts and potential channels of resource curse — An application to Phosphate Rock —" is divided into four chapters. Each generates some results and conclusions that may be of interest to policymakers.

Chapter 1: Global Phosphate Rock Market: An economic overview of future competition

Considered as a non-renewable resource, phosphate is an essential raw material for the fertilizer industry and therefore for agricultural production. Global distribution of phosphate reserves and production, as well as global supply, is highly concentrated and controlled by a limited number of countries. Demand for phosphate is expected to rise as a consequence of an increasing population and a growing production of biofuels. Since there is no yet known substitute for phosphate, this imbalance between demand- and supply-sides leads to price volatility or a price setting behavior by suppliers with significant market power. This Chapter overviews the recent literature and data on the availability of phosphate, and shows that the restricted number of producing and exporting countries give rise to factors which can potentially affect future supply and thereby future competition in the phosphate rock market.

Chapter 2: Equilibrium Phosphate Rock Capacity Expansion under imperfect competition

This chapter examine how the distribution of phosphate rock (PR) reserves may affect the supply and capacity investment decision in the future. Given the oligopolistic situation of PR market and the sequencing of decision making, we propose a multi-leader multi-follower Stackelberg model. For forward-looking considerations, we introduce the development costs (CAPEX) as a function of reserves in the producer's decision program. We show the properties of the model equilibrium, and obtain the solution in analytic form. The model is then calibrated to the PR real data. The overall analysis supports the notion that PR market will become more concentrated than it is today. The equilibrium capacities show that Morocco's annual production will rise significantly from 27 Mt to more than 127 Mt by 2100. The country should thus multiple its capacity of extraction by 3.7 by 2100. Additional capacities will come from 9 followers, with most important increases by three followers (Australia, Syria, Algeria) who should multiply there capacities by 12 to meet their equilibrium market share. Consequently, the industry cost curve will become flatter at lower cost in the future as the major new capacities will come from producers with low cost of production and lager reserves.

Chapter 3: Economic impacts of phosphate extraction and valorization on the Moroccan economy: An input-output analysis

This Chapter aims to estimate and analyze the impact of phosphate extraction and valorization activities on the Moroccan economy. By using an input-output framework, the study evaluate how an increase in final demand (e.g. export demand for phosphate rock or for fertilizers) of each of these industries affect the Moroccan economy. To do this, we have combined the detailed Profit and Loss (P&L) statement from OCP group, the state-owned company that has a monopoly in phosphate sector, with the latest 2014 Moroccan I-O table to bring out OCP activities and to split them into two sectors: "OCP-mining" and "OCP-chemical". From the estimated models, we calculate several multipliers (output, income and employment) and linkage measures. Our results indicate that the OCP-chemical sector has a high production-inducing effect and a high income and employment-inducing effect compared to OCP-mining sector. The OCP-chemical sector impact on production is the following: each 1US$ of fertilizers production generates a production valuated at 2,61 US$ in the Moroccan economy while the same amount of phosphate rock generates a production valuted at just 1,73 US$. In term of income, OCP-chemical activity generates 3,11 US$ for each 1US$ increase for the sector's production while OCP-mining impact is equal to 2,25 US$. In addition, the calculations show that OCP-chemical sector has more capacity to generate employment opportunities compared to the OCP-mining sector. The total employment multiplier is equal to 8 man-years for OCP-chemical sector while it is about 3 man-years for OCP-mining sector. Our linkage analysis shows that OCP-chemical sector is much more backward linked with the others sectors of the economy than OCP-mining sector. However, we note that both sectors have a low forward linkage effect.

Chapter 4: Natural Resources Revenues, Agriculture Development and Urbanization in African Countries: Evidence from a Static and Dynamic Panel Data

This chapter analyzes the mechanism through which natural resource abundance leads to a poor agricultural performance and a rapid urbanization in African countries. We conducted a static and dynamic panel data analysis for a panel of 39 African countries during the period 2000-2013. Our findings show that natural resources rents have a negative impact on agricultural performance and a positive impact on food import dependency. In addition, the results show a significant positive impact of resource rents on rural-urban migration and on urbanization rate. We argue that these findings can be explained by the government choice to specialize in primary commodities to the detriment of the development of other productive sectors, especially agriculture. Because policy makers tend to invest resources rents in developing infrastructures, mostly in cities, this inevitably creates some pulling factors for rural population in search of a better life. Consequently, we observe a rapid urbanization associated with serious problems (Expansion of urban slums, limited access to improved water and sanitations facilities) in many African countries, highly dependent on natural resource rents.

Chapter 1

Global Phosphate Rock Market: An economic overview of future competition

Résumé

La croissance des plantes depends essentiellement d'eau, d'azote et de phosphore, des éléments naturellement présents en quantités variables dans les sols. Le phosphore utilisé en agriculture provient de roches phosphatées, une ressource non renouvelable. L'épuisement de cette ressource est susceptible d'avoir des conséquences dramatiques sur la sécurité alimentaire mondiale. Ce chapitre expose l'état, les perspectives et les enjeux économiques et géopolitiques du marché mondial des phosphates. En s'appuyant sur des données statistiques, il s'attache à mettre en exergue un potentiel déficit, à long terme, de l'offre mondiale par rapport à la demande incitant les producteurs des phosphates, qui ont suffisamment de réserves, à investir dans des nouvelles capacités.

1.1 Introduction

Phosphate rock is important for crop nutrition because it contains phosphorus, an essential element for plant life, and is considered as a "primary" plant nutrient along with potassium and nitrogen. The most important use of phosphate rock is in the production of phosphate fertilizers for crops and animal feed supplements. Only about 5% of world production is used in other applications, such as construction, soaps and detergents (Prud'Homme, 2010).

Demand for phosphate is expected to increase by an average rate of 1.5% per year (Argus Strategy Report, 2017) due to population growth and the necessity of nurturing that population. The growing market for biofuels is another factor that increases phosphate demand. Future demand will mainly come from developing nations in Asia-Pacific and Latin America. Additional demand will come from Sub-Saharan Africa where many poor farmers are working with phosphorus deficient soils (Giraud, 2017). Moreover, the recent decreases in phosphate consumption observed in Europe and North America are due to a more efficient use of fertilizer and a buildup of phosphate in the soil. This trend could be reversed as increased efficiency has its limits (Van Vuuren et al. 2010). On the supply side, world phosphate rock reserves are concentrated in a few countries. Morocco, for example, has 50 billion metric tons of phosphate rock reserves, which represent 75% of the world's total reserves (USGS, 2017). The country plays an important role with regards to international trade as it is also the world's largest exporter of phosphate rock accounting for about one-third of total exports. Looking to production, China and the US are among the top producers, but their production is mainly oriented to the domestic market.

Phosphate was considered as a low price commodity for a long time. The picture has changed since 2008, when phosphate rock prices jumped up dramatically by 900%. Following this peak, prices dropped in 2009 but remained above the pre-2008 prices and became more volatile. Moreover, as phosphate rock is a finite resource and global production of phosphate is rising fast, several studies have warned that a 'peak phosphorus' could be reached by mid-21st century (Déry and Andersson, 2007; Cordell et al., 2009 and Rosemarin et al., 2009). Consequently, the world debate is becoming more focused on a looming scarcity and a threat to food security in developing countries (Cordell et al., 2009). Nevertheless, the methodology behind the peak phosphorus hypothesis and the data used in the studies have been rapidly disputed in a number of scientific studies (e.g., Vaccari and Strigul, 2011; Rustad, 2012; Giraud, 2012; Scholz and Wellmer, 2013).

The purpose of this Chapter is to discuss the following questions: what is the situation of the global phosphate rock market as of today, in what direction may this market evolve in the future, and what are the consequences for future competition? To answer these questions, we first discuss the problematic of global phosphate availability. We show that given the current reserve estimates for phosphate rock, neither an exhaustion of global reserves nor a peak event is likely to occur during this century. We also show that the global phosphate reserves and production are highly concentrated in a few countries. Then, we make an inventory of the global phosphate rock market by looking at the major players and price developments. Finally, we discuss the factors affecting future supply and thereby future competition.

1.2 Global availability of phosphate rock

1.2.1 Phosphate scarcity and the recent revision of reserves

During the last decade, there have been numerous published articles concerning a looming scarcity of phosphate rock. For instance, Cordell et al., (2009) and Rosemarin et al., (2009) have argued that global reserves may be depleted in 50–100 years and a so-called peak phosphorus is predicted to occur around 2033-2034. Before that, Déry and Anderson (2007) estimated that the world has already passed the phosphate peak in 1989. Nevertheless, the methodology behind the peak phosphorus hypothesis and the data used have been rapidly disputed in a number of scientific papers (e.g., Vaccari and Strigul, 2011; Rustad, 2012; Giraud, 2012; Scholz and Wellmer, 2013). Regarding the data, we note that all calculations of peak phosphorus published before 2011 are based on the previous U.S. Geological Survey (USGS) estimation of phosphate rock reserves. Moreover, the definition of reserves is a dynamic one because, when prices increase, deposits that were previously considered too expensive to access are reclassified as reserves (Vaccari, 2009). In 2011, the USGS have increased global phosphate reserves from 16,000 million metric tons (mmt) in 2010 to 65,000 mmt and to 67,000 mmt in 2014. The last estimate is reported at 68,000 mmt (USGS, 2017). The most significant revision is made to reserves data for Morocco based on the International Fertilizer Development Center (IFDC) report published in 2010, which estimates Moroccan phosphate reserves to 51,000 mmt, compared with 5,700 mmt previously reported by USGS. Based on these revised estimates, Van Kauwenbergh, the IFDC's Geologist and Principal Scientist, stated that there is no indication to an ongoing peak phosphorus event in the coming 20-25 years and, assuming the current production rates, phosphate rock reserves to produce fertilizer will be available for the next 300-400 years. The methodological criticism to the peak phosphorus theory is that the modeling was based essentially on a static approach, such as the static lifetime or the Hubbert curve-based prediction of peaks. Giraud (2012) have explored the scientific foundations and therefore the scope of validity of these forecasting techniques. Looking at the basic assumptions of Hubbert's thesis, he concludes that these techniques should not be used to forecast neither the peak (or plateau) of the annual production rate, nor the ultimate reserves of any mineral, unless given exceptional conditions. Scholz and Wellmer (2013) show that these analyzes do not sufficiently incorporate geological knowledge nor other aspects such as the dynamics of exploration and technology developments in phosphate mining and production, demand curves and market mechanisms. In addition, Ulrich and Frossard (2014) show that past worries about phosphate depletion have been systematically "refuted by means of new resource appraisals, indicating that the supply was substantially larger than previously thought".

1.2.2 Future capacities

Generally, the exploration process takes many years and requires significant investments to complete and open up a new mine. It is therefore difficult to determine the impact of ongoing exploration activities on future supply of phosphate rock. This also explains why changes in phosphate rock supply are very slow to respond to changes in prices.

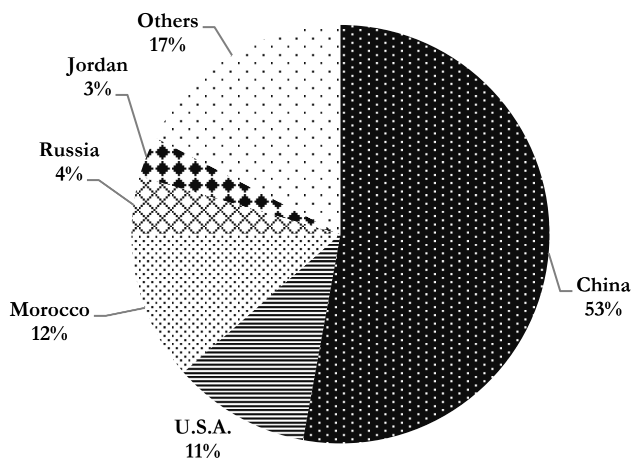
World phosphate rock production capacity is expected to increase by 2% per year through 2020. The largest expected areas of growth are Africa and the Middle East (USGS, 2017). Morocco's state-owned firm OCP announced in 2010 that it expects to double phosphate rock production capacity from 28 to 55 mmt by 2020. An additional 5.3 mmt of phosphate capacity will come from Saudi Arabia in 2017. Other significant phosphate rock projects are expected to begin by 2020 in Algeria, Brazil, Egypt, Jordan, Kazakhstan, Peru, Russia, and Senegal (USGS, 2017).

1.2.3 Phosphate reserves and production

As we mentioned above, the USGS estimated global deposits of phosphate rock that are economically recoverable with current technology—known as reserves—at 68,000 mmt. Geographically, phosphate rock reserves are concentrated. Morocco holds 50,000 mmt of phosphate rock reserves, which is about 75 percent of the world's total. Other major holders of phosphate rock reserves (ranked according to the size of their reserves, from large to small) are China, Algeria, Syria, South Africa, Russia, Egypt, Jordan, the US and Australia. All together, these countries hold about 14.5 mmt, or 20 percent of the world's total.

In terms of production, total world production of phosphate rock was estimated at 261 mmt in 2016. Figure 1.1 shows that China was the leading producer accounting for 138,000 mmt, followed by Morocco (30 mmt) and the United States (27.8 mmt).

Figure 1.1: Major phosphate rock producers



Source: USGS Mineral Commodity Summaries 2017

1.3 Global phosphate market and price development

1.3.1 Major players in the global phosphate market

Based on the IFA data, Figure 1.2 shows that the major phosphate rock exporting countries, in 2016, were Morocco, Jordan, Peru, Egypt and Russia. All together, these countries control about 80 percent of the global phosphate rock export market. Morocco is the world's largest exporter accounting for about one-third of total exports. Looking at production, China and the US are among the top producers of phosphate but their domestic consumption largely eclipses their exporting activities (Figure 1.1).

Figure 1.3 shows phosphate rock imports by country. India is, by far, the world's largest importer. Indonesia, Brazil and the USA have the largest share in global phosphate rock imports. Since the majority of phosphate rock is eventually turned into fertilizer products (e.g. Phosphoric Acid (PA), DAP, MAP and TSP), imports of phosphorus expressed as P2O5[1] in the form of fertilizer products is a viable alternative indicator. Looking at that indicator, India has an overwhelming lead, with 26%, followed by the EU with 15%. Poland, Belgium, Lithuania, France and Spain are the major importers accounting for about 60% of the EU's imports in 2016. Brazil comes third at 12% (Figure 1.4).

[1] P2O5, the chemical formula of phosphorus pentoxide, is generally used as the measurement of phosphorus concentration in phosphate rock and fertilizers.

Figure 1.2: Major phosphate rock exporting countries, 2016, (calculation based on tonne product)

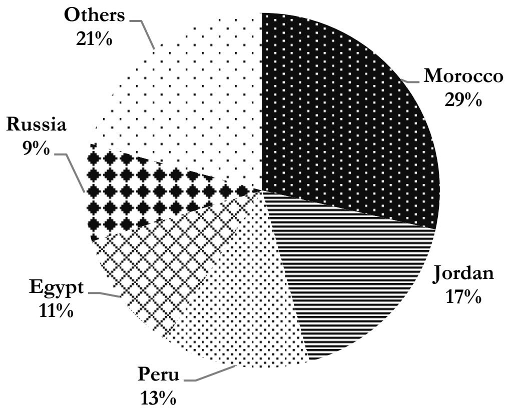


Figure 1.3: Major phosphate rock importing countries, 2016, (calculation based on tonne product)

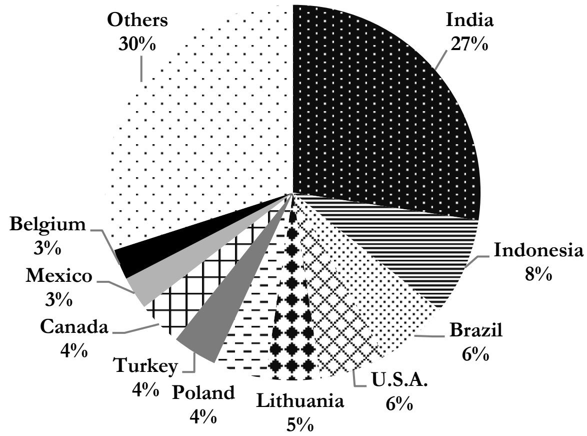
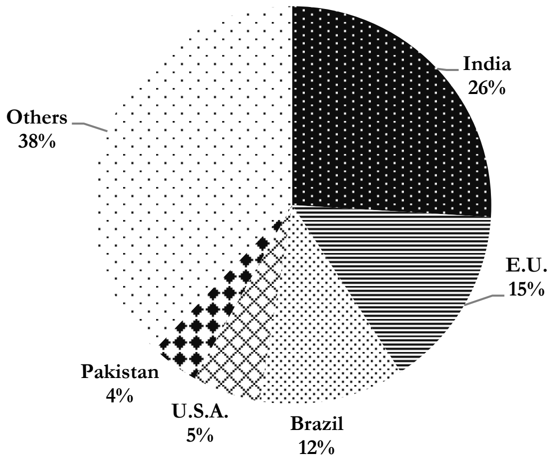


Figure 1.4: Major phosphate products (PR, PA, DAP, MAP and TSP) importing countries, 2016, (calculation based on tonne P205)



Source: International trade statistics, IFA, 2016

1.3.2 Structural price change

As mentioned before, global phosphate rock demand is rising due to an increasing demand for phosphate fertilizers, associated with food demand caused by growing world population. For a long time, phosphate rock was considered as a relatively cheap commodity. However, because there is no known substitute for phosphorus and there were at the time (see above) a prospect of limited supply, prices of phosphate rock soared in 2008. From an average of 40 USD per ton, prices reached a peak of 350USD per ton in 2008. Following this spike, prices dropped again in 2009, remaining nonetheless well above their pre-2008 level and oscillating between 120-145 USD per ton from 2009 to 2016. Prices are expected to remain around that level in the coming years. This structural change in price dynamics and volatility pattern (as culculted by Giraud (2017), PR volatity varies from 1,7% for 1987-2006 period to 7% for 2006-2016 period) made industrials, politicians and governments aware of future supply vulnerabilities.

1.4 Factors affecting future supply of phosphate rock

1.4.1 Moving towards a near-monopoly position in phosphate supply

Currently, production mainly takes place in China, the US and Morocco, including its disputed territory of Western Sahara. Given the distribution of world reserves, it is likely that oligopolistic or even monopolistic behaviors will become more pronounced in the future. Market power is increasingly concentrated in the hands of a few suppliers. Various studies show that Morocco, which accounts for more than 75% of global reserves, is moving towards a near-monopoly position in phosphate supply. That could potentially create a situation in which Morocco's state-owned firm OCP (already the world's largest exporter) would exhibit a price-setting behavior. Cooper et al. (2011) show that 70% of world production is currently produced from reserves that will be depleted in 100 years, and the combination with ever-increasing demand will result in a large global production deficit that will exceed current production by 2070. According to the author simulations, Morocco would need to increase production by around 700% by 2075 in order to meet most of this deficit. If this can be done, the country will then obtain a much greater share of worldwide production, rising from 15% in 2010 to 80% by 2100 (Cooper et al. ; 2011). In chapter 2 of this report, I show, using a Staclkeberg model, that that Morocco would rise significantly its annual production from 27 Mt to more than 127 Mt by 2100 (representing an increases of 470%) to meet the equilibrium position. At this position the country will be responsible for over 37.5% of global production, compared to 23% today. Using a disaggregated curve fitting model based on the production of major phosphate rock producing countries, Walan et al. (2014) confirm that the global trade of phosphate rock could be completely dependent on Morocco in the future.

1.4.2 Political instability in some major producing countries may disrupt trade flows

Geopolitical problems and civil unrest is a potential issue for phosphate rock production. The Arab Spring, which started in December 2010, has had a significant impact on global phosphate rock supply since it affected several important producing countries in the MENA region. In addition, the protracted conflict in Syria continues to influence the supply of phosphate (de Ridder et al., 2012). Although not as much affected by the Arab spring, Morocco is still receiving a lot of backlash due to the Western Sahara issue.

1.4.3 Technical and environmental developments may also disrupt the global phosphate rock market

Phosphate rock production process is highly water and energy intensive. Many countries producing phosphate rock, such as countries in the MENA region, already suffer from a shortage of fresh water (de Ridder et al., 2012). This presents a major constraint for producers and requires huge investments to overcome the problem. In Morocco, for example, seawater-desalination plants are built by OCP to cover its future needs (OCP 2011).

Since most phosphate rock is mined using large-scale surface mining, the producing countries are also faced with large environmental impacts as mentioned by the 2001 UNEP report (local landscape, water contamination, air emissions, noise and waste generation). Furthermore, the issue of cadmium, a toxic element often present in phosphate rock, is increasingly gaining attention, especially in the EU. Consequently, the increased awareness about the negative environmental impacts of phosphate rock will probably affect the structure of the global phosphate market.

1.5 Conclusion

In this study, we demonstrate that contrary to articles published before 2010 predicting a "peak phosphorus" in the nearest future, the current available data show no clear indications that phosphate rock deposits are facing depletion any soon. But, the "peak phosphorus" debate has contributed to a raising awareness about future phosphate supply from politician and scientist communities. The main reason for this is related to the phosphate reserves geographical distribution. The USGS data show that world phosphate rock reserves are concentrated in few countries mainly in the MENA region. Global trade is more concentrated, since some major producing countries are also among the major users. Recent studies have predicted that Morocco is moving towards a near-monopoly position in phosphate production and that could potentially create a price-setting behavior. The structural changes and the increasingly volatile phosphate rock prices observed since the 2007/2008 crisis may be the first warning to this situation. In this chapter, we have summarised the political, technical and environmental risks that can seriously affect future supply.

Finally, given that phosphorus as a nutrient that is not substitutable in agriculture and phosphate rock is a finite natural resource, the search for optimization of production by producers and increasing phosphorus use efficiency by users are the only ways to ensure a safe and stable supply. Through an integrated system framework, D. Cordell et al. (2011) examine the full spectrum of sustainable phosphorus recovery and reuse options (from small-scale low-cost to large-scale high-tech). Further researches are needed to help producers and users in their optimization process. Our next study will be focus on optimal capacity expansion for phosphate rock producers in order to satisfy future demand.

1.6 References

- Argus Strategy Report. (2017). *World Phosphate Rock Outlook to 2031*. London, Argus media. http://www.argusmedia.com/fertilizer/world-phosphate-rock-outlook/
- Cooper, J., Lombardi, R., Boardman, D., & Carliell-Marquet, C. (2011). The future distribution and production of global phosphate rock reserves. *Resources, Conservation and Recycling*, 57, 78-86.
- Cordell, D., Drangert, J.-O., & White, S. (2009). The Story of Phosphorus: Global Food Security and Food for Thought. *Global Environmental Change*, 19(2), 292–305.
- Cordell, D., Rosemarin, A., Schröder, J. J., & Smit, A. L. (2011). Towards global phosphorus security: A systems framework for phosphorus recovery and reuse options. *Chemosphere*, 84(6), 747-758.
- de Ridder, M., De Jong, S., Polchar, J., & Lingemann, S. (2012). *Risks and opportunities in the global phosphate rock market: Robust strategies in times of uncertainty*. Hague Centre for Strategic Studies.
- Déry, P., & Anderson, B. (2007). Peak phosphorus. *Energy Bulletin*, 13.
- Giraud, P. N. (2012). A Note on Hubbert's Thesis on Mineral Commodities Production Peaks and derived Forecasting Techniques. *Elsevier Procedia Engineering*, 46, 22-26.

- Giraud, P.N. (2017). *Economie des phosphates*. Paris: Presses des Mines, collection économie et gestion. Chapter 3, 51-60.
- OCP. (2011). *OCP Annual Report 2011*. Office Chérifien des Phosphates. http://www.ocpgroup.ma/sites/default/files/alldocs/rapport_annuel_ocp_2011_v_en.pdf
- Prud'homme, M. (2010). World phosphate rock flows, losses and uses. In *International Fertilizer Industry Association, Phosphates 2010 International Conference* (pp. 22-24).
- Rosemarin, A., de Bruijne, G., & Caldwell, I. (2009). Peak phosphorus: The next inconvenient truth. *The Broker*, 15, 6-9.
- Rustad, J. R. (2012). Peak nothing: recent trends in mineral resource production. *Environmental science & technology*, 46(3), 1903-1906.
- Scholz, R. W., & Wellmer, F. W. (2013). Approaching a dynamic view on the availability of mineral resources: What we may learn from the case of phosphorus?. *Global Environmental Change*, 23(1), 11-27.
- Ulrich, A. E., & Frossard, E. (2014). On the history of a reoccurring concept: phosphorus scarcity. *Science of the Total Environment*, 490, 694-707.
- UNEP. (2001). *Environmental Aspects of Phosphate and Potash Mining*. United Nations Environment Programme and International Fertilizer Industry Association, Paris, France.
- USGS. (2017). *Mineral commodity summaries 2017*. US Geological Survey. https://minerals.usgs.gov/minerals/pubs/commodity/phosphate_rock/mcs-2017-phosp.pdf
- Vaccari, D. A. (2009). Phosphorus: a looming crisis. *Scientific American*, 300(6), 54-59.
- Vaccari, D. A., & Strigul, N. (2011). Extrapolating phosphorus production to estimate resource reserves. *Chemosphere*, 84(6), 792-797.
- Van Kauwenbergh, S. J. (2010). *World phosphate rock reserves and resources* (p. 48). Muscle Shoals: IFDC.
- Van Vuuren, D. P., Bouwman, A. F., & Beusen, A. H. (2010). Phosphorus demand for the 1970–2100 period: a scenario analysis of resource depletion. *Global environmental change*, 20(3), 428-439.
- Walan, P., Davidsson, S., Johansson, S., & Höök, M. (2014). Phosphate rock production and depletion: Regional disaggregated modeling and global implications. *Resources, Conservation and Recycling*, 93, 178-187.

Chapter 2

Equilibrium Phosphate Rock Capacity expansion under imperfect competition

Résumé

Le deuxième chapitre developpe un modèle de théorie de jeux permettant la modélisation de la décision d'investissement dans de nouvelles capacités par les producteurs selon leurs niveaux de réserves et leurs coûts de développement. Compte tenu de la structure oligopolistique du marché des phosphates et de la nature séquentielle de la prise de décision, un modèle Stackelberg à plusieurs joueurs est proposé et calibré sur des données effectives du marché des phosphates. L'analyse globale soutient la thèse selon laquelle le marché est amené à connaitre, à long terme, une très forte concentration. Les résultats de simulations montrent que la production annuelle d'équilibre du Maroc passera de 27 Mt à plus de 127 Mt d'ici 2100. Ce pays devrait donc multiplier sa capacité d'extraction par 3,7 d'ici 2100. Des capacités supplémentaires concernent neuf autres pays dont trois (Australie, Syrie et Algérie) devraient multiplier leurs capacités actuelles par 12 pour atteindre leur équilibre.

2.1 Introduction

Phosphorus is an essential element for all form of life on earth. It is one of the three primary nutrients for plant growth, along with potassium and nitrogen. Up to 90% of global phosphorus is used in modern agriculture in the form of phosphate fertilizer and animal feed supplements, the remainder is for industrial applications like detergents (Brunner, 2010). The main source of phosphorus is Phosphate rock (PR) – a finite and non-renewable resource. Global PR reserves are unevenly distributed and highly concentrated. The worldwide reserves are estimated to 68 billion tons, with almost 85% of total reserves located in four countries: Morocco, China, Algeria, Syria and South Africa. Morocco alone holds 75% of the world's high-quality reserves (USGS, 2017). Global trade is even more concentrated, with only five countries controlling about 80% of the global phosphate rock export market (IFA, 2016). The major exporters are located in the MENA region, but some countries such as Tunisia, Egypt, Algeria and Syria are politically unstable. This could make agricultural production even more vulnerable to supply disruptions and price fluctuations, as there is no known substitute for phosphate to ensure high agricultural yields.

Historically, PR was considered as a commodity with low and stable price. The picture has changed since 2008 where prices jumped up dramatically by 900%. Following this peak, prices dropped in 2009 but remained above the pre-2008 prices and exhibiting much more volatility. In this period, several studies have warned that the maximumal phosphorus production could be reached before the mid-21st century (Déry and Andersson, 2007; Cordell et al., 2009a and Rosemarin et al., 2009). Therefore, the debate is becoming more focused on a looming scarcity and a threat to food security in developing countries (Cordell and Write, 2011). Nevertheless, the methodology behind the peak phosphorus hypothesis and the data that was used have been rapidly disputed in a number of scientific studies (e.g., Vaccari and Strigul, 2011; Rustad, 2012; Scholz and Wellmer, 2013).

The market size of PR in terms of value is estimated at 22billion US$[2] in 2016 and goes up to 64billion US$[3] if we integrate its derivatives (Phosphoric acid and fertilizers). There are at least four specific characteristics of the PR market. i) an oligopolistic structure since a small number of countries control about 80% of global exports; ii) the global trade is dominated by bilateral contracts between miners and fertilizer companies; iii) the producers have very different production costs (the range is between 25 to 90US$/ton); iv) the development of new capacities requires investments amounting to hundreds of millions dollars and takes several years (about 5-10 years).

The demand for phosphate rock (and therefore fertilizers) is projected to grow due to the combination of a growing world population, increasing standards of living and meat consumption and a growing production of biofuels (FAO, 2017). To keep up with future phosphate demand, mining companies will before have to increase their production capacity. The purpose of this study

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[2]Source: "Phosphate Rock Market: Global Industry Analysis and Forecasts" published by Persistence Market Research (https://www.persistencemarketresearch.com/).

[3]Source: "Phosphorus & Derivatives Market by Type by Application and by Region - Global Forecast to 2020" published by Markets and Markets (https://www.marketsandmarkets.com/Market-Reports/phosphorus-derivatives-market-1148.html).

is to determinate by how much production or capacity must be increased, by country, in order to meet the projected production deficit.

Several economic approaches have been used in the literature to examine and project future phosphate supply and market structure. For instance, Van Vuuren et al. (2010) developed a model for phosphate depletion, accounting for uncertainty in resource estimates, different types of resources, their geographic locations and using four realistic scenarios for phosphate demand. Cooper et al. (2011) used USGS data to derive reserve-to-production (R/P) ratios for individual countries, and combined this with a scenario based on increasing global demand hypothesis, to investigate how the global distribution of PR reserves and production will change throughout the 21st century. Mohr, S. & Evans, G. (2013) applied the demand-production interaction resource model of Mohr (2010) on a country-by-country basis for both static and dynamic modes of operation. The model is based on a market approach, whereby the supply of a resource is influenced by: demand, production capacity, and the amount of reserves available to supply that market. Walan et al. (2014) developed a disaggregated curve-fitting model based on production in individual major producing countries. The potential PR production outlooks are fitted using logistic and Gompertz functions constrained by the estimated ultimately recoverable resource (URR). Essentially, all these studies concluded that the global PR production would be more concentrated in the future, and the depletion of resources in some countries might lead to a high share of Morocco in world PR supply, as the country holds the most of the current resource, around 80% by 2100 (Cooper et al., 2011). This means one single country will have a significant market power and increasing control over the market price in the future and, a potential bottlenecks (Mohr, S. & Evans, G. 2013 and Walan et al., 2014).

In this study, we propose a strategic game theory based approach to examine the PR market structure in a forward looking manner. Given the structure of the PR market, Stackelberg and Cournot models are two of the leading frameworks widely used by economists to study oligopolistic competition. The Stackelberg model differs from the Cournot model by the sequencing of production choices. The producers act sequentially in a Stackelberg market and simultaneously in a Cournot market. We combine both models and propose a multi-leader multi-follower Stackelberg model as developed by Stackelberg (1952) and extended by Sherali et al. (1983), Sherali (1984) and Frantsev et al. (2012). Such a model is widely applied by reaserchers to deal with many real-world problems, for example: in transportation (Marcotte and Blain, 1991), in the analysis of deregulated electricity markets (Hobbs et al., 2000), in wireless networks (Kim,2012; Hu and Fukushima, 2015) and in water management systems (Ramos et al., 2016).

We distinguish between leader- and follower-producers according to their capacities and their ability to produce with a reasonable profit. This leads to a two-level strategic game where producers compete in terms of quantities. In the upper-level, the leaders who are supposed to predect correctly the follower's reaction function, decide independently and simultaneously about their individual supply. In the lower-level, the followers decide simultaneously upon their quantity after learning about the total quantity supplied by the leaders. In order to estimate the future production costs, we explicitly introduce, in the decision program, the development cost as a function of the remaining reserves for both leaders and followers. This is due to the fact that these reserves depend on long-term price developments and not so much on operating cash costs. We use the proposed model to derive the equilibrium quantities that could be produced and the corresponding capacities to be installed by each country. The proposed model combines three important aspects: the leader's market power, the sequencing of decisions, and the influence of reserves distribution on future competition.

The chapter is structured in the following manner. Section 2 discusses three specific characteristics of the PR market: i) PR scarcity and its implications on global food security. ii) The market structure and geopolitical risks and iii) the sequencing of decision making to justify the proposed multi-leader multi-follower Stackelberg model. In section 3, we formulate the model and derive the conditions for equilibria. Section 4 presents the data used to calibrate the model and give a brief description of the industry cost curve. Section 5 shows the results and section 6 highlights some limitations of the model. Finally, section 7 presents the conclusions that can be drawn from our findings and identifies possible leads for future research.

2.2 Three reasons why PR competition is interesting

As discussed in the introduction, phosphate is mainly used in agricultural production. The availability of PR is directly linked to global food security. The geological distribution of reserve and the market structure present potential geopolitical risks. In addition to these general reasons, the timing of investment decisions in the phosphate market may have some theoretical and practical implecations.

2.2.1 PR scarcity and vulnerability of the global food security

Phosphate plays a key role in the global production of food. To this date, there are no agricultural alternatives for it. Phosphate is an exhaustible, non-renewable and mismanaged resource since more than the four-fifths of phosphate consumption is lost or wasted from mines to food production (Cordell and White, 2014). The massive price fluctuations on the PR market in 2007/2008, with price increases exceeding 900%, hase given raise to a world debate on the question of physical PR scarcity and its implications on long-term phosphorus availability for meeting future global food demand. Soon after the spike, several scientific studies have emerged predicting that the "peak phosphorus"[4] would occur around the year 2033 and that global reserves will start to run out within 75–100 years (Cordell et al. 2009; Rosemarin et al. 2009). Essentially, all these calculations were based on the 2008 USGS estimations of PR reserves and using static approaches such as static lifetime or Hubbert curve to predict the peak. However, theses analyses were rapidly criticized due to the methodology and data that was used: the Hubbert curve approach does not provide robust predictions (Vaccari and Strigul, 2011 and Giraud, 2012); dynamics of rise and decline in production for any mineral in the world, are not symmetric (Rustad, 2012); and the dynamics of resources and reserves are not properly acknowledged by the Hubbert curve applications (Scholz and Wellmer, 2013). Furthermore, the estimated world phosphorus reserves increased from 15 billion tons PR in 2008 (USGS, 2009) to 65 billion tons in 2010 (USGS, 2011).

[4] The term "Peak phosphorus" denotes a moment in time at which the production of PR reaches its maximum due to the decreasing availability of reserves and demand for PR will exceed supply (Cordell et al. 2009a).

The USGS revision was based on the IFDC report (Van Kauwenbergh, 2010) which suggested that Morocco's estimated reserves were in fact much larger than previously indicated (50 billion tons instead of 5.7 billion tons). Using this revised estimation, the reserve-to-production ratio suggests that the remaining PR deposits will now cover 300 to 400 years. Meanwhile, there is still a consensus that the quality and accessibility of the remaining phosphates reserves are decreasing and costs will increase (Cordell and White, 2011).

2.2.2 PR as a strategic and geo-political commodity

PR is currently mined in more than 20 countries worldwide, with only very few countries making up most of total production. World production of PR is estimated at 261 million tons in 2016 (USGS, 2017). China is the largest producer in the world, accounting for 138 Mt or 53% of the total production of phosphate rock. Behind China, the largest producers are Morocco, the U.S. and Russia with respectively 11%, 12% and 4% of global output. Other important producers are primarily found in the Middle East North Africa (MENA) region with countries like Jordan, Egypt, Tunisia, Israel, Saudi Arabia, Syria, and Algeria. The MENA region, including Morocco, currently contributes with about one quarter of the global production. The recent turmoil in some countries in the region such as Tunisia, Egypt, Algeria and Syria shows that there is a possibility of severe production restrictions.

Global trade is even more concentrated. According to the Fertilizer Institute statistics, the major phosphate rock exporting countries are Morocco, Jordan, Peru, Egypt and Russia. All together, these countries control about 80% of the global phosphate rock export market. Morocco is the world's largest exporter accounting for about one-third of total exports (IFA, 2016). China and the US are among the top producers but their domestic consumption largely eclipses their exporting activities.

Phosphate companies in major exporting countries are state owned. This will put them in a position where can use their phosphate resources in a geo-strategic manner, through trade restrictions and strategic market behaviors (Keijser, 2016). The commodity should then be regarded as a strategic, geo-political commodity (Van Enk et al., 2011).

2.2.3 Sequencing of decision making in PR market

There is no doubt that phosphate demand will continue to raise. Producers need to undertake huge investments to build up their capacities in order to meet the future production deficit.

In the real world, PR producers publicly announce their investment plans under full commitment (CRU, 2015). Moreover, following a positive demand shock in the market, the biggest producers such as the United States, Morocco, Russia, Jordan and Brazil take the lead, being the first ones to invest and expand their production levels. The second group-movers or the small producers such as Egypt, Tunisia, Israel, Saudi Arabia determine their investments after they observe the investment decisions of the biggest producers in the first group, as well as their private signals about the state of the demand. For instance, OCP Group, the Moroccan state-owned company for PR mining and processing of phosphoric acid and fertilizers, has initiated an investment program of 130 billion Moroccan Dirhams in 2008 (around 15billion US$) to double its mining capacity and triple its fertilizer capacity. Five years later, Maaden Company, the Saudi phosphate mining compagny, announced a plan to invest 7.5billion US$ to develop two industrial sites (Ras Al-Khair and Wa'ad Al-Shamal) for an overall capacity of 16 million tons per year.

Consequently, the global PR market can be considered as an oligopolistic market with sequential production and investment decisions. This leads to the multi-leader multi-follower Stackelberg model that we are going to analyze in this paper.

2.3 Model

In this section, we develop a multi-leader multi-follower Stackelberg model for the PR market. In this case, we assume that there are two distinct groups: a group of producers, acting as leaders and deciding first; and the other group, called followers, which reacts to the leaders' decisions. Under some assumptions, we derive the optimality conditions and discuss the existence and uniqueness of equilibrium through a basic adaptation of Sherali's results. In order to meet the future PR demand, we use the model to compute the equilibrium production quantity and the corresponding capacity for each producer.

2.3.1 Model setup

We assume that the global demand curve for PR takes the linear form $Q(P) = (\alpha - P)/\beta$, with parameters $\alpha, \beta > 0$. This assumption is common in the literature (e.g. Pang and Fukushima, 2005; Huppmann, 2010 and Behar and Ritz, 2016) and will facilitate the empirical calibration of the model later on. On the supply side, we consider an oligopoly consisting of $\boldsymbol{M}$ leader-producers and $\boldsymbol{N}$ follower- producers that produce PR non-cooperatively. The distinction here between leader- and follower-producers is based on their capacity and their ability to produce a wide range of outputs with a reasonable profit margin. Because of its essential properties, and since there is no known substitute for it, demand for phosphate is only expected to increase in order to feed a growing world population. We study a situation where the global future demand of phosphate will exceed largely the current capacity of production. More formally, let's note Q^T the global demand of phosphate at horizon *T* and K is the current world capacity of production with $\left\{K = \sum_{i=1}^{M} k_i^l + \sum_{j=1}^{N} k_j^f\right\}$ where k_i^l , k_j^f are the current capacity of production for the *i-th* leader and the *j-th* follower respectively. In this situation, where $\{Q^T \gg K\}$, each producer may have an interest to develop a new capacity of production in order to maximize its future market share. Because the leaders have the ability to move first, the followers choose their supply (or capacity expansion) after observing the aggregate leader supply (i.e. the announced capacity expansion program). This leads to a two-level strategic game where producers compete in quantities.

- In the upper-level, the leaders who are supposed to correctly anticipate the reaction function of the followers decide independently and simultaneously about their individual supply.
- In the lower-level, the followers decide simultaneously upon their quantity after learning about the total quantity supplied by the leaders.

As a consequence, each of the M leaders acts as a traditional *Stackelberg* leader towards the N followers, but as a *Cournot* firms with respect to the other leaders. Similarly, the N followers act as *Stackelberg* followers towards the leaders and as *Cournot* firms with respect to each other.

For more simplicity, the production environment for the various producers are modelled by:

- a zero fixed cost for all producers,
- a constant per unit cost of production (OPEX) (denoted as $c_i^l,\ i = 1, \dots, M$ for the leaders and by $c_j^f, j = 1, \dots, N$ for the followers)
- a constant per unit investment cost for different producers (CAPEX), with τ_i^l and τ_j^f the *i-th* leaders' and *j-th* followers' per unit cost for developing a new capacity.
- the leader and follower producers' decision variables are production quantities q_i^l and q_j^f respectively.

Next, we adopt the additional following notations: the aggregate supply of all leaders and followers are defined as $Q^l = \sum_{i=1}^{M} q_i^l$ and $Q^f = \sum_{j=1}^{N} q_j^f$ respectively. $Q^{l-i} = \sum_{k\neq i}^{M} q_i^l$ is the aggregate leader's supply except the leader *i* and $Q^{f-j} = \sum_{k\neq j}^{N} q_j^f$ denote the aggregate follower's supply excluding the follower *j*.

Then, the objective function of the *j-th* follower can be written as follow:

$$\underset{q_j^f \geq 0}{\text{Max}}\, \pi_j^f = \left[\underbrace{P\left(Q^l + q_j^f + Q^{f-j}\right) q_j^f}_{Cash-flow} - \underbrace{c_j^f q_j^f}_{OPEX} - \underbrace{\tau_j^f \times max\left(0; q_j^f - k_j^f\right)}_{CAPEX} \right] \quad for\ j = 1\ to\ N \qquad (2.1)$$

which is maximized by $\hat{q}^f = q^f(q^l)$. We call this result the follower's best reaction function.

The *i-th* leader problem is to maximize the following function with respect to the follower's best reaction function:

$$\underset{q_i^l \geq 0}{\text{Max}}\, \pi_i^l = \left[\underbrace{P\left(Q^{l-i} + q_i^l + \hat{Q}^f(q^l)\right) q_i^l}_{Cash-flow} - \underbrace{c_i^l q_i^l}_{OPEX} - \underbrace{\tau_i^l \times Max(0; q_i^l - k_i^l)}_{CAPEX} \right] \quad for\ i = 1\ to\ M \qquad (2.2)$$

where the amounts $\left\{\tau_j^f \times max\left(0; q_j^f - k_j^f\right)\ and\ \tau_i^l \times Max(0; q_i^l - k_i^l)\right\}$ represents the investment needed by the *j-th* follower and the *i-th* leader to develop the additional capacity.

2.3.2 Generalized Stackelberg-Nash-Cournot (GSNC) equilibrium

In this subsection, we first define the equilibrium solution for the proposed multi-leader multi-follower Stackelberg model. Then, we present the assumptions and give the conditions for the existence and uniqueness of the equilibrium by using the main results of Sherali (1984).

Definition: *A set of output quantities* $\left(q_1^{l*}, \cdots, q_M^{l*}, q_1^{f*}, \cdots, q_N^{f*}\right)$ *for the M leaders and the N followers respectively is called a Generalized-Stackelberg-Nash-Cournot (GSNC) equilibrium if* q_i^{f*} *solves the following problem :*

$$\underset{q_i^l \geq 0}{Max}\, \pi_i^l = \left\{ P\left(Q^{l-i} + q_i^l + \sum_{j=1, j\neq i}^{N} q_j^{f*} \right) q_i^l - c_i^l q_i^l - \tau_i^l \times max\left(0; q_i^l - k_i^l\right) \right\} \quad for\ each\ \ i = 1, \cdots, M \qquad (2.3)$$

And moreover, $q_j^{f*} = q_j^f\left(Q^{l*}\right) for\ j = 1, \cdots, N,\ \ where\ Q^{l*} = \sum_{i=1}^{M} q_i^{l*}$

Assumption A (equivalent to Assumption A in Sherali (1984))

Let $TC_i^l(q_i^l)$ *and* $TC_j^f(q_j^f)$ *be the total cost function for the i-th leader and the j-th follower respectively with*

$$TC_i^l\left(q_i^l\right) = \underbrace{c_i^l q_i^l}_{OPEX} + \underbrace{\tau_i^l \times max\left(0; q_i^l - k_i^l\right)}_{CAPEX}$$

$$TC_j^f\left(q_j^f\right) = \underbrace{c_l^f q_j^f}_{OPEX} + \underbrace{\tau_j^f \times max\left(0; q_j^f - k_j^f\right)}_{CAPEX}$$

We assume that the inverse demand $P(Q)$ *is a strictly decreasing and twice differentiable function of aggregate production and*

$$\frac{\partial P(q)}{\partial q} + q\frac{\partial^2 P(q)}{\partial q^2} \leq 0\ for\ each\ q \geq 0$$

And the total cost functions $TC^l(q)$ *and* $TC^f(q)$ *are twice differentiable, nonnegative, and nondecreasing convex functions and that there exists a quantity* $q^* > 0$ *such that for all* $q^* > q$

$$\frac{\partial TC_i^l(q)}{\partial q} \geq P(q), \quad i = 1, \ldots, M$$
$$\frac{\partial TC_j^f(q)}{\partial q} \geq P(q), \quad j = 1, \ldots, N$$

Theorem 1 : *If Assumption A holds and the aggregate follower reaction curve* $Q^f(q)$ *is convex, then, by theorem 2 (Sherali, 1984), there **exists** a GSNC equilibrium*

Theorem 2 : *If Assumption A holds and* $P(q)$ *is linear, all follower marginal cost curves* $\frac{\partial TC_j^f(q)}{\partial q}$ *are concave, and all leaders' cost curves* $\left\{C_i^l(q) = C_\cdot^l(q)\ \forall i\right\}$ *are identical then, by theorem 5 (Sherali, 1984), the GSNC equilibrium solution is **unique**.*

Therefore, for the proposed model, the GSNC equilibrium exists, but not unique, since all the conditions of theorem 1 are satisfied whereas the condition that all leaders have the same cost curve in theorem 2 is not (see *Industry Cost Cuvre* in *Data* section).

2.3.3 Leader and follower equilibrium quantities

In this subsection, we derive the equilibrium output strategies, using the backward-induction technique as illustrated in Gibbons (1992). We proceed in three steps. First, we solve the follower problem (2.2) and we compute the follower's reaction as a function of the quantities chosen by the leaders $\boldsymbol{\hat{q}^f = q^f(q^l)}$. Second, we substitute the follower's best response function into the leader's problem (2.1) and we derive the leader's equilibrium decision $\boldsymbol{q^{l^*}}$. Finally, we substitute the equilibrium quantities chosen by the leaders in the followers' reaction functions to get the equilibrium quantities chosen by the followers $\boldsymbol{q^{f}}^{*}$.

Step1: follower's reaction function

From problem 2.2, the necessary and sufficient optimality conditions generate the follower's reaction curve:

$$\widehat{\boldsymbol{q}}^{f}(\boldsymbol{q}^{l}) = \boldsymbol{max}\left(\frac{\mathbf{1}}{\mathbf{2\beta}}\boldsymbol{A}_{f}^{-\mathbf{1}}\boldsymbol{V}_{f} - \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{A}_{f}^{-\mathbf{1}}\mathbb{I}_{f}\boldsymbol{q}^{l}; \mathbf{0}\right) \tag{2.4}$$

where

$$\boldsymbol{q}^{f}_{(N\times 1)} = \begin{bmatrix} q_1^f \\ q_j^f \\ q_N^f \end{bmatrix},\quad \boldsymbol{q}^{l}_{(M\times 1)} = \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix},\quad A_{f\,(N\times N)} = \begin{bmatrix} 1 & \cdots & 1/2 \\ \vdots & 1 & \vdots \\ 1/2 & \cdots & 1 \end{bmatrix},\quad \mathbb{I}_{f\,(N\times M)} = \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & 1 & \vdots \\ 1 & \cdots & 1 \end{bmatrix},$$

$$V_{f\,(N\times 1)} = \begin{bmatrix} \alpha - \left(c_1^f + \tau_1^f\right) \\ \alpha - \left(c_j^f + \tau_j^f\right) \\ \alpha - \left(c_N^f + \tau_N^f\right) \end{bmatrix}$$

Step2: leader's decision

The leaders solve the follower's problem and thereby anticipate the choice of the quantity supplied by the follower. Therefore, their implied objective function becomes:

$$\underset{q_i^l \geq 0}{\mathbf{Max}}\,\boldsymbol{\pi}_i^l = \left[\underbrace{\boldsymbol{P}\left(\boldsymbol{Q}^{l-i} + \boldsymbol{q}_i^l + \widehat{\boldsymbol{Q}}^{f}(\boldsymbol{q}^l)\right)\boldsymbol{q}_i^l}_{\boldsymbol{Cash-flow}} - \underbrace{\boldsymbol{c}_i^l\boldsymbol{q}_i^l}_{\boldsymbol{Production\ Cost}} - \underbrace{\boldsymbol{\tau}_i^l \times \boldsymbol{Max}(\mathbf{0}; \boldsymbol{q}_i^l - \boldsymbol{k}_i^l)}_{\boldsymbol{Investiment\ Cost}}\right] \quad \boldsymbol{for\ i = 1\ to\ M}$$

The necessary and sufficient optimality conditions gives the following solution:

$$\boldsymbol{q^{l}}^{*} = \boldsymbol{max}\left(\left(\boldsymbol{A}_l - \frac{\mathbf{1}}{\mathbf{4}}\mathbb{I}_l\boldsymbol{A}_f^{-\mathbf{1}}\mathbb{I}_f\right)^{-\mathbf{1}}\left(\frac{\mathbf{1}}{\mathbf{2\beta}}\boldsymbol{V}_l - \frac{\mathbf{1}}{\mathbf{4\beta}}\mathbb{I}_l\boldsymbol{A}_f^{-\mathbf{1}}\boldsymbol{V}_f\right); \mathbf{0}\right) \tag{2.5}$$

Where $A_{l(M\times M)} = \begin{bmatrix} 1 + \frac{1}{2}\sum_{j=1}^{N} d_{1j} & \cdots & 1/2 \\ \vdots & 1 + \frac{1}{2}\sum_{j=1}^{N} d_{ij} & \vdots \\ 1/2 & \cdots & 1 + \frac{1}{2}\sum_{j=1}^{N} d_{Mj} \end{bmatrix}$, $\left[d_{ij} = \frac{\partial\left(\hat{q}_j^f(q^l)\right)}{\partial q_i^l}\right]$,

$\mathbb{I}_{l(M\times N)} = \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & 1 & \vdots \\ 1 & \cdots & 1 \end{bmatrix}$ and $V_{l(M\times 1)} = \begin{bmatrix} \alpha - \left(c_1^l + \tau_1^l\right) \\ \alpha - \left(c_i^l + \tau_i^l\right) \\ \alpha - \left(c_M^l + \tau_M^l\right) \end{bmatrix}$

Step3: follower's decision

We substitute the equilibrium leader's quantities (2.5) in the follower reaction function (2.4). We obtain the follower's equilibrium quantities as a function of their production cost and the leader's cost of production.

$$\boldsymbol{q^{f^*}} = \boldsymbol{max}\left(\frac{\mathbf{1}}{\mathbf{2}\boldsymbol{\beta}}\boldsymbol{A_f^{-1}V_f} - \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{A_f^{-1}}\mathbb{I}_f\left(\left(\boldsymbol{A_l} - \frac{\mathbf{1}}{\mathbf{4}}\mathbb{I}_l\boldsymbol{A_f^{-1}}\mathbb{I}_f\right)^{-1}\left(\frac{\mathbf{1}}{\mathbf{2}\boldsymbol{\beta}}\boldsymbol{V_l} - \frac{\mathbf{1}}{\mathbf{4}\boldsymbol{\beta}}\mathbb{I}_l\boldsymbol{A_f^{-1}V_f}\right)\right); \mathbf{0}\right) \tag{2.6}$$

For demonstration: See Appendix A.1

2.3.4 Leader's and follower's equilibrium capacities

To derive the equilibrium production capacity, we use the following methodology: for each producer, if the equilibrium quantity is less than its actual capacity, then the producer will not invest in any capacity expansion. In this case, the producer's equilibrium capacity is equal to its actual capacity. If the producer's equilibrium quantity is above of it actual capacity and if we assume a capacity utilization rate of 95% in the mining sector, then the equilibrium capacity is equal to $(q_i^* - k_i)/95\%$. We summarize this in the following equation.

$$k_i^* = \begin{cases} (q_i^* - k_i)/95\% & if\ q_i^* > k_i \\ k_i & if\ q_i^* \leq k_i \end{cases} \quad \forall i \in [1, \ldots, M; 1, \ldots, N] \tag{2.7}$$

2.4 Data

In this section, we describe the observed data, the estimated development cost and the parameters' empirical values for the model calibration and simulations. We also present the current industry cost curve and the potential future demand for PR.

2.4.1 Data description

Table 2.1 reports the dataset used for the analysis. The number of leaders and followers is fixed exogenously. We considers the top five producers (United States, Morocco, Russia, Jordan and Brazil) as leaders (M=5) and the remaining as followers (N=16). We do not include China in the analysis for two main reasons: the chinise market is mainly oriented towards domestic consumption and the official statistics were incomplete and unreliable. We note that the selected leader group members produced, in average from 2010 to 2015, around 70% of the global annual PR production.

On the supply side, the estimated reserves per country for the year 2015 (column (a), Table 2.1), are extracted from USGS (2016). The production (column (b)), capacity (column (c)) and the weighted average production costs (column (d)) are computed using the detailed CRU database[5] (by site and by company). Handling missing values is done through the use of average values over the period 2010-2015 for production. Looking at the capacity utilization ratio, which represents

[5] Unfortunately, this type of data is not public. We have an exceptional access with non-publication condition. All data used in this study were extracted from "*CRU Phosphate Rock Cost Report - Cost Sheets*"

how the phosphate producers in a country use their installed capacities and approximated by the ratio between production and capacity, we note that the top teen producers for the period 2010-2015 have used in average 80% of its installed capacity. Tunisia and Syria have respectively used only 23% and 35% of their capacity mainly due to the frequent social unrest in Tunisia and the political instability in Syria.

The production costs (also called *cash operating costs* or OPEX) expressed in US$ per ton, include all royalties, fees and taxes associated with the extraction of ore as well as the others traditional costs associated with mining, internal transportation and beneficiation (raw materials, labor, energy, consumables, maintenance materials and services). Globally, we note that the production costs of PR averaged 43US$/t in 2015. The most competitive mines are found in Syria and Australia with just 25US$/t while the highest operating cost mines are located in South Africa with more than 88US$/t.

Table 2.1: Data set used for model calibration

Leader/ Follower		Country	Reserves, 2015, '10^6t	Capacity, 2015, '10^6t	Production, 2010-15, '10^6t	Prod. cost, 2015, US$/t	Devep. Cost, US$/t	Total Cost, US$/t
			(a)	(b)	(c)	(d)	(e)	((d)+(e))
Leader's Group	1	United States	1 100	34,6	27,9	42,32	1,73	44,04
	2	Morocco	50 000	35,8	26,6	33,11	0,90	34,01
	3	Russia	1 300	14,9	10,8	50,84	1,68	52,52
	4	Jordan	1 200	11,1	6,9	50,15	1,70	51,86
	5	Brazil	320	8,3	5,9	44,57	2,13	46,71
Follower's Group	6	Egypt	1 200	6,5	4,8	35,72	1,70	37,43
	7	Tunisia	100	9,8	3,9	29,50	2,60	32,10
	8	Israel	130	4,8	3,3	48,61	2,49	51,09
	9	Peru	820	4,0	3,0	40,99	1,82	42,81
	10	Vietnam	30	3,5	2,5	41,00	3,20	44,20
	11	Saudi Arabia	680	5,3	2,5	30,28	1,87	32,15
	12	Australia	1 100	3,0	2,2	25,24	1,73	26,97
	13	South Africa	1 500	2,7	2,1	88,61	1,64	90,25
	14	Syria	1 800	3,3	2,0	25,01	1,59	26,60
	15	Mexico	30	2,2	1,9	58,87	3,20	62,06
	16	Kazakhstan	260	6,0	1,8	31,27	2,21	33,48
	17	India	65	3,1	1,5	48,00	2,80	50,80
	18	Senegal	50	3,1	1,4	60,00	2,93	62,93
	19	Algeria	2 200	2,3	1,3	30,39	1,53	31,92
	20	Togo	30	2,0	1,0	59,88	3,20	63,08
	21	Finland	10	1,0	0,9	59,81	3,86	63,67

Sources: USGS, CRU and Author's calculations.

2.4.2 Estimation of development costs

The development costs represent the capital expenditures (CAPEX) associated with an increase in capacity. Depending on the location of the mine, the stripping ratio and the quantity of phosphate ores, development costs can vary considerably across different mining projects. Most phosphate ores require some degree of beneficiation after mining (size reduction, washing, mineral separation and thermal drying) to meet commercial specifications. Beneficiation facilities should be included in CAPEX calculations. Infrastructure requirements can also be a large capital cost for projects that are not located close to an existing railroad, a slurry pipeline, gas, water or electricity supply networks. Therefore, mining data play a key role in mining project development costs.

To obtain an average estimate of the CAPEX associated with a production unit in each country, we need to explore the historical data on the detailed CAPEX for all phosphate-mining projects in the world. In general, this information can be found on the companies's balance sheets, news releases or presentations on their website. However, in practice this approach is not feasible because we need to know, beforehand, the name and the start-up year for each mining. Moreover, historical data related to some mining projects are not publicly released or aggregately published. Consequently, in this study, we proceed to an econometric estimation of the per-unit development cost using data collected from CRU phosphate reports for some selected mining project currently planned in different countries.

We start out the theoretical formulation by the general agreement that the size of the deposit has a strong influence on the production rate (Smith, 1997) and thereby on the size of installed capacities. We use this agreement to estimate the producers CAPEX as a function of proved reserves at country level. In addition, to achieve economies of scale and higher output, the producers with large reserves tend to invest in a large capacity of production and vice versa. Consequently, the per-unit CAPEX is lower for producers with large reserves. Moreover, the majority of the current phosphate production is mined using conventional open-pit operations and where draglines or shovel excavators are the norm. We can then easily assume that there is a universal process and technology to extract phosphate. Thus, the proposed function can be expressed as:

$$\tau_i = \kappa_i R_i^{-\gamma} \tag{2.8}$$

Where τ_i is the per-unit CAPEX in the country *i*, R_i is the proved reserves and parameters κ_i, γ >0. The parameter κ_i may represents the specific characteristic of the producer's mining projects.

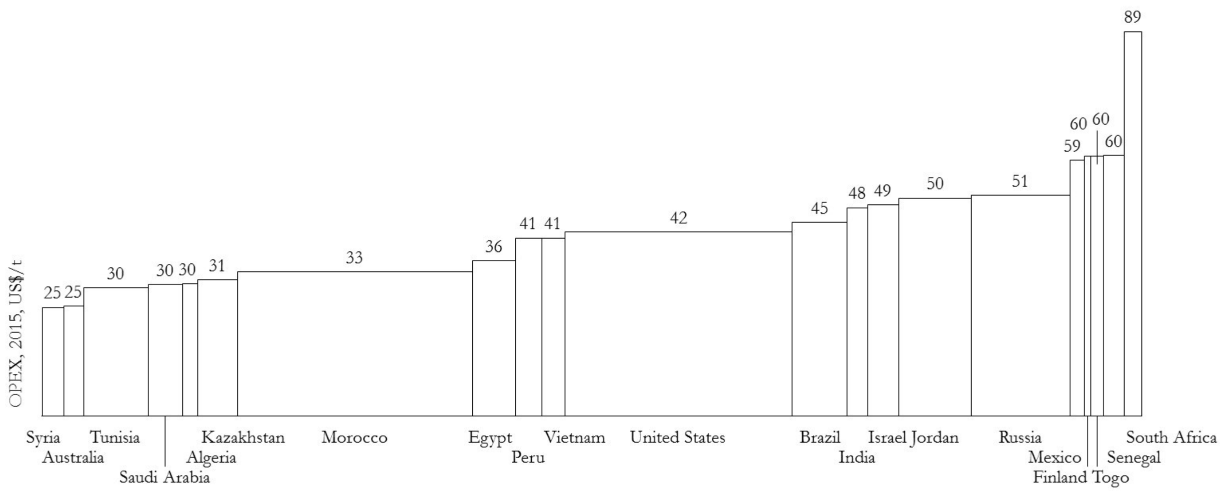
In this study, we assume that the κ_i are constant and equal to κ, and we estimate these parameters by regressing actual and announced CAPEX on the corresponding capacities for some selected projects. The data is collected from CRU's phosphate rock cost report, edition 2015 (Table 2.4 in Appendix A.2). To compute the per-unit CAPEX, we need an additional assumption on the period over which mining companies depreciate their CAPEX. We assume that this period is equal to 25 years in average (see box 1 in Appendix A.2). The estimation results show $\kappa = 5.72$ and $\gamma = -0.17$ (Figure 2.3 in Appendix A.2). We conducted a sensitivity analysis of parameter γ to show how it can affect the result (see Table 2.5 in Appendix A.2).

The estimated per-unit development costs (column (e), Table 2.1) are varying from 0.90 to 3.86US$/t (column (e)). Morocco, which has considerably greater reserves than any other country, or all other countries added together, has therefore the smallest development cost. Due to its smallest reserve size, Finland has the highest development cost.

2.4.3 Industry Cost curve

We combine capacity with the production costs to derive the industry cost curve as shown in Figure 2.1. Looking at this chart, the low end of the curve is mostly occupied by exporting countries in the MENA region. The most competitive producers, with respect to capacity, are Morocco, Tunisia and Saudi Arabia. The average production cost in this area is around 30US$/t due to either high quality ores or low energy costs. The mines in these countries are fully or in the process of being integrated with downstream chemical complexes. This can provide a picture of future PR exporting operations. In the middle of the cost curve, we can find producers located in net importing regions, primarily the United States and Brazil, with an average production cost around 40US$/t. Both regions consume large volumes of phosphate rock and phosphate fertilizers, but are far behind the major exporting countries of the MENA region. The highest cost producers are generally located in exporting countries with unfavorable mining environments and locations far from key markets. Jordan and Russian mines are an example, with production costs above of 50US$/t due in part to location and lower quality.

Figure 2.1: PR Cost Curve by country, OPEX at capacity in 2015, US$/ton



Sources: CRU and Author's calculations.

2.4.4 Future trends of PR demand

Since the majority of PR is used to produce fertilizers, the key input to modern agricultural production, the future demand for PR is driven by factors affecting the long-term trends of crop and food demand. The literature review indicates that there are two long term drivers of phosphate demand. First, the growing population will lead to a significantly increase in global food demand. By 2050, global population is expected to reach 9.8 billion people according to the UN's medium scenario (UN 2017). Second, the increasing income per capita in developing countries is likely to lead to a shift in dietary habits; from a mostly vegetarian diet to one with a higher share of meat and dairy based products, which in turn, results in a sharper increased demand for crops and animal feeds (IFA 2011; Cordell et al. 2009b; Smit et al. 2009; Schröder et al. 2011). Consequently, fertilizer demand is expected to increase by around 1–1.5% per year to 2030 (FAO, 2000, 2002) and slowing to 0.9% per year between 2030 and 2050 (FAO, 2002). Cordell et al. (2009b) suggest that the probable demand for phosphorus will grow by 2% per year up to 2050. Beyond 2050, the world's population is expected to peak and stabilize, or even slightly decline towards the end of the century (UN, 2017; IIASA, 2007). This is likely to influence growth in food, fertilizer and phosphate rock production. Cordell et al. (2009b) estimate that the demand for phosphorus will grow by 0.5% during the second-half of the century, whereas Smit et al. (2009), Cooper et al. (2011) and Mew (2011) expect phosphorus demand to plateau around mid-century. In term of quantities, the global PR consumption, excluding China, was estimated at 118 million tons in 2015 (according to the IFA statistics). If we apply the forecasts of Cordell et al. (2009b), this would lead to a future demand for PR of approximately 235 million tons by 2050 and more than 302 million tons by 2100.

2.4.5 Model Calibration

We use 2015 as the base year for the model calibration because it is a year with no exceptional events (no strike, no production shutdown, and no price fly-up) and the last year in the database with minimum missing values.

On the demand side, the parameters α and β are estimating using a log-regression models based on CRU data from 2007 to 2016 for the major exporting countries (Morocco, Russia, Peru, Joran and Egypt). The more significant results show that α values are included in the range [6.3-7.3] and β values in the range [0.255-0.822] (see Table 2.6 in Appendix 2.3). For model simulation, we simply choose the central value of these intervals and we set α=7 and β=0.5.

2.5 Results

This subsection presents the numerical results for the proposed multi-leader multi-follower Stackelberg model. The equilibrium quantities are reported in Table 2.2 and the corresponding capacities are shown in Table 2.3.

Using the calibrated inverse demand parameters and the estimated development costs, the equilibrium quantities show a total production of 339 million tons of PR (Table 2.2). If we consider a time horizon T equal to 2100, this means that global PR production will grow at a CAGR of around 1.28%. At this peace, the producers will be able to meet future demand which is supposed to reach, as discussed before, 302 million tons by 2100. It is important to note that the result should not be interpreted as a projection of future PR supply, but as an equilibrium situation when both the leaders and the followers act strategically.

The analysis shows, at equilibrium, that future production will become more concentrated than it is today. The PR will be produced by only 11 countries instead of more than 20 countries today. Eigh countries alone will provide more than 90% of global PR production by 2100 (China excluded). Results also suggest that producers with a per-unit total production cost (OPEX+CAPEX) above 46US$ will be out of the market. The equilibrium quantities show that 3 of 5 selected leaders (Russia, Jordan and Brazil) and 7 of 16 selected followers (India, Israel, Mexico, Togo, Senegal, Finland and South Africa) will be inactive due to their high costs of production (see also their positions in the industry cost curve Figure 2.2). The observation of an increasing market concentration is consistent with the findings of Van Vuuren et al. (2010) who concluded that global production will concentrate in Asia, Africa and West Asia.

In term of individual country production, the equilibrium quantities show that Morocco's annual production will rise significantly from 27 Mt to more than 127 Mt by 2100, representing an increases of 470%. The country will be responsible for over 37.5% of global production, compared to 23% today. This seems to be a more realistic conclusion than the one drawn by Cooper et al. (2011) which suggest that Morocco will need to increase production by around 700% by 2075 in order to meet the phosphate demand deficit and, moreover, the country will obtain a much greater share of worldwide production, from 15% in 2010 to 80% by 2100. The others majors' producers are mainly located in the MENA region (Syria, Tunisia, Algeria, Saudi Arabia and Egypt), in Australia and in Kazakhstan. The share of these 7 countries is projected to increase to more than 56% of global PR production. Thus, these results point to the fact that the PR market will remain in an oligopolistic situation and will mitigate any eventual future monopoly as it is shown in Cooper et al. (2011), Mohr, S. & Evans, G. (2013) and Walan et al., (2014).

Table 2.2: Phosphate Rock Equilibrium Quantities

		Country	Real Production (avrg. 2010-2015)		Equilibrium Quantity (2100)	
			'10^6t	%	'10^6t	%
Leader's Group	1	United States	27,9	24,4	13,36	3,94
	2	Morocco	26,6	23,3	127,08	37,47
	3	Russia	10,8	9,4	-	-
	4	Jordan	6,9	6,0	-	-
	5	Brazil	5,9	5,2	-	-
Follower's Group	6	Egypt	4,8	4,2	15,6	4,6
	7	Tunisia	3,9	3,4	26,2	7,7
	8	Israel	3,3	2,9	-	-
	9	Peru	3,0	2,6	4,8	1,4
	10	Vietnam	2,5	2,2	2,1	0,6
	11	Saudi Arabia	2,5	2,2	26,1	7,7
	12	Australia	2,2	1,9	36,5	10,8
	13	South Africa	2,1	1,9	-	-
	14	Syria	2,0	1,7	37,3	11,0
	15	Mexico	1,9	1,7	-	-
	16	Kazakhstan	1,8	1,6	23,5	6,9
	17	India	1,5	1,3	-	-
	18	Senegal	1,4	1,2	-	-
	19	Algeria	1,3	1,2	26,6	7,8
	20	Togo	1,0	0,9	-	-
	21	Finland	0,9	0,8	-	-
Total			114,3	100,0	339,1	100,0

Sources: CRU and Author's calculations.

Increasing production requires extensions to existing mines and the development of new mines and related infrastructures. The results suggest that Morocco is the only leader who will invest in order to increase capacity, from 36 Mt/y to over 133Mt/y by 2100 (Table 2.3). But such a development plan, requires investments in the billions of U.S. dollars (Van Kauwenbergh, 2010) and may not be possible with regards to the country's financial capacities. However, and keeping in mind the country's reserve size, it is clear that no other country would be capable to producing such volumes.

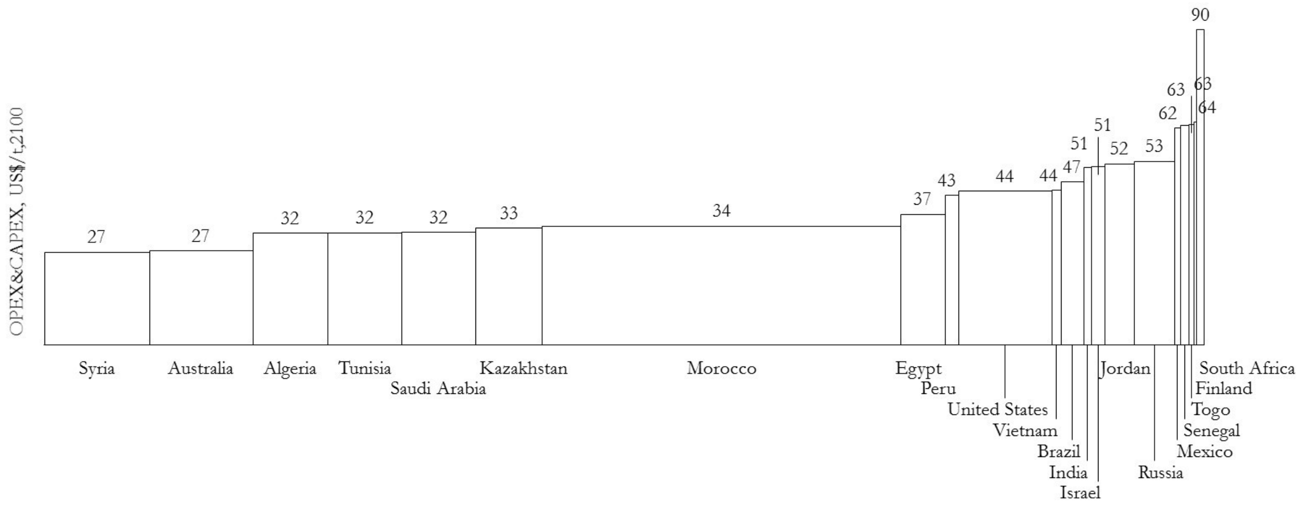
Additional capacities will come from 9 followers, with the most notable increases exhibited by three followers (Australia, Syria, Algeria) who should multiply there capacities by about 12 times in order to meet their equilibrium market share. The future industry cost curve (Figure 2.2) will become flatter at lower costs, as new capacities will mainly come from producers with low production costs and larger reserves.

Table 2.3: Phosphate Rock Equilibrium Capacities

		Country	Capacity (2015)	Equilibrium Capacity (2100)	
			'10^6t	'10^6t	xCap.2015
Leader's Group	1	United States	34,6	34,6	-
	2	Morocco	35,8	133,4	3,7
	3	Russia	14,9	14,9	-
	4	Jordan	11,1	11,1	-
	5	Brazil	8,3	8,3	-
Follower's Group	6	Egypt	6,5	16,4	2,5
	7	Tunisia	9,8	27,6	2,8
	8	Israel	4,8	4,8	-
	9	Peru	4,0	5,1	1,3
	10	Vietnam	3,5	3,5	-
	11	Saudi Arabia	5,3	27,4	5,2
	12	Australia	3,0	38,3	12,7
	13	South Africa	2,7	2,7	-
	14	Syria	3,3	39,1	12,0
	15	Mexico	2,2	2,2	-
	16	Kazakhstan	6,0	24,7	4,1
	17	India	3,1	3,1	-
	18	Senegal	3,1	3,1	-
	19	Algeria	2,3	27,9	12,1
	20	Togo	2,0	2,0	-
	21	Finland	1,0	1,0	-
Total			167,2	431,1	

Sources: CRU and Author's calculations.

Figure 2.2: PR Cost Curve by country, OPEX&CAPEX at capacity by 2100, US$/ton



Sources: CRU and Author's calculations.

2.6 Limitations of the model

Under a potential scenario of the future PR production deficit, the analysis shows the equilibrium quantities of PR production and the corresponding capacities to be installed by country in a non-cooperative competition. To do this, a number of assumptions were adopted and thus should be considered when interpreting these results.

- We simplify reality by considering PR as a homogenous good, neglecting quality differences of PR produced in different regions.
- As we model PR competition in quantities, we do not make any monetary adjustments to future costs.
- The depletion of low-cost and high-grade resources will have consequences for the future operating costs, which are supposed to be linear and constants in the analysis.
- The future structure of operating costs may also changes with the arrival of unconventional energy resources.
- Long-term technology innovation may change the PR mining process and accelerate reductions in both CAPEX and OPEX. For instance, bucket excavators may become bigger, and change from a human to a robotic operation mode.
- The distribution and the size of PR reserves taken as constants in the analysis are likely to be different in the future than it is today. The marine deposit of PR that are generally omitted from any reserves calculation could be unlocked with the arrival of dredging technology. The technology that was initially developed for diamond mining at a depth of about 150m is being now adapted to deeper-water mining (Argus, 2017).

2.7 Conclusions and Future Directions

Two particular conclusions could be considered as the most important: First, the research shows that game theory can be used as a strategic tool for forward-planning decision-making. Given the oligopolistic situation of the PR market, the sequencing of decision making and by introducing the development cost in the producer's decision program, this study proposes a multi-leader multi-follower Stackelberg model to investigate how the distribution of PR reserves may affect the share of supply and capacity investment decision in the future. Second, the empirical results contribute to the discussion on the future PR market structure. The main findings are summarized below:

- The future PR market will become more concentrated than it is today. World PR will be produced by 11 countries and just 8 countries will provide more than 90% of global PR production by 2100 (China excluded). This is in line with the conclusions of Van Vuuren et al. (2010) who show that global production will concentrate in Asia, Africa and West Asia, by using a model for phosphate depletion and under different potential future phosphate demand trajectories.
- Besides China, long-term supply will mainly come from Morocco (about 37% of global production), Syria (11%), Australia (10.8%), Algeria (7.8%), Tunisia and Saudi Arabia (7.7% each) and Kazakhstan (6.9%). Therefore, we conclude that the PR market will likely remain in an oligopoly situation and mitigate the eventual future monopoly as it is shown in Cooper et al. (2011), Mohr, S. & Evans, G. (2013) and Walan et al., (2014).
- By contrast, three of the current major producers (Russia, Joran and Brazil) will be inactive, at equilibrium, due to their highest costs of production.
- New capacities will come from Morocco, with a capacity multiplied by 3.7 times. From a present capacity of 36 Mt/y to over 133Mt/y by 2100. The Moroccan phosphate mining company, OCP Group, is already engaged in an investment program, which spans 10 years (2011-2020) and aims to double its mining capacity and triple its fertilizer capacity.
- Additional capacities will come from 9 followers, with the most significant increases exhibited by three followers (Australia, Syria, Algeria) who should multiply there capacities by about 12 times to meet their equilibrium market share. However, such development plans require hudge investments amounting to billions of U.S. dollars (Van Kauwenbergh, 2010) and may not be possible according to the financial difficulties in some countries like, Syria, Algeria, Tunisia and Egypt.

As the major PR producing countries are moving toward vertical integration, where mining companies will also produce fertilizers, phosphoric acid and other derivatives of phosphate rock, phosphate rock producers will face two options: exporting phosphate rock or exporting fertilizers. The proposed model could similarly be used to examine the equilibrium state and compute the equilibrium quantities of PR to be exported with or without transformation. However, some extensions are required to better capture the specific characteristics of the fertilizers industry. First, the production of phosphate fertilizer requires three major raw materials: Sulphur, phosphate rock and nitrogen. Some PR producers (for example: Morocco and Tunisia) need to purchase Sulphur and nitrogen at market prices while others PR producers (Saudi Arabia) have access to a cheaper raw materials. The cost function of phosphate fertilizers should explicitly take into account these differences. Second, there is a variety of phosphate fertilizer products (DAP, MAP, TSP and others) each corresponding to specific soil needs in different regions. Therefore, phosphate fertilizers cannot be considered as a homogenous good and a regional market dimension should be introduced.

2.8 References

- Argus. (2017). *Agrus Strategy Report: World Phosphate Rock Outlook to 2031*. Argus media group. London.
- Behar, A., & Ritz, R. A. (2016). OPEC vs US shale oil: Analyzing the shift to a market-share strategy.
- Brunner, P. H. (2010). Substance flow analysis as a decision support tool for phosphorus management. *Journal of Industrial Ecology*, 14(6), 870-873.
- Cooper, J., Lombardi, R., Boardman, D., & Carliell-Marquet, C. (2011). The future distribution and production of global phosphate rock reserves. *Resources, Conservation and Recycling*, 57, 78-86.
- Cordell, D., Drangert, J. O., & White, S. (2009a). The story of phosphorus: global food security and food for thought. *Global environmental change*, 19(2), 292-305.
- Cordell, D., Schmid-Neseta, D., Whiteb, D., & Drangerta, J. O. (2009b). Preferred future phosphorus scenarios: A framework for meeting long-term phosphorus needs for global food demand. *In International Conference on Nutrient Recovery from Wastewater Streams*: *May 10e13* (p. 23).
- Cordell, D., White, S., & Lindström, T. (2011). Peak phosphorus: the crunch time for humanity. *The Sustainability Review*, 2(2), 3.
- CRU. (2015). *Phosphate Rock Cost Report 2015 edition*. London.
- Déry, P., & Anderson, B. (2007). Peak phosphorus. *Energy Bulletin*, 13.
- FAO. (2000). *Fertilizer requirements in 2015 and 2030*. Rome: Food and Agriculture Organization of the United Nations.
- FAO. (2002). *World agriculture: towards 2015/2030*. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-y4252e.pdf
- FAO. (2017). *World fertilizer trends and outlook to 2020*. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-i6895e.pdf
- Frantsev, A., Sinha, A., & Malo, P. (2012). Finding optimal strategies in multi-period Stackelberg games using an evolutionary framework. *IFAC Proceedings Volumes*, *45*(25), 33-38.
- Gibbons, R. (1992). *Game theory for applied economists*. Princeton University Press.
- Giraud, P. N. (2012). A Note on Hubbert's Thesis on Mineral Commodities Production Peaks and derived Forecasting Techniques. *Procedia Engineering*, 46, 22-26.
- Hobbs, B. F., Metzler, C. B., & Pang, J. S. (2000). Strategic gaming analysis for electric power systems: An MPEC approach. *IEEE transactions on power systems, 15(2)*, 638-645.
- Hu, M., & Fukushima, M. (2015). Multi-leader-follower games: models, methods and applications. *Journal of the Operations Research Society of Japan, 58(1)*, 1-23.
- Huppmann, D.,& Holz, F. (2010). Global Oil Markets Revisited – Cartel or Stackelberg Market?. German Institute for Economic Research (DIW Berlin). In *Annual Meeting of the Verein für Socialpolitik*.
- IFA. (2011). *Feeding the Earth – Food Prices and Fertiliser Markets – Factors Influencing Variations in Fertilizer Market Conditions*. Paris: International Fertilizer Industry Association. www.fertilizer.org/ifacontent/download/60070/876243/version/1/file/2011_ifa_food_prices.pdf
- IFA. (2016). *Production and Trade Statistics – Phosphate Rock*. Paris: International Fertilizer
- IIASA. (2007). *Global development challenges for science*. In: Options. Winter 2007. International Institute for Applied Systems Analysis. http://www.iiasa.ac.at/web/home/resources/publications/IIASAMagazineOptions/opt-07wint.pdf
- Keijser, B.M.J. (2016). Mixing and Matching Building Blocks for Commodity Market Models: The Case of Phosphate Market Imbalances. *Faculty of Technology, Policy & Management, Delft University of Technology*. https://repository.tudelft.nl/islandora/object/uuid:b56622b5-cd33-44d5-b26c-8c4a565fc11f/datastream/OBJ1/download
- Kim, S. (2012). Multi-leader multi-follower Stackelberg model for cognitive radio spectrum sharing scheme. *Computer Networks, 56(17),* 3682-3692.
- KPMG. (2017). *Mining Reporting Survey 2016*. KPMG International. Swiss. https://assets.kpmg.com/content/dam/kpmg/ca/pdf/2016/11/ca-mining-reporting-survey-2016.pdf
- Marcotte, P., & Blain, M. (1991). A Stackelberg-Nash model for the design of deregulated transit system. In *Dynamic Games in Economic Analysis (pp. 21-28).* Springer, Berlin, Heidelberg.

- Mew, M. (2011). Future phosphate rock production–peak or plateau. *Fertecon Research Center Limited. Available online: http://www. fertecon-frc. info/page15. htm (accessed March 10 2011).*
- Mohr, S., & Evans, G. (2013). Projections of future phosphorus production. *Philicacom*, *2013*.
- Pang, J. S., & Fukushima, M. (2005). Quasi-variational inequalities, generalized Nash equilibria, and multi-leader-follower games. *Computational Management Science, 2(1),* 21-56.
- Ramos, M. A., Boix, M., Aussel, D., Montastruc, L., & Domenech, S. (2016). Water integration in eco-industrial parks using a multi-leader-follower approach. *Computers & Chemical Engineering, 87*, 190-207.
- Rosemarin, A., De Bruijne, G., & Caldwell, I. (2009). Peak phosphorus: The next inconvenient truth. *The Broker, (15),* 6-9.
- Rustad, J. R. (2012). Peak nothing: recent trends in mineral resource production. *Environmental science & technology, 46(3),* 1903-1906.
- Scholz, R. W., & Wellmer, F. W. (2013). Approaching a dynamic view on the availability of mineral resources: what we may learn from the case of phosphorus?. *Global Environmental Change, 23(1),* 11-27.
- Schröder, J. J., Cordell, D., Smit, A. L., & Rosemarin, A. (2010). *Sustainable use of phosphorus: EU tender ENV. B1/ETU/2009/0025* (No. 357). Plant Research International. http://ec.europa.eu/environment/natres/pdf/sustainable_use_phosphorus.pdf
- Sherali, H. D. (1984). A multiple leader Stackelberg model and analysis. *Operations Research, 32(2),* 390-404.
- Sherali, H. D., Soyster, A. L., & Murphy, F. H. (1983). Stackelberg-Nash-Cournot equilibria: characterizations and computations. *Operations Research, 31(2),* 253-276.
- Smit, A. L., Bindraban, P. S., Schröder, J. J., Conijn, J. G., & van der Meer, H. G. (2009). Phosphorus in Agriculture: Global Resources, Trend and Developments, *Report 282. Wageningen: Plant Research International B.V.* http://edepot.wur.nl/12571.
- Smith, L D. (1997). A critical examination of the methods and factors affecting the selection of an optimum production rate, *CIM Bulletin 90(1007):*48-54.
- UN (2017). *World Population Prospects – The 2017 Revision: Key findings & advance tables*. United Nations Department of Economic and Social Affairs, Population Division. https://www.compassion.com/multimedia/world-population-prospects.pdf
- UN. (2004). *World population to 2300*. New York: United Nations Department of Economic and Social Affairs, Population Division.
- USGS. (2009). *Mineral Commodity Summaries*, Phosphate Rock, US Geological Survey, Washington DC.
- USGS. (2011). *Mineral Commodity Summaries*, Phosphate Rock, US Geological Survey, Washington DC.
- USGS. (2017*). Mineral Commodity Summaries*, Phosphate Rock, US Geological Survey, Washington DC.
- Vaccari, D. A., & Strigul, N. (2011). Extrapolating phosphorus production to estimate resource reserves. *Chemosphere, 84(6),* 792-797.
- Van Enk, R. J., Acera, L. K., Schuiling, R. D., Ehlert, P., De Wilt, J. G., & Van Haren, R. J. F. (2011). The phosphate balance: Current developments and future outlook. *Innovation Network Reports,* (10.2. 232E).
- Van Kauwenbergh, S. J. (2010). *World phosphate rock reserves and resources* (p. 48). Muscle Shoals: IFDC.
- Van Vuuren, D. P., Bouwman, A. F., & Beusen, A. H. W. (2010). Phosphorus Demand for the 1970 – 2100 Period: A Scenario Analysis of Resource Depletion, *Global Environmental Change, 20(3),* 428–439.
- Von Stackelberg, H. (1952). *The theory of the market economy*. Oxford University Press.
- Walan, P., Davidsson, S., Johansson, S., & Höök, M. (2014). Phosphate rock production and depletion: Regional disaggregated modeling and global implications. *Resources, Conservation and Recycling, 93*, 178-187.

2.9 Appendices A

Appendix A.1: Proof of Analytical solution for Multi-leader Multi-follower Stackelberg Model

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Step 1: Follower's decision as a function of leader's strategy

$$\underset{q_j^f \geq 0}{\textbf{Max}}\, \pi_j^f = \left[\underbrace{P\left(Q^l + q_j^f + Q^{f-j}\right) q_j^f}_{Cash-flow} - \underbrace{c_j^f q_j^f}_{Production\ Cost} - \underbrace{\tau_j^f \times max\left(0; q_j^f - k_j^f\right)}_{Investment\ Cost} \right] \quad for\ j = 1\ to\ N$$

The j-th follower profit function can be derived with respect to q_j^f as

$$\Rightarrow \frac{\partial \pi_j^f}{\partial q_j^f} = P'\left(Q^l + q_j^f + Q^{f-j}\right) q_j^f + P\left(Q^l + q_j^f + Q^{f-j}\right) - (c_j^f + \tau_j^f) = 0$$

$$\Rightarrow \frac{\partial\left(\alpha - \beta(Q^l + q_j^f + Q^{f-j}\right)}{\partial q_j^f} q_j^f + \left(\alpha - \beta(Q^l + q_j^f + Q^{f-j}\right) - (c_j^f + \tau_j^f) = 0$$

$$\Rightarrow -2\beta q_j^f - \beta\left(q_1^f + \cdots + q_{i\neq j}^f + .. + q_N^f\right) - \beta\left(q_1^l + \cdots + q_i^l + .. + q_M^l\right) + \alpha - (c_j^f + \tau_j^f) = 0$$

$$\Rightarrow 2\beta q_j^f + \beta\left(q_1^f + \cdots + q_{i\neq j}^f + .. + q_N^f\right) = \alpha - \left(c_j^f + \tau_j^f\right) - \beta\left(q_1^l + \cdots + q_i^l + .. + q_M^l\right)$$

For all followers, we have the following system

$$\Rightarrow \begin{Bmatrix} 2\beta q_1^f + \beta\left(q_2^f + \cdots + q_j^f + .. + q_N^f\right) = \alpha - \left(c_1^f + \tau_1^f\right) - \beta\left(q_1^l + \cdots + q_i^l + .. + q_M^l\right) \\ \vdots \\ 2\beta q_j^f + \beta\left(q_1^f + \cdots + q_{h\neq j}^f + .. + q_N^f\right) = \alpha - \left(c_j^f + \tau_j^f\right) - \beta\left(q_1^l + \cdots + q_i^l + .. + q_M^l\right) \\ \vdots \\ 2\beta q_N^f + \beta\left(q_1^f + \cdots + q_j^f + .. + q_{N-1}^f\right) = \alpha - \left(c_N^f + \tau_N^f\right) - \beta\left(q_1^l + \cdots + q_i^l + .. + q_M^l\right) \end{Bmatrix}$$

The system can be rewritten as

$$\Rightarrow \begin{bmatrix} 2\beta & \cdots & 0 \\ \vdots & 2\beta & \vdots \\ 0 & \cdots & 2\beta \end{bmatrix} \begin{bmatrix} q_1^f \\ q_j^f \\ q_N^f \end{bmatrix} + \begin{bmatrix} 0 & \cdots & \beta \\ \vdots & 0 & \vdots \\ \beta & \cdots & 0 \end{bmatrix} \begin{bmatrix} q_1^f \\ q_j^f \\ q_N^f \end{bmatrix} = \begin{bmatrix} \alpha - \left(c_1^f + \tau_1^f\right) \\ \alpha - \left(c_j^f + \tau_j^f\right) \\ \alpha - \left(c_N^f + \tau_N^f\right) \end{bmatrix} - \begin{bmatrix} \beta & \cdots & \beta \\ \vdots & \beta & \vdots \\ \beta & \cdots & \beta \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} 2\beta & \cdots & \beta \\ \vdots & 2\beta & \vdots \\ \beta & \cdots & 2\beta \end{bmatrix} \begin{bmatrix} q_1^f \\ q_j^f \\ q_N^f \end{bmatrix} = \begin{bmatrix} \alpha - \left(c_1^f + \tau_1^f\right) \\ \alpha - \left(c_j^f + \tau_j^f\right) \\ \alpha - \left(c_N^f + \tau_N^f\right) \end{bmatrix} - \beta \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & 1 & \vdots \\ 1 & \cdots & 1 \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} 1 & \cdots & 1/2 \\ \vdots & 1 & \vdots \\ 1/2 & \cdots & 1 \end{bmatrix} \begin{bmatrix} q_1^f \\ q_j^f \\ q_N^f \end{bmatrix} = \frac{1}{2\beta} \begin{bmatrix} \alpha - \left(c_1^f + \tau_1^f\right) \\ \alpha - \left(c_j^f + \tau_j^f\right) \\ \alpha - \left(c_N^f + \tau_N^f\right) \end{bmatrix} - \frac{1}{2} \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & 1 & \vdots \\ 1 & \cdots & 1 \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix}$$

In a matrix form, we can write

$$\Rightarrow A_f q^f = \frac{1}{2\beta} V_f - \frac{1}{2} \mathbb{I}_f q^l$$

$$\Longrightarrow \boldsymbol{\hat{q}^f} = \boldsymbol{max}\left(\left(\frac{\mathbf{1}}{\mathbf{2}\boldsymbol{\beta}}\boldsymbol{A_f^{-1}V_f} - \frac{\mathbf{1}}{\mathbf{2}}\boldsymbol{A_f^{-1}}\mathbb{I}_f\boldsymbol{q^l}\right), \mathbf{0}\right)$$

$$\Longrightarrow \boldsymbol{\hat{q}^f} = \boldsymbol{q^f}(\boldsymbol{q^l})$$

where

$$\boldsymbol{q}^f_{(N\times1)} = \begin{bmatrix} q_1^f \\ q_j^f \\ q_N^f \end{bmatrix}, \boldsymbol{q}^l_{(M\times1)} = \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix},$$

$$A_{f\,(N\times N)} = \begin{bmatrix} 1 & \cdots & 1/2 \\ \vdots & 1 & \vdots \\ 1/2 & \cdots & 1 \end{bmatrix},\ \mathbb{I}_{f\,(N\times M)} = \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & 1 & \vdots \\ 1 & \cdots & 1 \end{bmatrix} and\ V_{f\,(N\times1)} = \begin{bmatrix} \alpha - \left(c_1^f + \tau_1^f\right) \\ \alpha - \left(c_j^f + \tau_j^f\right) \\ \alpha - \left(c_N^f + \tau_N^f\right) \end{bmatrix}$$

Step 2: Leader's decision

$$\underset{q_i^l\geq0}{\mathbf{Max}}\,\boldsymbol{\pi_i^l} = \left[\underbrace{\boldsymbol{P\left(Q^{l-i}+q_i^l+\hat{Q}^f\right)q_i^l}}_{\boldsymbol{Cash-flow}} - \underbrace{\boldsymbol{c_i^lq_i^l}}_{\boldsymbol{Production\ Cost}} - \underbrace{\boldsymbol{\tau_i^l} \times \boldsymbol{Max(0; q_i^l - k_i^l)}}_{\boldsymbol{Investiment\ Cost}}\right] \quad \boldsymbol{for\ i = 1\ to\ M}$$

The ith leader profit function can be derived with respect to q_i^l as

$$\Rightarrow \frac{\partial\pi_i^l}{\partial q_i^l} = P'\left(Q^{l-i}+q_i^l+\hat{Q}^f\right)q_i^l + P\left(Q^{l-i}+q_i^l+\hat{Q}^f\right) - (c_i^l+\tau_i^l) = 0$$

$$\Rightarrow \frac{\partial\left(\alpha-\beta(Q^{l-i}+q_i^l+\hat{Q}^f)\right)}{\partial q_i^l}q_i^l + \left(\alpha - \beta(Q^{l-i}+q_i^l+\hat{Q}^f)\right) - (c_i^l+\tau_i^l)=0$$

$$\Rightarrow -\beta q_i^l - \beta\frac{\partial(\hat{Q}^f)}{\partial q_i^l}q_i^l + \left(\alpha - \beta(Q^{l-i}+q_i^l+\hat{Q}^f)\right) - (c_i^l+\tau_i^l)=0$$

$$\Rightarrow -\beta q_i^l - \beta\frac{\partial(\hat{Q}^f)}{\partial q_i^l}q_i^l + \left(\alpha - \beta(Q^{l-i}+q_i^l+\hat{Q}^f)\right) - (c_i^l+\tau_i^l)=0$$

$$\Rightarrow -\beta q_i^l - \beta\frac{\partial\left(\hat{q}_1^f+\cdots+\hat{q}_N^f\right)}{\partial q_i^l}q_i^l + \left(\alpha - \beta(Q^{l-i}+q_i^l+\hat{Q}^f)\right) - (c_i^l+\tau_i^l)=0$$

$$\Rightarrow -\beta q_i^l - \beta\left(\frac{\partial\left(\hat{q}_1^f\right)}{\partial q_i^l} + \cdots + \frac{\partial\left(\hat{q}_N^f\right)}{\partial q_i^l}\right)q_i^l + \left(\alpha - \beta(Q^{l-i}+q_i^l+\hat{Q}^f)\right) - (c_i^l+\tau_i^l)=0$$

$$\Rightarrow -2\beta q_i^l - \beta(d_{i1}+\cdots+d_{iN})q_i^l + \alpha - \beta(Q^{l-i}+\hat{Q}^f) - (c_i^l+\tau_i^l)=0$$

$$\Rightarrow 2\beta q_i^l + \beta(d_{i1}+\cdots+d_{iN})q_i^l + \beta Q^{l-i} + \beta\hat{Q}^f = \alpha - (c_i^l+\tau_i^l)=0$$

For all leaders, we have the following system

$$\Rightarrow \left\{ \begin{array}{c} 2\beta q_1^l + \beta\left(q_2^l + \cdots + q_i^l + .. + q_M^l\right) + \beta(d_{11} + \cdots + d_{1N})q_1^l + \beta\left(\hat{q}_1^f + \cdots + \hat{q}_j^f + .. + \hat{q}_N^f\right) = \alpha - (c_1^l + \tau_1^l) \\ \vdots \\ 2\beta q_i^l + \beta\left(q_1^l + \cdots + q_{h\neq i}^l + .. + q_M^l\right) + \beta(d_{i1} + \cdots + d_{iN})q_i^l + \beta\left(\hat{q}_1^f + \cdots + \hat{q}_j^f + .. + \hat{q}_N^f\right) = \alpha - (c_i^l + \tau_i^l) \\ \vdots \\ 2\beta q_M^l + \beta\left(q_1^l + \cdots + q_i^l + .. + q_{M-1}^l\right) + \beta(d_{M1} + \cdots + d_{MN})q_M^l + \beta\left(\hat{q}_1^f + \cdots + \hat{q}_j^f + .. + \hat{q}_N^f\right) = \alpha - (c_M^l + \tau_M^l) \end{array} \right\}$$

In a matrix form, we can write

$$\Rightarrow \begin{bmatrix} 2\beta & \cdots & \beta \\ \vdots & 2\beta & \vdots \\ \beta & \cdots & 2\beta \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix} + \beta \begin{bmatrix} \sum_{j=1}^{N} d_{1j} & \cdots & 0 \\ \vdots & \sum_{j=1}^{N} d_{ij} & \vdots \\ 0 & \cdots & \sum_{j=1}^{N} d_{Mj} \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix} + \beta \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & 1 & \vdots \\ 1 & \cdots & 1 \end{bmatrix} \begin{bmatrix} \hat{q}_1^f \\ \hat{q}_j^f \\ \hat{q}_N^f \end{bmatrix} = \begin{bmatrix} \alpha - (c_1^l + \tau_1^l) \\ \alpha - (c_i^l + \tau_i^l) \\ \alpha - (c_M^l + \tau_M^l) \end{bmatrix}$$

$$\Rightarrow 2\beta \begin{bmatrix} 1 & \cdots & 1/2 \\ \vdots & 1 & \vdots \\ 1/2 & \cdots & 1 \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix} + \beta \begin{bmatrix} \sum_{j=1}^{N} d_{1j} & \cdots & 0 \\ \vdots & \sum_{j=1}^{N} d_{ij} & \vdots \\ 0 & \cdots & \sum_{j=1}^{N} d_{Mj} \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix} + \beta \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & 1 & \vdots \\ 1 & \cdots & 1 \end{bmatrix} \begin{bmatrix} \hat{q}_1^f \\ \hat{q}_j^f \\ \hat{q}_N^f \end{bmatrix} = \begin{bmatrix} \alpha - (c_1^l + \tau_1^l) \\ \alpha - (c_i^l + \tau_i^l) \\ \alpha - (c_M^l + \tau_M^l) \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} 1 & \cdots & 1/2 \\ \vdots & 1 & \vdots \\ 1/2 & \cdots & 1 \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix} + \frac{1}{2} \begin{bmatrix} \sum_{j=1}^{N} d_{1j} & \cdots & 0 \\ \vdots & \sum_{j=1}^{N} d_{ij} & \vdots \\ 0 & \cdots & \sum_{j=1}^{N} d_{Mj} \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix} + \frac{1}{2} \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & 1 & \vdots \\ 1 & \cdots & 1 \end{bmatrix} \begin{bmatrix} \hat{q}_1^f \\ \hat{q}_j^f \\ \hat{q}_N^f \end{bmatrix} = \frac{1}{2\beta} \begin{bmatrix} \alpha - (c_1^l + \tau_1^l) \\ \alpha - (c_i^l + \tau_i^l) \\ \alpha - (c_M^l + \tau_M^l) \end{bmatrix}$$

$$\Rightarrow \begin{bmatrix} 1 + \frac{1}{2}\sum_{j=1}^{N} d_{1j} & \cdots & 1/2 \\ \vdots & 1 + \frac{1}{2}\sum_{j=1}^{N} d_{ij} & \vdots \\ 1/2 & \cdots & 1 + \frac{1}{2}\sum_{j=1}^{N} d_{Mj} \end{bmatrix} \begin{bmatrix} q_1^l \\ q_i^l \\ q_M^l \end{bmatrix} + \frac{1}{2} \begin{bmatrix} 1 & \cdots & 1 \\ \vdots & 1 & \vdots \\ 1 & \cdots & 1 \end{bmatrix} \begin{bmatrix} \hat{q}_1^f \\ \hat{q}_j^f \\ \hat{q}_N^f \end{bmatrix} = \frac{1}{2\beta} \begin{bmatrix} \alpha - (c_1^l + \tau_1^l) \\ \alpha - (c_i^l + \tau_i^l) \\ \alpha - (c_M^l + \tau_M^l) \end{bmatrix}$$

$$\Rightarrow A_l q^l + \frac{1}{2}\mathbb{I}_l \hat{q}^f = \frac{1}{2\beta} V_l$$

Substituting $\hat{\boldsymbol{q}}^{\boldsymbol{f}}$ into (.) and rearranging terms

$$\Rightarrow A_l q^l + \frac{1}{2}\mathbb{I}_l \left(\frac{1}{2\beta} A_f^{-1} V_f - \frac{1}{2} A_f^{-1} \mathbb{I}_f q^l \right) = \frac{1}{2\beta} V_l$$

$$\Longrightarrow A_l q^l + \frac{1}{4\beta}\mathbb{I}_l A_f^{-1} V_f - \frac{1}{4}\mathbb{I}_l A_f^{-1}\mathbb{I}_f q^l = \frac{1}{2\beta} V_l$$

$$\Longrightarrow A_l q^l - \frac{1}{4}\mathbb{I}_l A_f^{-1}\mathbb{I}_f q^l = \frac{1}{2\beta} V_l - \frac{1}{4\beta}\mathbb{I}_l A_f^{-1} V_f$$

$$\Longrightarrow \left(A_l - \frac{1}{4}\mathbb{I}_l A_f^{-1}\mathbb{I}_f\right) q^l = \frac{1}{2\beta} V_l - \frac{1}{4\beta}\mathbb{I}_l A_f^{-1} V_f$$

$$\Longrightarrow \boldsymbol{\hat{q}^l} = \left(\boldsymbol{A_l} - \frac{\boldsymbol{1}}{\boldsymbol{4}}\mathbb{I}_l \boldsymbol{A_f^{-1}}\mathbb{I}_f\right)^{\boldsymbol{-1}} \left(\frac{\boldsymbol{1}}{\boldsymbol{2\beta}}\boldsymbol{V_l} - \frac{\boldsymbol{1}}{\boldsymbol{4\beta}}\mathbb{I}_l \boldsymbol{A_f^{-1} V_f}\right)$$

$$\Longrightarrow \boldsymbol{\hat{q}^l} = \boldsymbol{q^l}(\boldsymbol{C^l}, \boldsymbol{C^f}, \boldsymbol{\tau^l}, \boldsymbol{\tau^f}, \alpha, \beta)$$

Step 3: Follower's final decision

$$\Longrightarrow \hat{q}^f = \frac{1}{2\beta} A_f^{-1} V_f - \frac{1}{2} A_f^{-1}\mathbb{I}_f \left(\left(A_l - \frac{1}{4}\mathbb{I}_l A_f^{-1}\mathbb{I}_f\right)^{-1}\left(\frac{1}{2\beta} V_l - \frac{1}{4\beta}\mathbb{I}_l A_f^{-1} V_f\right)\right)$$

$$\Longrightarrow \boldsymbol{\hat{q}^f} = \boldsymbol{q^f}(\boldsymbol{C^l}, \boldsymbol{C^f}, \boldsymbol{\tau^l}, \boldsymbol{\tau^f}, \alpha, \beta)$$

Appendix A.2: Estimation of development costs

Box 1. Determination of mining CAPEX depreciation period

Mining is a capital-intensive industry. Mining companies often require significant capital expenditures to develop a new mine or to expand an existing one. The estimation of the per unit CAPEX requires a determination of the period over which these CAPEX should be depreciated. This often represents one of the challenges for mining companies because it can have a significant impact on the mining project feasibility. It is clear that this period depend directly on the life of the mine project. However, there are various factors such as ongoing exploration activities, changing commodity prices and input costs that can have a significant impact on the useful life of the mine project, and therefore the total material extracted (KPMG, 2017).

The unit-of –production method is commonly used in the mining industry to depreciate mineral reserves, property, plants and equipment (International Accounting Standards (IAS) 16) on the basis of proven and probable reserves. For example, a machine may be depreciated on the basis of output produced during a period in proportion to its total expected production capacity. Therefore, the useful life of an asset under the units-of-production method is stated in terms of production output or usage rather than years of service.

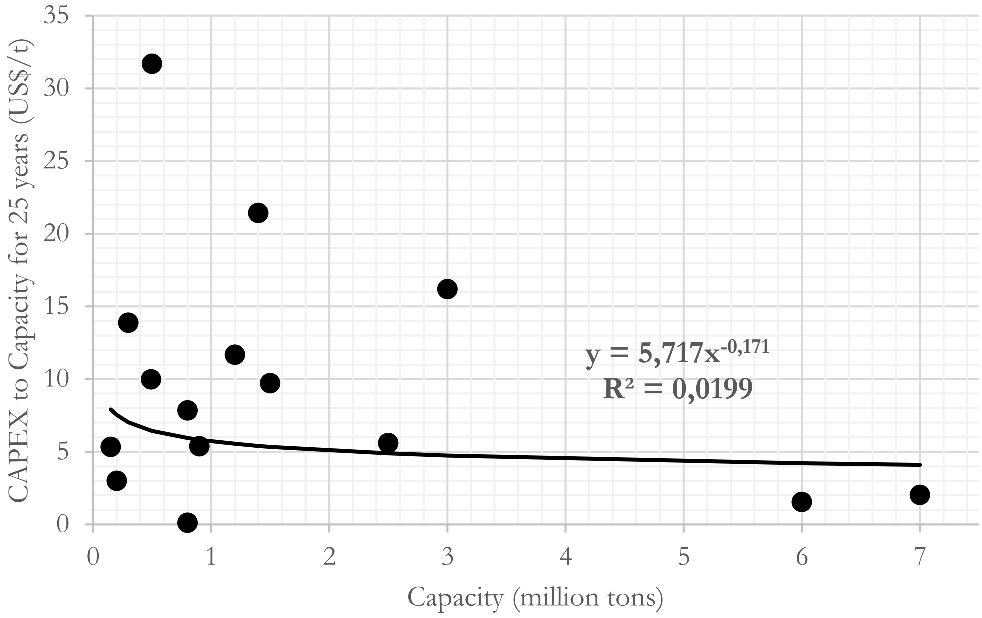
Generally, the useful life of a mine project varies from 10 to 50 years. In this paper, we assume that the period over which mining companies depreciate their CAPEXs is equal to 25 years.

Table 2.4: Selected phosphate rock projects

Selected Projects[a]	Location	CAPEX (million US$)	Capacity (million tons)	CAPEX to Capacity for 25[b] years (US$/t)
Paris Hills	US	121	0,9	5,38
Lac à Paul	Canada	1214,7	3,0	16,20
Mine Arnaud	Canada	750	1,4	21,43
Wapiti	Canada	2,2	0,8	0,11
Angico dos Dias	Brazil	20	0,2	5,33
Irecê	Brazil	15	0,2	3,00
Santana	Brazil	396	0,5	31,68
Serra do Salitre	Brazil	350	1,2	11,67
Don Diego	Mexico	357,3	7,0	2,04
Bayóvar	Peru	350	2,5	5,60
Dinner Hill	Australia	104,1	0,3	13,88
Ouled Fares	Morocco	233	6	1,55
Chaketma	Tunisia	364	1,5	9,71
Cabinda	Angola	157	0,8	7,85
Duyker Eiland	South Africa	122,2	0,49	9,98

a: the selected project's statue can be firm, probable or speculative.
b: the 25 years represent an average period over which the mining CAPEX should be depreciated.
Source: Phosphate Rock Cost Report, CRU, 2015

Figure 2.3: Phosphate Rock mining: CAPEX and Capacity



Source: Phosphate Rock Cost Report, CRU, 2015

Sensitivity Analysis

As noted earlier, in order to evaluate how the parameter γ can affect the results, we carry out a sensitivity analysis with respect to this parameter using values of -0.09 and -0.26, in addition to the value of -0.17 used in our base specification. Table 2.5 lists the equilibrium quantities that each country could produce by 2100. The results show that the market structure at equilibrium is not very sensitive to a ±50 percentage change of this parameter.

Table 2.5: Sensivity analysis

Gamma		Equilibrium Production Quantities (2100)					
		-0,09		-0,17		-0,26	
		'10^6t	%	'10^6t	%	'10^6t	%
1	United States	12,2	3,6	13,4	3,9	13,9	4,1
2	Morocco	126,5	37,6	127,1	37,5	124,9	36,9
3	Russia	-	-	-	-	-	-
4	Jordan	-	-	-	-	-	-
5	Brazil	-	-	-	-	-	-
1	Egypt	15,4	4,6	15,6	4,6	15,7	4,6
2	Tunisia	26,4	7,8	26,2	7,7	26,5	7,8
3	Israel	-	-	-	-	-	-
4	Peru	4,6	1,4	4,8	1,4	4,9	1,5
5	Vietnam	2,5	0,7	2,1	0,6	2,2	0,6
6	Saudi Arabia	26,0	7,7	26,1	7,7	26,3	7,8
7	Australia	36,3	10,8	36,5	10,8	36,6	10,8
8	South Africa	-	-	-	-	-	-
9	Syria	37,0	11,0	37,3	11,0	37,3	11,0
10	Mexico	-	-	-	-	-	-
11	Kazakhstan	23,4	7,0	23,5	6,9	23,7	7,0
12	India	-	-	-	-	-	-
13	Senegal	-	-	-	-	-	-
14	Algeria	26,4	7,8	26,6	7,8	26,6	7,9
15	Togo	-	-	-	-	-	-
16	Finland	-	-	-	-	-	-
#	Total	336,6	100	339,1	100	338,6	100

Source: Author's calculations.

Appendix 2.3: Estimated parameters for inverse demand function

Table 2.6: Estimated parameters for inverse demand function

	Estimated equation: $Ln(P) = \alpha - \beta * Ln(Q)$				
	Morocco	Russia	Peru	Jordan	Egypt
α	7,259 *** (0,971)	11,460 *** (1,814)	6,264 ** (2,243)	3,254 (1,928)	1,080 (3,054)
β	0,255 ** (0,106)	0,822 *** (0,239)	0,204 (0,285)	-0,202 (0,245)	-0,423 (0,391)
Sample	2007-2016	2007-2016	2011-2016	2007-2016	2010-2016
R-squared	0,027	0,451	0,026	0,068	0,033

Method: Least Squares with HAC standard errors & covariance (Pre-whitening with lags = 2 from AIC max lags = 2, Bartlett kernel, Newey-West fixed bandwidth = 3.0000)

Chapter 3

Economic impacts of phosphate extraction and valorization on the Moroccan economy: An input-output analysis

Résumé

Le troisième chapitre vise à évaluer quantitativement les effets d'entraînement que le Maroc dégage de son exploitation des phosphates. Pour atteindre cet objectif, la méthodologie utilisée repose sur l'analyse entrée-sortie de Leontief. La combinaison des données du Groupe OCP avec celles de la comptabilité nationale a permis de scinder les activités du Groupe OCP en deux branches « OCP-Mine » pour l'activité d'extraction et « OCP-Chimie » pour l'activité de transformation. L'analyse empirique proposée compare les impacts socio-économiques de l'extraction à ceux liés à la transformation ou à la valorisation sur les autres secteurs de l'économie nationale. Les résultats de cette analyse montrent que la transformation des phosphates est plus reliée en amont avec les autres branches de l'économie et génère plus de valeur ajoutée, de revenues et d'emplois. Ainsi, la production d'engrais d'une valeur d'un dollar génère une production totale évaluée à 2,61 dollars dans l'économie tandis qu'une même quantité d'extraction de phosphate brut génère une production équivalente à 1,73 dollar. En termes de revenus, l'activité OCP-Chimie génère 3,11 dollars pour chaque dollar de la production du secteur, tandis que l'impact OCP-Mine équivaut à 2,25 dollars. En outre, les calculs montrent le multiplicateur d'emploi total est égal à 8 pour OCP-Chimie, alors qu'il est d'environ 3 pour OCP-Mine.

3.1 Introduction

The Moroccan mining sector is dominated by phosphate, which account more than 90% of the sector's total production. With about 75% of the world's estimated reserves of Phosphate Rock[6], Morocco is the second larger phosphate producer and the world's leading phosphate rock exporter, accounting for roughly one-third of world trade. Morocco is also leader in the export of phosphoric acid and fertilizers with respectively 47% and 19% of global export (IFA[7] statistics, 2013). Phosphate exploration and extraction are exclusively managed by a state-owned company named OCP[8] Group, wheras the valorization activity (e.g. production of Phosphoric Acid and Fertilizers) is managed mostly by OCP along with some others foreign producers in the form of joint ventures. A brief presentation of the OCP group is reported in Appendix B.1 and the detailed capacity by site, logistics and target markets of finished products are presented in Appendix B.2 and Appendix B.3.

At national level, both extraction and valorization activities significantly contribute to the Moroccan economy. For instance, between 2009 and 2014, phosphate and fertilizers exports represented on average 22% of total exports (Figure 3.1) and contributed by 13% of total foreign exchange earnings (Figure 3.2). In addition, the OCP Group's added value represented on average 4.4% of the national value added (Figure 3.3). The company's direct contribution, in terms dividends and corporate tax, amounted to an average of 7,2% of the government's total revenues (Figure 3.4). In terms of investments, OCP Group started an expansion program in 2010, aiming at doubling mining output and triple fertilizer production by 2020, with an overall budget of US$ 12billion. Moreover, OCP Group is among the lagest employer in Morocco with a direct workforce of over 21000 employees and about 40000 indirect jobs, mainly through sub-contracting (a network of over 1500 local sub-contractors). This has a significant impact on employment at the regional level. For instance, OCP's share in regional employment in the industrial branch reached 35% where OCP's chemical activities are located and from 5 to 25% where the company has its mining activities(Table 3.1 and Figure 3.5).

Beyond these direct macro-economic impacts, the sector has a substantial contribution when it is integrated into the economy. This is achieved through several channels: additional revenues from industries' related activities, employment generated by these activities, intermediate inputs provision from and for other sectors, research and development activities and, finally, technology transfers. Therefore, the company also contributes to the services sector like banking, inssurance, financial services, transportations and logistics.

This study aims to estimate and analyze the impact of phosphate extraction and valorization activities on the Moroccan economy. By using an input-output methodological framework, this work evaluates how an increase in demand adressed to each of these industries could potentially affect the Moroccan economy. A significant advantage of utilizing an input-output methodology is that the multipliers (output, income and employment) and linkage measures incorporate not only

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[6] According to the latest U.S. Geological Survey (2016), Phosphate rock reserves in Morocco are estimated at 50 billion tonnes (World phosphate reserves are estimated at 69 billions tons).

[7] International Fertilizers Association (www.fertilizer.org)

[8] Office Chérifien des Phosphates (www.ocpgroup.ma)

the direct effects, but also the indirect and the induced effects on the economy in response to an exogenous shock on one of the components of final demand (e.g. export demand, investment or stock variation). These detailed measures are useful for OCP Group's decision makers in order to identify an industrial target for a region or to plan a future production program. It is also useful for national policy makers and planners who need to know in which sectors output, income and employment changes will occur. The next section discusses the application of I-O techniques to OCP's mining and chemical activities. It is then followed by a presentation of the results and, finally, a concluding section summarizes the implications of theses results for future economic development in Morocco.

OCP's major economic impacts

Figure 3.1: Contribution to total exports in %

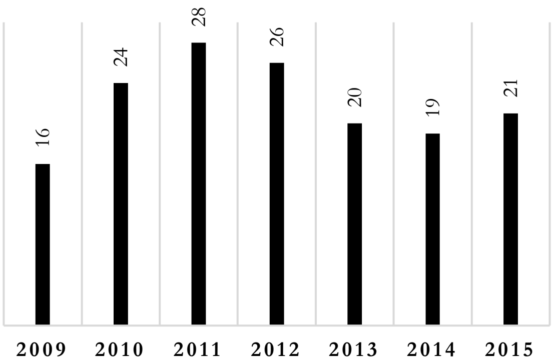


Figure 3.2: Contribution to foreign exchange earnings in %

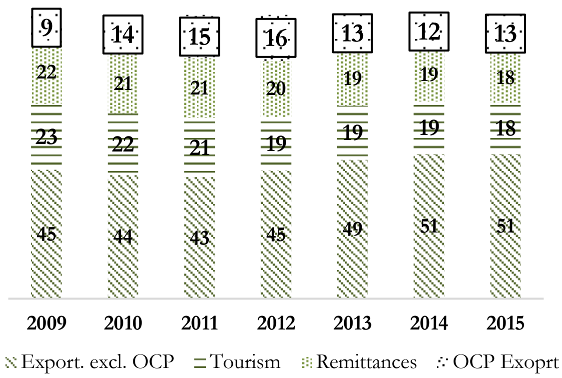


Figure 3.3: Contribution to national value added in %

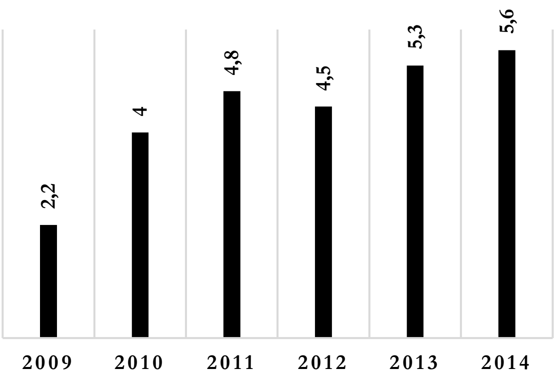
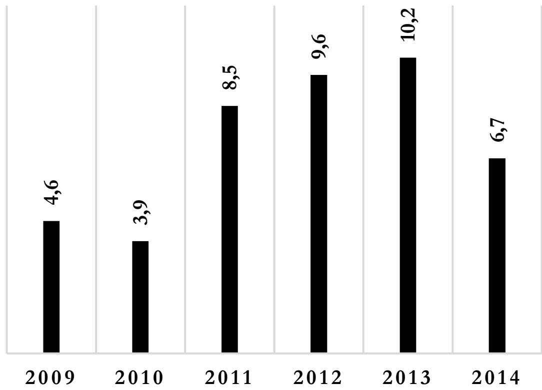


Figure 3.4: Contribution to government revenues in %



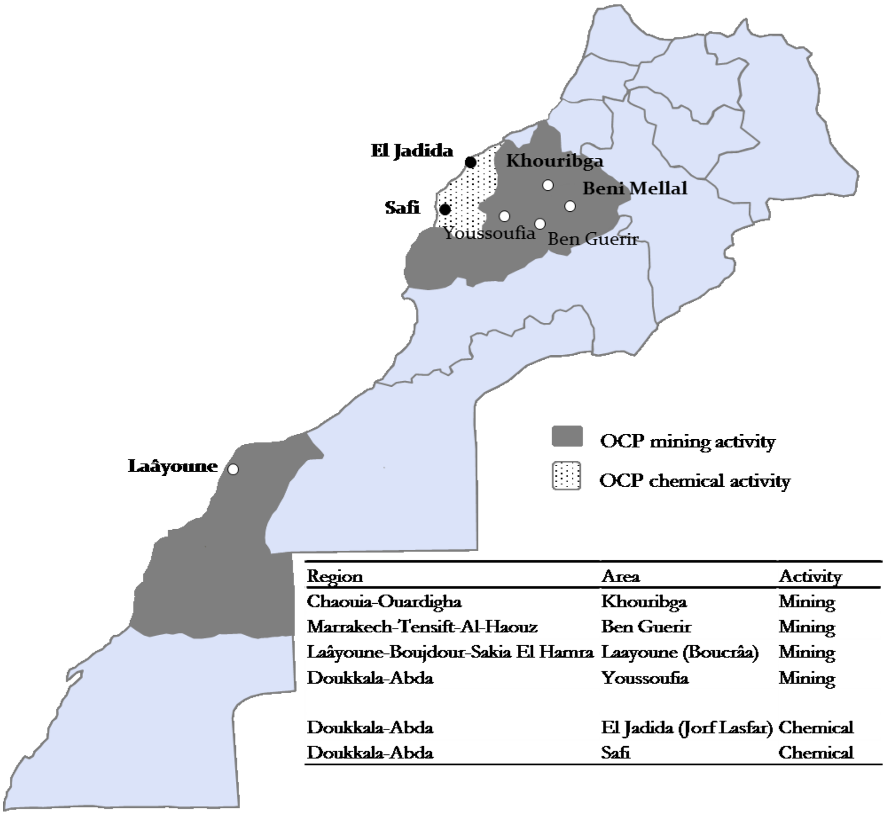
Sources: Author's calculations based on data from Office des Changes and Finance Ministry

Table 3.1: Employment contribution of OCP's activities by region

	Employment (jobs)		
	All Industries	OCP sites	in %
Chaouia-Ouardigha	34 110	5574	16%
Marrakech-Tensift-Al-Haouz	21 177	1088	5%
Laâyoune-Boujdour-Sakia El Hamra	7105	1780	25%
Doukkala-Abda	27 781	9769	35%

Sources: Author's calculations based on data from Haut Commissariat aux Plans (HCP) and OCP Group.

Figure 3.5: Location of OCP Group's activities by region



3.2 Methodology and data

3.2.1 Input-output analysis

Input-output analysis, an analytical framework developed by Wassily Leontief in the late 1930s, represent the interdependencies between different branches (or industries or sectors) of a national economy or different regional economies (Leontief, 1936, 1951, 1986 and Thijs Ten Raa, 2010). Input-output analysis specifically shows how industries are linked together through supplying inputs for the output of an economy. Since it was initially developed, the framework has been continually improved and it is, today, one of the most applied methods in economics (Baumol, 2000). The advantage of the I-O framework is the easy-to-understand, transparent and very detailed picture it provides regarding the structure of the economy at a specific point of time, making disaggregated analyses possible. Another advantage is that the model does not incorporate any specific behavioral equations for individuals or companies so it is politically and ideologically neutral (Foran et al., 2005).

The model is widely applied to analyze impacts at both national and local levels. In recent years, the I-O model has been used to analyze the effects of investments in South Africa (L.C. Stilwell et al., 2000), Chile (Aroca, 2001) and North Sweden (Ejdemo and Söderholm, 2011). At local level, we find an abundant literature using regional I-O tables based model to estimate the economic impacts of mining activities (Lagos and Blanco, 2010; Pascó-Font et al., 2001; Castillo et al., 2001; Eggert, 2001; Tonts, 2010; Ivanova and Rolfe, 2011; Rolfe et al., 2011; Xu et al., 2011; Tianya Qi et al., 2012).

The I-O model is used in this study to describe the interactions between the phosphate mining and fertilizers sectors and the rest of the economy at a national level. We note that the Moroccan National Statistics Office (HCP[9]) does not publish I-O tables at a regional level. By using the model, we will evaluate direct, indirect (by associated industries) and induced (by households income spending interactions) effects of a change in final demand for a particular product (i.e. for OCP Group, it could be a new export demand for phosphate rock or for fertilizers).

3.2.2 I-O table

The I-O model is based on the input-output table (presented in detail in Appendix B.4) which, in general, can be divided vertically according to the type of demand (inter-industry demands and final demands) and horizontally according to the type of input (domestic intermediate goods, domestic primary factors of production and imports). The rows describe the distribution of a producer's output throughout the economy. The columns describe the composition of inputs required by a particular industry to produce its output. In others words, the rows of an I-O table shows "who gives to whom" and its columns shows "who receives from whom" in economic sectors (Kerschner and Hubacek, 2009). These inter-industry exchanges of goods constitute the *endogenous* section of the table. The additional columns, labeled Final Demand, record the sales by each sector to purchasers (or final users) who are external or *exogenous* to the industrial sectors that constitute the producers in the economy, such as households, government, and foreign trade (rest of the world). The additional rows, labeled Value Added, account for the other (non-industrial) inputs to production (Miller and Blair, 2009). The Moroccan I-O table contain 19 sectors (Table 3.2).

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[9] Haut-Commissariat au Plan (www.hcp.ma)

Table 3.2: Sectors classifications in Moroccan I-O table

N°	Code	Sector
1	A00	Agriculture and forestry
2	B05	Fishing and aquaculture
3	C00	Food products, beverages and tobacco
4	D01	Textiles and leather
5	D02	Chemicals and chemical products
6	D03	Mecanical, metallical and electrical industries
7	D04	Other manufacturing industries
8	D05	Refined petroleum and other energy products
9	D06	Electricity and water supply
10	E00	Construction
11	F45	Wholesale and retail trade
12	G00	Hotels and restaurants
13	H55	Transport
14	I01	Post and telecommunications
15	I02	Financial activities and Insurance
16	J00	Real estate activities
17	K00	Public administration and social security
18	L75	Education, health and social work
19	MNO	Other non-financial services

Source: Moroccan Classification of Activities, NMA, 2010 (HCP)

3.2.3 Establishing the I-O table with OCP activities

The present analysis is based on a dataset composed of the following informations:

- The latest Moroccan Input-Output tables of the morocan economy in 2014 (evaluation at current prices and expressed in millions MAD) (HCP, National Accounts 2015)
- The detailed data from OCP's Profit and Loss (P&L) statement (OCP, Financial Report 2014 and internal data). OCP's data show : i) the detailed expenditure on domestic inputs and employee's wages and salaries for exploration, extraction, development and transformation activities; ii) imports of intermediate inputs and exports of final products; iii) taxes, dividends and others financial contributions to the Governement revenues; iv) the voluntary expenditures on local communities such as infrastructures, education, social actions, sports and other sponsoring activities.

Since our focus is on OCP's activities (mining and chemicals) and thier linkages, we have added to the I-O table two columns in order to separately show "*OCP-Mining"* activity [coded: C00-OCP] and "*OCP-Chemical"* activity [coded: D02-OCP], and two lines to represent "*phosphate rock"* product and "*phosphate fertilizers"* products respectively. We use OCP data to split intermediate purchases and sales, final demand decomposition and primary inputs components. Taking these facts into account along the data availability, we have constructed a 21x21 sectors (for an open system with respect to households) and a 22x22 sectors (for closed system) I-O flow table for the present study. The additional sector in the closed system contains "Households" activities. We will explain the difference between an open and a closed system in the next section.

3.2.4 I-O Model

An I-O model shows the relationship between the productive sectors. By showing details of the flow of goods and services among industries, the model describe the process of production, the use of goods and services and the income generated in the production process. Under some assumptions such as constant returns to scale, linearity, sector homogeneity and no capacity constraints and by assuming that the economy can be categorized into *n* sectors, the relationship between productive sectors and final demand[10] in an open system can be expressed as follows:

$$x_j = \sum_{i=1}^{n} z_{ij} + f_j = \sum_{i=1}^{n} a_{ij}x_j + f_j \qquad (3.1)$$

Where x_j is the total output (production) of sector j; f_j is the final demand for sector j's product and z_{ij} represents inter-industry sales by sector i (also known as intermediate sales) to sector j (including itself, when j = i). The terms z_{ij} can be expressed as a multiplication of sector j's production and a_{ij}. Coefficients a_{ij} ($a_{ij} = z_{ij}/x_j$) represent the technical I-O coefficient or the proportion of input i used per unit output of product j.

In simpler matrix notation, the system in (3.1) can be written as:

$$X = AX + F \qquad (3.2)$$

The I-O coefficients matrix (A) is used to estimate output, income and employment effects and linkages measures for the various sectors, which are expected to have linkages with OCP's activities.

In addition, if we can assume that the matrix A is non-negative, productive and (I-A) is singular[11] (Waugh 1950), the output can be written as an equation of final demand

$$X = (I - A)^{-1}F = LF \qquad (3.3)$$

With $(I - A)^{-1} = L = [l_{ij}]$ is the so-called Leontief inverse. This inverse represents the sum of direct and indirect effects from unitary changes in the exogenous vector, culminating in a matrix of multipliers:

$$(I - A)^{-1} = (I + A + A^2 + \cdots + A^{\infty}) \qquad (3.4)$$

Combining (3.3) and (3.4), we obtain:

$$X = F + AF + A^2F + \cdots + A^{\infty}F \qquad (3.5)$$

Equation (3.5) shows how the output of each sector is generated "round" by "round" to satisfy a given final demand (F) and how industrial interdependencies take place in the economy "down the

[10] The final demand includes domestic final demand (Consumption, investments and government expenditures) and foreign final demand (exports).

[11] known as the *Hawkins–Simon condition (*see also Nikaido, 1970)

stream". The equation give also a picture of the consolidated structure of the economy's production chains.

Table 3.3 reports the estimated technical coefficients for OCP-mining and OCP-chemical activities. The table contains two sets of technical coefficients for the both OCP activities. The first two columns show the technical coefficients for intermediate purchases by OCP Group from others sectors. The two last columns give technical coefficients for intermediate sales of OCP group to others sectors. Technical coefficients less than 0,001 (a_{ij}<0,001) are supposed to be not significants. The results point to a lack of linkage between mining activities and the rest of the Moroccan economy compared to chemical activities in terms of intermediate purchases. Export demand for fertilizers generates a significant effect for 12 sectors in the economy while export demand for phosphate rock generates a significant effect for 8 sectors. The sum of the technical coefficients for both OCP-Mining and OCP-Chemical activities is 34% lower than the average of 0,646 for all 22 sectors in the I-O table. In terms of intermediate sales, the OCP-Mining sector sold 0,202 unit per output unit to its downstream industry. Inter-industry sales of OCP-chemical products are mainly confined to the agriculture sector as fertilizers and the OCP-chemical sector itself in the form of sulfur acid and phosphoric acid. The sum of technical coefficients (total intermediate sales) for OCP-Mining and OCP-chemical sectors is 30% below average (0,646). The whole I-O coefficients table for Moroccan economy for 2014 is reported in Appendix B.6.

Table 3.3: Technical coefficients for the mining and chemical activities, 2014 (bold type indicates coefficients >0,001)

OCP Group purchases from the sectors below and OCP Group sales to the sectors below	Intermediate purchases of OCP Group activities		Intermediate sales of OCP Group activities	
	Mining	Chemical	Mining	Chemical
Agriculture and forestry	0,0000	0,0000	0,0000	**0,1733**
Fishing and aquaculture	0,0000	0,0000	0,0000	0,0000
Mining industry	0,0000	0,0000	0,0000	0,0000
OCP-Mining	0,0000	**0,2022**	0,0000	0,0000
Food products, beverages and tobacco	0,0000	0,0000	0,0000	0,0000
Textiles and leather	0,0000	0,0000	0,0000	0,0000
Chemicals and chemical products	**0,0077**	**0,0044**	0,0000	0,0000
OCP-Chemical	0,0000	**0,0827**	**0,2022**	**0,0827**
Mecanical, metallical and electrical industries	**0,0026**	**0,0029**	0,0000	0,0000
Other manufacturing industries	**0,0054**	**0,0072**	0,0000	0,0000
Refined petroleum and other energy products	**0,0383**	**0,0075**	0,0000	0,0000
Electricity and water supply	**0,0114**	**0,0163**	0,0000	0,0000
Construction	0,0000	0,0000	0,0000	0,0000
Wholesale and retail trade	0,0000	0,0000	0,0000	0,0000
Hotels and restaurants	0,0003	**0,0014**	0,0000	0,0000
Transport	**0,0156**	**0,0029**	0,0000	0,0000
Post and telecommunications	0,0005	0,0009	0,0000	0,0000
Financial activities and Insurance	0,0010	**0,0018**	0,0000	0,0000
Real estate activities	**0,0036**	**0,0031**	0,0000	0,0000
Public administration and social security	0,0000	0,0000	0,0000	0,0000
Education, health and social work	0,0000	0,0000	0,0000	0,0000
Other non-financial services	**0,0020**	**0,0017**	0,0000	0,0000
Total intermediate purchases/sales	**0,0886**	**0,3350**	**0,2022**	**0,2560**

Source: Author's calculations.

3.2.5 Limits of the I-O model

Like every model, the static I-O model has a number of limitations relating to its basic assumptions. One major limitation mainly when used in impact analysis, lies in the fixed coefficients assumption which implyies that the amount of each input necessary to produce one unit of each output is constant. No consideration is made with regards to price effects, changing technology or economies of scale. An other major limitation is the lack of supply constraints. Supply is assumed to be infinite and perfectly elastic (OECD, 1992)[12]. Sometimes these limitations can be overcame by using some extensions. That is the case for the analysis of environmental and energy problems (Miller and Blair, 2009). Other extensions require changes to the model structure by introducing a time dimension (dynamic I-O model) to track both inter-temporal and inter-sectoral relationships.

3.3 I-O techniques to estimate the impact of increased phosphate mining and valorization activities

The economic impacts of a change in final demand are estimated through the multipliers and linkage measures. By using I-O model, we can decompose the final impact in three components: Direct, Indirect and Induced effects. For any an increase in **final demand** for a particular product (i.e for OCP group, it could be a new export demand for phosphate rock or for fertilizers), there will be an increase in the output of that product as the producers react to meet the increased demand; this is the **direct effect**. As these producers increase their output, there will also be an increase in demand on their suppliers and so on down the supply chain; this is the **indirect effect**. In parallel of the direct and indirect effects, the employment will increase and therefore the level household income throughout the economy will increase. A proportion of this increased income will be re-spent on final goods and services: this is the **induced effect**. Direct and indirect effects are estimated from open system and induced effect is estimated from closed system.

3.3.1 Multipliers

One of the major uses of the I-O model is to estimate the effects of exogenous changes, in a given sector, on i) the outputs of other sectors in the economy, ii) income earned by households in each sector and iii) employment (jobs, measured in physical unit) that is expected to be generated in each sector.

By using I-O models, these effects are represented through, respectively, output, income and employment multipliers. The notion of multipliers represent the magnitude of an exogenous change between the initial situation and the total effects of that change. The total effects can be defined as the direct and indirect effects (when we use open system) or as direct, indirect and induced effects (when we use closed system). The multipliers that incorporate direct and indirect effects are known as simple multipliers. When direct, indirect and induced effects are captured, they are often called total multipliers.

[12] See for Appendix B.5 more details.

Output multiplier

An output multiplier for sector j is defined as the change in the total economy output resulting from a unit change in final demand for sector j's output. In general, there are two types of output multipliers: a *Simple Output Multiplier* and the *Total Output Multiplier*. The first one is obtained from a model with households exogenous (open system) and it is defined as a ratio of the direct and indirect effect to the initial effect. Formally, as we assume constant returns to scale, this multiplier is obtained by the flowing formula:

$$m(o)_j = i'(I-A)^{-1} = \sum_{i=1}^{n} l_{ij} \tag{3.6}$$

where i' is the transpose unit vector using here to generate the j column sum of the Leontief inverse.

The second one is derived from a closed I-O model matrix with respect to households (i.e the households are considered as an *endogenous* sector).The Total Output Multiplier capture direct and indirect effects and the additional induced effects that generating by households –as consumers-demand on goods and services. Similarly, the total output multiplier, for sector j, is given by

$$\breve{m}(o)_j = i'(I-\breve{A})^{-1} = \sum_{i=1}^{n+1} \breve{l}_{ij} \tag{3.7}$$

here $[\breve{l}_{ij}]$ is the augmented coefficient matrix, with an add household's row and column.

Income and Employment Multipliers

In order to analyze the economic impacts of a change in final demand in terms of employment, jobs needed to satisfy this additional demand, measured in physical units (the employment multiplier) or in monetary units (the income multiplier), can be computed using the I-O approach. Both multipliers are computed using the same approach, the only difference lays in the unit of the L matrix elements (monetary or physical units). Income multiplier measures the income generated in the economy by a unit change in final demand. It is calculating by the ratio of total direct and indirect income effects to the direct income effect. In general, for the *simple* household income multiplier for sector j,

$$m(h)_j = \sum_{i=1}^{n} a_{n+1,i} l_{ij} \tag{3.8}$$

with, $a_{n+1,i} = z_{n+1,i}/x_j$ indicating household income received per dollars' worth of sector output.

As before, we can also calculate the *total* (direct plus indirect plus induced) household income effects for sector j using the augmented coefficient matrix by

$$\breve{m}(h)_j = \sum_{i=1}^{n+1} a_{n+1,i}\breve{l}_{ij} \quad (3.9)$$

3.3.2 Backward and forward linkage

Another application of the I-O models is linkage analysis, which analyses the backward and forward linkages of each industry. An industry's backward and forward linkages measure the industry's economic interdependence with other industries along the supply chain. The direction of interconnection with the *upstream* sectors from which the sector j purchases its inputs is called **backward** linkage. The increased output in sector j also means that additional product j which can be used as inputs to other sectors as inputs. This direction of interconnection with the *downstream* sectors from which the sector j sells its outputs is called **forward** linkage. To calculate the linkage measures, we use the formulas given in Table 3.4.

Table 3.4: Linkage Measures

	Backward linkage	Forward linkage
Direct	$BL(d)_j = \sum_{i=1}^{n} a_{ij}$	$FL(d)_i = \sum_{j=1}^{n} b_{ij}$
Total	$BL(t)_j = \sum_{i=1}^{n} l_{ij}$ [13]	$FL(t)_i = \sum_{j=1}^{n} g_{ij}$ [14]

According to Hirschman (1958), we use normalized linkages to compare how closely linked sectors are with each other. In this case, sector j's backward (forward) linkage is divided by the simple average of all backward (forward) linkages. The average value of normalized backward (forward) linkages is equal to unity.

3.4 Results

3.4.1 Output multipliers

Column (1) of Table 3.5 shows the direct output effect for each of the industries. The result indicates that for one additional dollar for OCP products, the output of OCP group increases by 0,202US$ if the new order is for the phosphate rock and by 0,256US$ if the new order is for the fertilizer products. In column (2) of Table 3.5, we show the combined direct and indirect output change for one additional dollar of final demand for the various sectors in Moroccan economy. The estimation indicates that the output will rise by 1,299US$ as result of one additional dollar increase in the final demand for phosphate rock and by 1,481US$ for fertilizer products. The Column (3) of au-dessous shows the combined direct, indirect, and induced output effects for each of the industries in turn. As the results show, an additional dollar of exogenous final demand for the fertilizers will generate 2,611 US$ in overall production from all sectors in the economy. The

[13] The elements l_{ij} from the Leontief inverse $L = (I - A)^{-1}$ are colled the input inverse

[14] The elements g_{ij} from the Ghosh inverse $= (I - B)^{-1}$, are interpreted as measuring "the total value of production that comes about in sector j per unit of primary input in sector i." (Augustinovics, 1970, p. 252.)

effect for phosphate rock is 1,729US$. Comparing the results obtained from these output multipliers, we observe that the added household endogeneity has generated a consistent impact in terms of the magnitude of the multiplier effects for OCP chemical activity compare to OCP mining activity. We also note that the additional induced effects cause a significant changes in terms of the relative ranking amongst sectors (column (5) and (6) of Table 3.5). The decomposition of the OCP's total output multipliers by activity is reported in Table 3.6. The result suggest that an additional 1US$ of final demand for OCP products, generate a changes in output of major sector of the economy. This can be interpreted as a measure of linkage of OCP group and the rest of the economy.

Table 3.5: Output Multipliers[a] for different sectors in Morocco with a focus on OCP activities

N°	Sector	Direct Effect	Direct & Indirect Effect	Direct, Indirect & Induced Effect	Rank for Col (1)	Rank for Col (2)	Rank for Col (3)
		(1)	(2)	(3)	(4)	(5)	(6)
1	Agriculture and forestry	0,634	2,067	7,794	(5)	(7)	(2)
2	Fishing and aquaculture	0,491	1,789	3,179	(10)	(11)	(10)
3	**OCP Mining**	**0,202**	**1,299**	**1,729**	**(17)**	**(16)**	**(20)**
4	Food products, beverages and tobacco	0,277	1,452	2,172	(12)	(15)	(17)
5	Textiles and leather	0,582	2,381	5,608	(6)	(6)	(4)
6	Chemicals and chemical products	1,735	6,603	10,399	(1)	(1)	(1)
7	**OCP Chemical**	**0,256**	**1,481**	**2,611**	**(13)**	**(14)**	**(15)**
8	Mecanical, metallical and electrical industries	0,945	3,638	4,657	(4)	(3)	(5)
9	Other manufacturing industries	1,179	3,088	4,388	(3)	(4)	(6)
10	Refined petroleum and other energy products	1,448	4,379	5,815	(2)	(2)	(3)
11	Electricity and water supply	0,512	1,909	3,721	(8)	(9)	(9)
12	Construction	0,033	1,061	2,757	(20)	(19)	(13)
13	Wholesale and retail trade	0,036	1,040	4,218	(19)	(20)	(8)
14	Hotels and restaurants	0,209	1,289	3,087	(15)	(17)	(12)
15	Transport	0,226	1,542	3,170	(14)	(12)	(11)
16	Post and telecommunications	0,191	1,272	1,460	(18)	(18)	(22)
17	Financial activities and Insurance	0,526	1,953	2,621	(7)	(8)	(14)
18	Real estate activities	0,495	1,849	2,026	(9)	(10)	(18)
19	Public administration and social security	0,000	1,000	1,976	(22)	(22)	(19)
20	Education, health and social work	0,021	1,028	2,523	(21)	(21)	(16)
21	Other non-financial services	0,203	1,510	1,641	(16)	(13)	(21)
-	**OCP activities[b]**	**0,458**	**2,780**	**4,339**	**(11)**	**(5)**	**(7)**

[a]The multipliers show the direct, indirect and induced effects on output of a one dollar increase in exogenous final demand. For instance, a one dollar increase in demand for phosphate fertilizer would generate 2,611 dollars in total national production.
[b] The multipliers show the impact on output of a one dollar increase in demand for phosphate rock and a one dollar increase in demand for phosphate fertilizer simutanisouly.
Source: Author's calculations.

Table 3.6: Decomposition of the OCP's total output multipliers by activity

N°	Sector	OCP Mining		OCP Chemicals	
		Total effect*	(Rank)	Total effect*	(Rank)
1	Agriculture and forestry	0,008	(19)	0,121	(3)
2	Fishing and aquaculture	0,003	(22)	0,007	(22)
3	**OCP Mining & others extractive industries**	1,000	(1)	0,008	(21)
4	Food products, beverages and tobacco	0,056	(4)	0,114	(4)
5	Textiles and leather	0,020	(7)	0,056	(7)
6	Chemicals and chemical products	0,009	(18)	0,024	(18)
7	**OCP Chemical**	0,219	(2)	1,085	(1)
8	Mecanical, metallical and electrical industries	0,028	(5)	0,080	(5)
9	Other manufacturing industries	0,020	(8)	0,055	(8)
10	Refined petroleum and other energy products	0,014	(11)	0,041	(11)
11	Electricity and water supply	0,010	(16)	0,030	(16)
12	Construction	0,021	(6)	0,060	(6)
13	Wholesale and retail trade	0,013	(13)	0,035	(13)
14	Hotels and restaurants	0,012	(14)	0,033	(15)
15	Transport	0,019	(9)	0,055	(9)
16	Post and telecommunications	0,012	(15)	0,034	(14)
17	Financial activities and Insurance	0,014	(12)	0,041	(12)
18	Real estate activities	0,018	(10)	0,052	(10)
19	Public administration and social security	0,010	(17)	0,027	(17)
20	Education, health and social work	0,008	(20)	0,022	(19)
21	Other non-financial services	0,007	(21)	0,020	(20)
22	Households	0,210	(3)	0,610	(2)
-	**Total OCP activities**	**1,729**		**2,611**	

(*) Total effect= Direct + Indirect + Induced effects
Source: Author's calculations.

3.4.2 Income multipliers

Table 3.7 shows the Direct, indirect and induced income multipliers for all sectors in the economy. The results show that, for instance, every additional one dollar increase in demand for the phosphate rock would result immediately in a rise of 0,149US$ in income OCP mining sector. We note also that the income will rise by 0,162US$ for OCP chemical sector in response for an equivalent change in final demand for fertilizers. As an increase of final demand for a particular sector's product implies an expansion of output in sectors that are directly and indirectly linked to the industry experiencing the change in demand. In column (2) of Table 3.7, we show the combined direct and indirect income change for one US$ change of final demand for the various industries in morocco. For example, the data for OCP mining sector indicates that the income will rise by 0,711US$ as result of an increase in the demand for phosphate rock. Similarly, we can see for the OCP chemical sector, the corresponding income increase is 0,980US$. This rise in income stimulate a further change in consumption expenditures and generate further rounds. Column (3) of Table 3.7 shows the combined direct, indirect, and induced income effects for each sector. As the results show, the total income effect for OCP mining sector is 2,253 US$ and for OCP chemical sector is 3,109 US$. According to our estimates, the ranks of OCP mining and OCP chemical sectors are respectively 9 and 3 among the 21 sectors in the economy.

Table 3.7: Income Multipliers(a) for different sectors in Morocco with a focus on OCP activities

N°	Sector	Direct Effect	Direct & Indirect Effect	Direct, Indirect & Induced Effect	Rank for Col (1)	Rank for Col (2)	Rank for Col (3)
		(1)	(2)	(3)	(4)	(5)	(6)
1	Agriculture and forestry	0,214	0,939	2,978	(6)	(4)	(4)
2	Fishing and aquaculture	0,120	0,411	1,302	(11)	(18)	(18)
3	**OCP Mining**	**0,149**	**0,711**	**2,253**	**(10)**	**(9)**	**(9)**
4	Food products, beverages and tobacco	0,110	0,445	1,410	(13)	(17)	(17)
5	Textiles and leather	0,111	0,455	1,442	(12)	(16)	(16)
6	Chemicals and chemical products	0,094	0,031	0,100	(14)	(22)	(22)
7	**OCP Chemical**	**0,162**	**0,980**	**3,109**	**(9)**	**(3)**	**(3)**
8	Mecanical, metallical and electrical industries	0,239	0,848	2,689	(4)	(6)	(6)
9	Other manufacturing industries	0,342	0,850	2,694	(2)	(5)	(5)
10	Refined petroleum and other energy products	0,495	0,818	2,593	(1)	(8)	(8)
11	Electricity and water supply	0,168	0,541	1,714	(8)	(12)	(12)
12	Construction	0,010	0,301	0,954	(19)	(19)	(19)
13	Wholesale and retail trade	0,006	0,495	1,569	(20)	(13)	(13)
14	Hotels and restaurants	0,051	0,472	1,496	(18)	(15)	(15)
15	Transport	0,085	0,482	1,527	(15)	(14)	(14)
16	Post and telecommunications	0,059	0,608	1,927	(17)	(10)	(10)
17	Financial activities and Insurance	0,229	0,822	2,607	(5)	(7)	(7)
18	Real estate activities	0,175	1,004	3,184	(7)	(2)	(2)
19	Public administration and social security	0,000	0,098	0,311	(22)	(21)	(21)
20	Education, health and social work	0,006	0,169	0,536	(21)	(20)	(20)
21	Other non-financial services	0,068	0,597	1,892	(16)	(11)	(11)
-	**OCP activities(b)**	**0,311**	**1,691**	**5,362**	**(3)**	**(1)**	**(1)**

(a)The multipliers show the direct, indirect and induced effects on income of a one US$ increase in exogeneous final demand. For instance, a one US$ increase in demand for phosphate fertilizer would generate 3,109US$ in total national economy.
(b)The multipliers show the impact on income of a one dollar increase in demand for phosphate rock and a one dollar increase in demand for phosphate fertilizer simutanisouly.
Source: Author's calculations.

3.4.3 Employment multipliers

Similar to three income effects, we have also estimated three employment effects for the 21 sectors. Here also, we assume that the change in final demand consists of one million MAD increase in final demand for a given industry' output by the final consumers. The column (1) of Table 3.8 shows the direct employment effects for each of the industries. A value of 5 for OCP chemical sector means that employment of about 5 man-years is generated in this sector as a result of increase in export demand by one million MAD for this sector's output. The result indicate that the direct effect of one million MAD change in final demand for phosphate rock is not significant in term of employment generated by OCP mining activity (just 0,5 man-years). Column (2) of Table 3.8 shows the direct plus indirect employment impacts as the industries adjust their outputs to meet the additional demand. The employment multipliers for the OCP chemical sector is 7 jobs while the OCP mining sectors have employment multiplier of about 2 man-year.

We have also estimated employment effects associated with the induced consumption-income interactions by the similar procedure used to compute the income multipliers. The results show that in total 8 jobs is generated in response of a change in final demand for fertilizers when the computation of employment expansion multiplier takes into account the changes which takes place as a result of the increase in income and consumption (see column (3) of Table 3.8). The corresponding value for the OCP mining sector is 3 man-years. The ranks of OCP chemical and OCP mining sectors are respectively 17 and 21 respectively.

Table 3.8: Employment Multipliers[(a)] for different sectors in Morocco with a focus on OCP activities

N°	Sector	Direct Effect	Direct & Indirect Effect	Direct, Indirect & Induced Effect	Rank for Col (1)	Rank for Col (2)	Rank for Col (3)
		(1)	(2)	(3)	(4)	(5)	(6)
1	Agriculture and forestry	5	35	38	(4)	(2)	(2)
2	Fishing and aquaculture	2	10	15	(14)	(10)	(11)
3	**OCP Mining**	**0**	**2**	**3**	**(21)**	**(21)**	**(21)**
4	Food products, beverages and tobacco	3	6	6	(10)	(17)	(18)
5	Textiles and leather	4	17	30	(7)	(4)	(3)
6	Chemicals and chemical products	12	46	48	(1)	(1)	(1)
7	**OCP Chemical**	**5**	**7**	**8**	**(6)**	**(15)**	**(17)**
8	Mecanical, metallical and electrical industries	4	13	15	(8)	(8)	(10)
9	Other manufacturing industries	7	15	18	(3)	(6)	(7)
10	Refined petroleum and other energy products	11	26	20	(2)	(3)	(5)
11	Electricity and water supply	3	15	19	(9)	(5)	(6)
12	Construction	0	8	15	(18)	(14)	(12)
13	Wholesale and retail trade	0	14	27	(19)	(7)	(4)
14	Hotels and restaurants	1	10	17	(17)	(11)	(8)
15	Transport	2	11	16	(13)	(9)	(9)
16	Post and telecommunications	1	2	3	(15)	(22)	(22)
17	Financial activities and Insurance	3	8	10	(12)	(13)	(15)
18	Real estate activities	3	5	5	(11)	(18)	(19)
19	Public administration and social security	0	4	9	(22)	(19)	(16)
20	Education, health and social work	0	7	13	(20)	(16)	(13)
21	Other non-financial services	1	3	3	(16)	(20)	(20)
-	**OCP activities[(b)]**	**5**	**9**	**10**	**(5)**	**(12)**	**(14)**

[(a)]The multipliers show the direct, indirect and induced effects on employment of a one million MAD increase in exogenous final demand. For instance, a one million MAD increase in demand for phosphate fertilizer would generate 8 additional jobs in the economy (5 jobs from which in the OCP chemical units, 2 jobs in industries expected to have linkage with OCP chemical units and one additional job in other sectors associated with the secondary or induced consumption-income interactions).
[(b)]The multipliers show the impact on income of a one dollar increase in demand for phosphate rock and a one dollar increase in demand for phosphate fertilizer simutanisouly.
Source: Author's calculations.

3.4.4 Backward and forward linkages analysis

Table 3.9 presents two sets of the backward and forward linkages for each sector within the Moroccan economy. The first set of measures is derived from open system with no impact of households spending (open system). A broad examination of theses linkages within the Moroccan economy indicates that 'Chemical industy' has the highest direct backward linkage sore (2,33), followed by 'energy sector' (1,55), 'Mecanical, metallical and electrical industries' (1,28), 'Other manufacturing industries' (1,09) and 'OCP activities'(0,98). The intermediate direct backward linkage of OCP activities is mainly due to weak linkage of OCP-Mining sector. As we have seen in Table 3.3, extraction activity does not require more intermediate inputs from others sectors. In term of direct forward linkages, what is of interest is that within the wider Moroccan economy, 'OCP activities' sectors are occupied the second place as the strongest forward linkages sectors. This because two reason. The first one is phosphate rock (output of OCP-Mining sector) is used as intermediate input for OCP-Chemical sector. The second reason is that sulfur acid and phosphoric acid are used as intermediate input by OCP-chemical sector itself and fertilizers are also used as intermediate input by agriculture sector.

To continue the analysis, the second set of linkages measures is computed with endogeneity of households spending (open system). From Table 3.9, one can see that the two OCP sectors are ranked within the top 10 with the strongest backward linkages. The magnitude of the OCP chemical sector backward linkage is 1,19US$. This implies that for every 1US$ produced within the OCP chemical sector, 0,19US$ is backward linked to its direct, indirect and induced downstream suppliers. The story is very different when we examine the total forward linkages. As result shows, OCP sectors are not within the most forward linkages sectors in Moroccan economy. We find that the intensive employment sectors (e.g. Chemicals industry; Food products, beverages and tobacco and textiles; Hotels and restaurants; Education, health and social work and Energy sectors) generates the largest upstream impacts. The weakness total forward linkage of OCP activities is because OCP-chemical products (phosphoric acid and fertilizers) are mostly exported and the additional household's income is spending in goods and services produced by non-OCP activities related sectors.

Table 3.9: Comparison of backward and forward linkages (Direct and Total measures)

	Sector	Open System				Closed System			
		Direct Backward Linkage	Rank	Direct Forward Linkage	Rank	Total Backward Linkage	Rank	Total Forward Linkage	Rank
1	Agriculture and forestry	0,7*	(7)	0,8*	(14)	1,2***	(6)	1,0**	(12)
2	Fishing and aquaculture	0,6*	(11)	0,8*	(16)	0,6*	(17)	0,8*	(16)
3	**OCP Mining**	0,5*	**(16)**	0,9**	**(11)**	0,9**	**(9)**	0,6*	**(18)**
4	Food products, beverages and tobacco	0,5*	(15)	1,1***	(8)	0,6*	(19)	1,7***	(2)
5	Textiles and leather	0,8*	(6)	1,5***	(3)	0,8*	(14)	1,5***	(3)
6	Chemicals and chemical products	2,3***	(1)	2,0***	(1)	0,8*	(10)	1,9***	(1)
7	**OCP Chemical**	0,5*	**(14)**	0,7*	**(20)**	1,2***	**(7)**	0,3*	**(22)**
8	Mecanical, metallical and electrical industries	1,3***	(3)	1,5***	(4)	1,3***	(3)	1,1***	(11)
9	Other manufacturing industries	1,1***	(4)	1,4***	(5)	1,2***	(5)	1,2***	(8)
10	Refined petroleum and other energy products	1,5***	(2)	1,3***	(6)	1,4***	(2)	1,4***	(5)
11	Electricity and water supply	0,7*	(9)	1,0***	(10)	0,8*	(12)	1,2***	(9)
12	Construction	0,4	(19)	1,3***	(7)	0,4	(20)	0,8*	(15)
13	Wholesale and retail trade	0,4	(20)	0,9**	(12)	0,6*	(18)	0,6*	(19)
14	Hotels and restaurants	0,5*	(17)	0,9**	(13)	0,6*	(16)	1,5***	(4)
15	Transport	0,5*	(12)	1,0***	(9)	0,7*	(15)	1,1***	(10)
16	Post and telecommunications	0,4	(18)	0,8*	(15)	0,8*	(13)	1,3***	(7)
17	Financial activities and Insurance	0,7*	(8)	0,7*	(19)	1,1***	(8)	0,9**	(14)
18	Real estate activities	0,7*	(10)	0,6*	(22)	1,3***	(4)	0,6*	(17)
19	Public administration and social security	0,4*	(22)	0,7*	(18)	0,2*	(22)	0,4*	(20)
20	Education, health and social work	0,4*	(21)	0,6*	(21)	0,3*	(21)	0,4*	(21)
21	Other non-financial services	0,5*	(13)	0,8*	(17)	0,8*	(11)	1,4***	(6)
-	**OCP activities**	**1,0****	**(5)**	**1,6*****	**(2)**	**2,1*****	**(1)**	**0,9****	**(13)**

Linkages are ranked as either strong, intermediate or weak:
(***) Strong if Linkage index > 1; (**) Intermediate if 0,9 ≤ linkage index ≤ 1; (*) Weak if Linkage index < 0,9.
Source: Author's calculations.

3.5 Conclusion

This Chapter attempted to evaluate the macroeconomic impact arising from the OCP activities within the overall economy using an Input-Output Analysis model. We have combined the detailed Profit and Loss (P&L) statement from OCP group with the latest 2014 Moroccan I-O table to bring out OCP activities and to split them into two sectors: "OCP-Mining" and "OCP chemical". Two types of I-O models, open and closed models, were estimated to measure the direct, indirect and induced effects of a change in final demand for OCP products. The difference between open and closed models is that the open model is estimated with households exogenous, while the closed model uses households as endogenous. Several multipliers, such as output, income and employment multipliers were estimated as well as backward and forward linkages measures for all 21 sectors in the economy. The output, income and employment multipliers results are presented in Table 3.5, Table 3.7 and Table 3.8. The backward and forward linkages results are shown in Table 3.9. These detailed measures are useful for OCP group decision makers and for national policy makers and planners who need to know in which sectors output, income and employment changes will be more significant.

Although the OCP activities as whole has a significant macroeconomic contribution in the Moroccan economy as shown in the Figure 3.1, Figure 3.2, Figure 3.3 and Figure 3.4 , this study found that there are some differences between the OCP-mining and OCP-chemical sectors. Our results indicate that the OCP-chemical sector has a high production-inducing effect and a high income and employment-inducing effect compared to OCP-mining sector. The OCP-chemical sector impact on output implies that for each US$ sold fertilizers generate 2,61US$ in the Moroccan economy while the same amount demand for phosphate rock generate just 1,73US$. In term of income, OCP-chemical activity generate 3,11US$ for each US$ increase for the sector's product. On the other hand, OCP-mining impact on income is equal to 2,25US$. In addition, the result show that OCP-chemical sector has more capacity to generate employment opportunities on a large scale compare to the OCP-mining sector. The total employment multiplier is equal to 8 man-years for OCP-chemical sector while it is about 3 man-years for OCP-mining sector. This result is justified by the lower linkage of OCP-mining activity. As we have shown in the Table 3.9, OCP-chemical sector is strongly backward linked with the others sectors of the economy compared to OCP-mining sector that is intermediately backward linked with the rest of the economy. The two OCP sectors are ranked within the top 10 sectors with the strongest backward linkages (rank of Total backward linkage in Table 3.9). However, their position, relative to other sectors, drop considerably when we take out the induced effect. This result demonstrates that households' additional (induced) income is spending mostly in goods and services produced by national industries. In addition, we note that the both OCP sectors have a low forward linkage effect. This is because the OCP products are mainly oriented to external market.

Finally, OCP group is engaging in important investment program during the period 2010-2020. This program aimed to increase significantly production capacity for its both mining and chemical activities, reducing production costs and increase flexibility by introducing new production tools and technologies. Also, OCP group announced that this investment program would have a positive impact on the environment and local communities (OCP group activity report, 2013). A future extensions of the framework presented in this paper will involve introducing a time dimension in the model (dynamic I-O model) in order to measure the socio-economic and environmental impacts of the OCP investment program.

3.6 References

- Aroca, P. (2001). Impacts and development in local economies based on mining:: the case of the Chilean II region. *Resources Policy*, *27*(2), 119-134.
- Augustinovics, M. (1970). Methods of international and intertemporal comparison of structure. *Contributions to input-output analysis*, *1*, 249-269.
- Baumol, W. J. (2000). Leontief's great leap forward: beyond Quesnay, Marx and von Bortkiewicz. *Economic Systems Research*, *12*(2), 141-152.
- Castillo, J., Sánchez, J. M., Kunze, V., & Araya, R. (2001). Chile: size does matter. *Large Mines and the Community*, 87-142.
- Eggert, R. G. (2001). Mining and economic sustainability: National economies and local communities. *A Study Prepared for the Mining, Minerals, and Sustainable Development Project, Colorado School of Mines*.
- Ejdemo, T., & Söderholm, P. (2011). Mining investment and regional development: A scenario-based assessment for Northern Sweden. *Resources Policy, 36(1),* 14-21.
- Foran, B., Lenzen, M., & Dey, C. (2005). Balancing act: a triple bottom line analysis of the Australian economy.
- Hirschman, A. O. (1958). *The strategy of economic development* (No. HD82 H49).
- Ivanova, G., & Rolfe, J. (2011). Using input-output analysis to estimate the impact of a coal industry expansion on regional and local economies. *Impact Assessment and Project Appraisal, 29(4),* 277-288.
- Kerschner, C., & Hubacek, K. (2009). Erratum to "Assessing the suitability of Input-Output analysis for enhancing our understanding of potential effects of Peak-Oil"[Energy (2008) 34: 284–290]. *Energy*, *34*(10), 1662-1668.
- Lagos, G., & Blanco, E. (2010). Mining and development in the region of Antofagasta. *Resources Policy*, *35*(4), 265-275.
- Leontief, W. (Ed.). (1986). *Input-output economics*. Oxford University Press.
- Leontief, W. W. (1936). Quantitative input and output relations in the economic systems of the United States. *The review of economic statistics*, 105-125.
- Leontief, W. W. (1951). *The structure of American economy, 1919-1939: an empirical application of equilibrium analysis* (No. HC106. 3 L3945 1951).
- Miller, R. E., & Blair, P. D. (2009). *Input-output analysis: foundations and extensions*. Cambridge university press.
- Nikaido, H. (1970). *Introduction to Sets and Mappings in Modern Economics*. New York: Elsevier. pp. 13–19. ISBN 0-444-10038-5.
- OECD. (1992). *Structural Change and Idustrial Performance : A Seven Country Growth Decomposition Study (OECD Documents)*. OECD Publishing, Paris.
- Pascó-Font, A., Hurtado, A. D., Damonte, G., Fort, R., & Salas, G. (2001). Peru: learning by doing. *Large Mines and the Community: Socioeconomic and Environmental Effects in Latin America, Canada and Spain*.
- Rolfe, J., Gregg, D., Ivanova, G., Lawrence, R., & Rynne, D. (2011). The economic contribution of the resources sector by regional areas in Queensland. *Economic Analysis and Policy*, *41*(1), 15.
- Stilwell, L. C., Minnitt, R. C. A., Monson, T. D., & Kuhn, G. (2000). An input–output analysis of the impact of mining on the South African economy. *Resources Policy*, *26*(1), 17-30.
- Ten Raa, T. (2010). *Input-output economics: theory and applications: featuring Asian economies*. World Scientific.
- Qi, T., Zhou, L., Zhang, X., & Ren, X. (2012). Regional economic output and employment impact of coal-to-liquids (CTL) industry in China: an input–output analysis. *Energy*, *46*(1), 259-263.
- Tonts, M. (2010). Labour market dynamics in resource dependent regions: an examination of the Western Australian goldfields. *Geographical Research*, *48*(2), 148-165.
- Waugh, F. V. (1950). Inversion of the Leontief matrix by power series. *Econometrica: Journal of the Econometric Society*, 142-154.
- Xu, T., Baosheng, Z., Lianyong, F., Masri, M., & Honarvar, A. (2011). Economic impacts and challenges of China's petroleum industry: an input–output analysis. *Energy*, *36*(5), 2905-2911.

3.7 Appendices B

Appendix B.1 : OCP Group Background

Founded

Established as a state owned company in 1920 and privatized in 2008.

Industry focus

Involved in exploration, mining and production of phosphates and fertilizers.

Scale

In 2014, the group employs a direct workforce of over 21,000 employees and generate revenues of US$ 4.9billion.

Global presence

OCP started its phosphate mining operations at Khouribga in 1921 and Youssoufia in 1931. Construction of the Benguerir mine began in 1974. In 1976, OCP took control of Phosboucraa, which operates its Bou Craa mine, around 400km south-west of its Gantour Hub. The company has long been the world's largest phosphate rock exporter, accounting for a stable market share above 30%. OCP has direct access to Morocco's reserves, accounting for about three quarters of the world's mineable phosphate. In addition to its extensive mining and beneficiation operations at the Khouribga and Gantour hubs, OCP produces

phosphoric acid and phosphate fertilizers at Jorf Lasfar and Safi, and is also engaged in a variety of JV and partnerships in Morocco and abroad.

Expansion program

The company is planning a huge downstream expansion in two phases - the Jorf Phosphate Hub 1-4 and 5-10 projects, which will be fed by the addition of new phosphate rock capacity at Ouled Fares and Extension Centrale Zone. The expansion program started since 2010, OCP included plans to raise downstream capacity to 4.8 Mt/year P_2O_5 and increase mining capacity to 50.0 Mt/year by 2020. The company aimed to connect its mining sites Khouribga and Gantour, with its units at Jorf Lasfar and Safi through a network of slurry pipelines.

Capacity of OCP group and its JVs by product, 2014

Product	Capacity (Mt)
Phosphate Rock	36,2
Phos. acid (P2O5)	5,165
DAP	3,417
MAP	2,597
TSP	1,366

Source, CRU Phosphate Rock and Fertilizers cost reports 2015 and 2016

Appendix B.2 : OCP-Mining activity (capacity, production and Target Market by site)

Site	Location	Start-up	Capacity (Mt)	Production (Mt)	Logistics	Target Market
Bou Craa	Lâayoune	1973	3,0	2,4	All rock mined at Bou Craa is conveyed to the beneficiation plant in Laâyoune (100km), adjacent to the Port of Laâyoune.	All of the rock mined at Bou Craa is exported (Canada, Russia and Oceania)
Gantour Hub	Youssoufia and Benguérir	1932	7,6	4,2	The Gantour mines are connected by railway to OCP's downstream facilities in Safi (90 km from Youssoufia and 160km from Benguérir). The Port of Safi is around 11km from the downstream plants and is also used for the direct export of rock.	Rock from Gantour is used for downstream processing in Safi Hub and the rest is exported via the port of Safi to North America and India.
Khouribga Hub	Khouribga	1922	25,6	19,0	Rock is pumped to Jorf Lasfar (Slurry Pipeline 235km) or railed to OCP's downstream facilities in Jorf Lasfar. Rock for export is directly railed to the Port of Casablanca (145km).	Rock from Khouribga is used for downstream processing in Jorf LAsfar Hub and the rest is exported via the port of Casablanca to North America and India.

Source, CRU Phosphate Rock and Fertilizers cost reports 2015 and 2016

Appendix B.3 : OCP-Chemical activity (capacity, production and Target Market by site)

Site	Location	Start-up	Capacity ('000tonnes)					Logistics	Target Market
			Sulphuric acid	Phos acid (P2O5)	DAP	MAP	TSP		
Maroc Chimie 1	Safi	1965	762	215	-	-	900	Phosphoric acid and TSP are railed 14 km to the Port of Safi for export.	OCP primarily supplies TSP to the South Asian (Bangladesh) and South American (Brazil) markets, phosphoric acid is mainly sold to the Indian market and feed phosphate is exported to Latin America, USA and Europe.
Maroc Chimie 2	Safi	1965	592	215	-	-	-		
Maroc Phosphore	Safi	1976	1 900	730	-	-	-		
Jorf Lasfar	Jorf Lasfar	1986	6 020	2 150	2 977	1 738	-	The finished products are conveyed approximately 2km to berths 1 and 2 at the Jorf Lasfar Port for export.	DAP is primarily exported to Europe, Turkey and USA. MAP is primarily exorted to Brazil
Indo Marco Phosphore (IMACID)	Jorf Lasfar	2000	1 200	430	-	-	-	Phosphoric acid is transported approximately 500 m to berth 6 at the Jorf Lasfar Port for export.	The Indo-Maroc Phosphore plant (IMACID) is a JV between OCP, Chambal Fertilizers and Tata Chemicals, which each own a third stake. All of the phosphoric acid produced is exported to Chambal's Indian production facilities for phosphate fertilizer granulation.
Pak-Maroc Phosphore (PMP)	Jorf Lasfar	2008	1 125	375	-	-	-	Phosphoric acid is transported approximately 500 m to berth 6 at the Jorf Lasfar Port for export.	The Pak-Maroc Phosphore plant (PMP) is a 50:50 JV between OCP and Fauji Fertilizers. Fauji has an exclusive contract with OCP for the import of 300,000 tonnes of phosphoric acid from PMP. The plant's remaining volume is sold on the merchant market.
Jorf Fertilizer Company V (JFCV)	Jorf Lasfar	2009	1 125	375	-	340	270	The finished products are conveyed 500 m to berths 1 and 2 at the Jorf Lasfar Port for export.	The Bunge Marco Phosphore plant was initially a 50:50 JV between OCP and Bunge Fertilizantes. In September 2013, OCP acquired Bunge's 50% stake and the plant was renamed JFC V. The finished product is primarily destined to the South American market, mainly to Brazil where it is distributed through OCP's subsidiary, OCP Fertilizantes, and Heringer, which OCP has a 10% stake in.
Jorf Lasfar (JPH 1-4)	Jorf Lasfar	2015	1 890	675	440	519	196	The finished products are conveyed approximately 2km to berths at the Jorf Lasfar Port for export.	DAP is mainly exported to Europe, USA, and MENA, while MAP to Brazil.

Source: Phosphate Fertilizer Cost Report 2016, CRU

Appendix B.4 : Input-Output Table

		Intermediate Users : Sectors/Industries					*Final Demand*				***Total Demand***
		1	...	*j*	...	*n*	*C*	*I*	*G*	*E*	***X***
Sales by:	*1*	X_{11}	...	X_{1j}	...	X_{1n}	C_1	I_1	G_1	E_1	$\mathbf{X_1}$
	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.
Sectors/ Industries	*i*	X_{i1}	...	X_{ij}	...	X_{in}	C_i	I_i	G_i	E_i	$\mathbf{X_i}$
	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.
	.	.	.	.	.	.	.	.	.	.	.
	n	X_{n1}	...	X_{nj}	...	X_{nn}	C_n	I_n	G_n	E_n	$\mathbf{X_n}$
Value-Added	*W*	W_1	...	W_j	...	W_n	W_C		W_G		***W***
	R	R_1	...	R_j	...	R_n					***R***
Imports	*M*	M_1	...	M_j	...	M_n	M_C	M_I	M_G		***M***
Total Supply	***X***	$\mathbf{X_1}$	**...**	$\mathbf{X_j}$	**...**	$\mathbf{X_n}$	***C***	***I***	***G***	***E***	

Where:

X_i__ value of the output of sector i (i = 1 · · · n)

X_{ij}__ sales by sector i to sector j, or the value of inputs from sector i used to produce the output of sector j (i = 1 · · · n; j = 1 · · · n).

W_j__ wages in sector j (j = 1 · · · n). It represents the payments to labor in sector j

Rj__ interest and profits in sectorj. It represents the payments to the owners of capital in sector j

M_j__ imports of sectors j

C_i__ personal consumption expenditures on the output of sector i

I_i__ investment expenditures for the output of sector i

G_i__ government purchases of the output of sector i

E_i__ exports of the output of sector i

M_C, M_I, M_G__ imports of final goods by consumers, firms, and the government, respectively

*Matrix 1 (n×n)*__ represents the interindustry transactions

*Matrix 2 (n×4)*__ represents the final demands for the output of sector i: by consumers or personal consumption (C_i), firms (I_i), the government (G_i), and foreigners (E_i).

*Matrix 3 (3×n)*__ represents the value added which accounts for the other (nonindustrial) inputs to production. It is composed of the factor payments by each sector to labor (W_j) and the owners of capital (R_j), and payments to foreigners for imports (M_j).

*Matrix 4*__ accounts for the final consumption of labor (e.g., domestic help hired by households, W_C, and the employees of the government, W_G), and imports of final goods by consumers (M_C), firms (M_I) and the government (M_G).

Appendix B.5 : Limitations of the I-O approach, according to the OECD

The limitations of the I-O approach, according to the OECD document "Structural Change and Industrial Performance" are:

- The basic input-output analysis assumes constant returns to scale. The input-output model assumes that the same relative mix of inputs will be used by an industry to create output regardless of quantity.
- Each industry is assumed to produce only one type of product. For example, the automobile industry produces only cars. The distribution and sale of this product is fixed.
- Each product within the industry is assumed to be the same. Also, there is no substitution between inputs. The output of each sector is produced with a unique set of inputs.
- Technical coefficients are assumed to be fixed: that is, the amount of each input necessary to produce one unit of each output is constant. The amount of input purchased by a sector is determined solely on the level of output. No consideration is made to price effects, changing technology or economies of scale.
- It is assumed that there are no constraints on resources. Supply is infinite and perfectly elastic.
- It is assumed that all local resources are efficiently employed. There is no underemployment of resources.
- Timeliness of input-output data. There is a long time lag between the collection of data and the availability of the input-output tables. The sporadic nature of input-output tables means that continuous time series are impossible to construct without estimating input-output tables for the years between benchmarks. In effect, input-output tables provide a snapshot of the complete economy and all of its industrial interconnections at one time.

Appendix B.6: Input-output coefficient Matrix for Moroccan economy, 2014 (bold type indicates coefficients >0,001)

	A00	B05	C00	C00_ OCP	D01	D02	D03	D03_ OCP	D04	D05	D06	E00	F45	G00	H55	I01	I02	J00	K00	L75	MNO	OP0	Total
A00	**0,151**	0,000	0,000	0,000	**0,095**	**0,004**	**0,091**	**0,173**	**0,003**	0,001	**0,117**	**0,044**	**0,003**	0,001	0,000	**0,021**	**0,003**	**0,007**	0,000	0,000	**0,004**	0,000	0,718
B05	0,000	**0,131**	0,000	0,000	0,000	0,000	0,000	0,000	0,001	**0,001**	**0,046**	0,001	0,000	0,000	0,000	0,001	0,000	**0,005**	0,000	0,000	0,000	0,000	0,187
C00	0,000	0,000	**0,012**	0,000	0,000	0,001	**0,002**	0,000	**0,004**	**0,005**	**0,055**	0,000	0,000	0,000	0,000	**0,010**	0,000	**0,002**	**0,002**	0,000	0,000	**0,006**	0,099
C00_OCP	0,000	0,000	0,000	0,000	0,000	0,000	**0,008**	0,000	**0,003**	**0,005**	**0,038**	**0,011**	0,000	0,000	0,000	**0,016**	0,000	**0,001**	**0,004**	0,000	0,000	**0,002**	0,089
D01	**0,436**	**0,327**	**0,006**	0,000	**0,128**	**0,002**	**0,105**	0,000	**0,019**	**0,085**	**0,075**	**0,033**	**0,001**	0,000	**0,001**	**0,018**	**0,004**	**0,013**	**0,022**	0,000	0,000	**0,017**	1,294
D02	**0,006**	0,001	0,001	0,000	0,001	**0,527**	**0,113**	0,000	**0,010**	**0,031**	**0,009**	**0,018**	0,000	0,000	**0,002**	**0,003**	**0,002**	**0,007**	**0,007**	0,000	0,000	**0,011**	0,748
D03	**0,008**	**0,006**	**0,957**	0,000	0,000	**0,001**	**0,366**	0,000	**0,002**	**0,010**	**0,010**	0,000	0,000	0,000	**0,001**	0,001	**0,002**	**0,002**	**0,006**	0,000	0,000	**0,003**	1,375
D03_OCP	0,000	0,000	0,000	0,202	0,000	0,000	0,004	0,083	0,003	0,007	0,008	0,016	0,000	0,000	0,001	0,003	0,001	0,002	0,003	0,000	0,000	0,002	0,335
D04	0,000	**0,001**	**0,112**	0,000	0,000	**0,002**	**0,128**	0,000	**0,538**	**0,080**	**0,039**	**0,036**	**0,002**	0,000	**0,006**	**0,009**	**0,005**	**0,026**	**0,029**	0,000	0,000	**0,017**	1,031
D05	**0,007**	0,000	**0,100**	0,000	0,000	**0,018**	**0,515**	0,000	**0,055**	**0,185**	**0,109**	**0,058**	0,001	0,000	**0,002**	**0,010**	**0,003**	**0,011**	**0,014**	0,000	0,000	**0,030**	1,118
D06	0,000	0,000	**2,122**	0,000	0,000	0,000	0,001	0,000	**0,001**	**0,002**	0,001	**0,003**	0,001	0,000	0,000	**0,002**	0,000	0,001	0,000	0,000	0,000	0,000	2,134
E00	0,000	0,000	**0,449**	0,000	0,000	0,000	**0,010**	0,000	**0,015**	0,001	**0,081**	**0,026**	**0,002**	0,000	0,000	**0,001**	**0,003**	**0,022**	**0,007**	0,000	0,000	**0,020**	0,638
F45	0,000	0,000	**0,203**	0,000	0,000	0,001	**0,105**	0,000	**0,151**	**0,587**	**0,110**	**0,018**	0,000	0,000	0,000	**0,002**	**0,005**	**0,048**	**0,016**	0,000	0,000	**0,006**	1,253
G00	**0,012**	0,000	**0,006**	0,000	**0,007**	**0,004**	**0,105**	0,000	**0,062**	**0,095**	**0,126**	**0,046**	**0,005**	**0,002**	**0,003**	**0,038**	**0,031**	**0,054**	**0,062**	0,000	0,000	**0,016**	0,672
H55	**0,009**	**0,024**	0,000	0,000	**0,038**	**0,001**	**0,009**	0,000	**0,001**	**0,004**	**0,010**	**0,019**	0,000	0,000	**0,006**	0,000	**0,002**	**0,011**	**0,014**	0,000	0,000	**0,006**	0,156
I01	0,000	0,000	0,000	0,000	0,000	0,001	**0,004**	0,000	**0,016**	**0,010**	**0,428**	**0,020**	**0,001**	**0,005**	**0,003**	**0,040**	**0,010**	**0,012**	**0,084**	0,000	0,000	0,001	0,636
I02	0,000	0,000	0,000	0,000	0,000	0,000	**0,004**	0,000	**0,028**	**0,005**	**0,026**	**0,026**	0,001	0,000	**0,020**	**0,002**	**0,018**	**0,016**	**0,031**	0,000	0,000	**0,002**	0,180
J00	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	**0,009**	0,000	**0,014**	**0,004**	0,000	**0,037**	**0,009**	**0,021**	**0,138**	**0,055**	0,000	**0,002**	0,000	0,290
K00	0,001	0,000	0,000	0,000	0,000	**0,002**	**0,025**	0,000	**0,009**	**0,012**	**0,014**	**0,006**	**0,002**	0,001	0,000	**0,001**	**0,007**	**0,107**	**0,042**	0,000	0,000	**0,020**	0,248
L75	**0,001**	0,000	**0,037**	0,000	**0,004**	**0,016**	**0,039**	0,000	**0,010**	**0,022**	**0,117**	**0,083**	**0,008**	**0,026**	**0,108**	**0,023**	**0,058**	**0,037**	**0,056**	0,000	**0,008**	**0,013**	0,668
MNO	0,001	0,000	0,000	0,000	**0,001**	**0,002**	**0,077**	0,000	**0,010**	**0,011**	**0,021**	**0,026**	**0,002**	**0,002**	**0,012**	**0,009**	**0,014**	**0,003**	**0,029**	0,000	**0,006**	**0,011**	0,235
OP0	0,001	0,000	0,000	0,000	0,001	0,001	**0,024**	0,000	**0,004**	**0,010**	**0,008**	**0,008**	0,000	0,000	**0,006**	**0,007**	**0,002**	**0,001**	**0,011**	0,000	0,001	**0,020**	0,104
Total	0,634	0,491	4,006	0,202	0,277	0,582	1,735	0,256	0,945	1,179	1,448	0,512	0,033	0,036	0,209	0,226	0,191	0,526	0,495	0,000	0,021	0,203	14,208

Chapter 4

Natural Resources Revenues, Agriculture Development and Urbanization in African Countries: Evidence from a Static and Dynamic Panel Data

Résumé

Le dernier chapitre s'évertue à traiter à de nouveaux frais la question de la malédiction des ressources naturelles en reliant la performance agricole et l'explosion urbaine à l'abondance de ces ressources. Deux hypothèses principales sont testées. La première hypothèse stipule que l'abondance des ressources naturelles entraînerait l'éviction des secteurs productifs en particulier le secteur agricole. Ceci aurait comme conséquences la baisse de la production agricole, l'amplification de la dépendance alimentaire, l'augmentation du chômage dans milieu rural et donc un mouvement massif vers les villes (exode rural). La deuxième hypothèse suggère que les revenus pétroliers et miniers sont généralement dépensés dans les villes, notamment en amélioration des conditions de vie (logement, eau, électricité, santé, éducation, etc.). Cela aurait normalement un effet positif sur la croissance mais ce processus d'urbanisation se trouve accéléré par l'exode des populations venant chercher leur part de ces revenus dégagés du secteur extractif. Ce qui aurait comme conséquence une urbanisation dégénérée (villes entourées de taudis, développement du secteur informel, problèmes de sécurité, etc.). L'étude empirique, basée sur un panel de 39 pays africains, exhibe un lien significatif entre l'abondance de ces ressources, le sous-développement du secteur agricole et l'explosion urbaine.

4.1 Introduction

The possession of natural resources such as oil, natural gas, diamonds or other mineral deposits does not necessarily lead to economic growth. Many African countries such as Nigeria, Angola, Sudan, Algeria and Congo are classified as resource-rich countries with non-significant economic development, less democracy, a low per capita income and poor living standards. Richard Auty (1986) is apparently the first one who used the term "natural resources curse" to describe this puzzling phenomenon. Empirically, the most popular study by Sachs and Warner (1995) found a strong correlation between natural resources abundance and poor economic growth. Since then, abundant literature has evaluated the effects of natural resources on a wide range of economic, institutional and political performance indicators, and offered a variety of theories and explanations to this complicated phenomenon. The purpose of this study is to propose new possible explications for the resource curse in African countries. In particular, the literature on the subject does not consider explicitly the impact of natural resources revenues on agricultural performance and urbanization. As such, this study seeks to answer the following questions: first, can oil and mineral resources abundance explain the agricultural poor performance? Second, is there a relationship between natural resources abundance and urbanization trends?

Two main hypotheses are tested. The first one suggests that the abundance of oil and mineral resources allows policy makers to specialize in primary commodities and prevents the development of other productive sectors, especially agriculture. This would have a negative consequence on agricultural production, rural employment, food security and would therefore lead to an acceleration of rural-urban migration. The second hypothesis suggests that oil and mining revenues are mostly spent in cities in order to improve living conditions (housing, water, electricity, health, education, etc.). In general, this could have a positive effect on economic growth. However, the urbanization trend is accelerated by the migration of a rural population looking for jobs and a better life. This may explain the current situation of major African cities with considerable urban problems (slums, pollution, crime, overcrowding, informal sector, etc.). At this point, we note that the available empirical studies show no clear effect of urbanization on growth. The causal relationship between economic growth and urbanization remains unclear, according to the 2010 UN-HABITAT's report[15].

This study differs from others on three points. First, we use the same framework to present two explanations (or channels) for the natural resources curse in African countries. We link natural resources abundance to the poor agricultural performance and the current urbanization situation. Second, our findings are derived from an empirical analysis based on a panel of 39 African countries. Therefore, the results can provide a global picture of the resource curse for the whole continent. Third, we conduct both static and dynamic panel regression models. The static specification allows the estimation of a country-specific effect while the dynamic specification captures the second round effects and reduces the effects of unobserved or missing variables. This help us better capture the complexity of the resource curse paradox.

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[15] UN-HABITAT's report, Urban Trends: Urbanization and Economic Growth (2010).

The rest of the chapter is organized as follows. Section 2 presents the literature review related to natural resources curse channels in Africa and the most used proxies for natural resources abundance or dependency measures. The analytical framework is introduced in Section 3. The next section displays a description of the selected variables, data sources and some statistical evidences. We discuss our empirical investigation in Section 5. Finally, we make concluding remarks in Section 6.

4.2 Review of natural resources curse explanations in Africa

The resource curse is a paradoxical phenomenon observed in countries with abundant natural resources, specifically non-renewable resources like oil and minerals tend not to perform as well economically as those without. The Sub Saharan Africa (SSA) region has become a classic case of the resource curse in the literature. Many countries in the region like the Democratic Republic of Congo (DRC), Chad, Mali, Liberia, Sierra Leone, Sudan and several others, are rich in natural resources, notably oil, minerals and precious metals, but are still classified as low-income economies. Only one country, Botswana has succeeded in becoming an upper middle-income country using its natural resources and has escaped the Resource Curse (Engelbert, 2002; Sarraf and Jimanji, 2001; Iimi, 2006).

How could resources abundance be a curse? What could be the mechanism for this counter-intuitive relationship?

The literature proposes several theories to explain this phenomenon. Several authors (e.g. Frankel, 2010; Van der Ploeg, 2011; Torres et al., 2013; Badeed et al., 2017) have conducted a very thorough literature review and summarized potential mechanisms for the resource curse. Broadly speaking, there are at least four lines of arguments: **Dutch Disease, volatility in commodity prices, rent seeking/corruption and institutional quality**. The first explanation based on the Dutch Disease suggests that the resource curse might occur when a boom in the resource sector causes a persistent appreciation of the real exchange rate and inflation. This appreciation makes non-resource commodities exports more expensive and imports cheaper and leads to a trade balance deficit in the short term. In the medium and long terms, this situation can create barriers to investments in non-resource tradable sectors and consequently curbs development (Sachs and Warner, 1995, 1997 and 2001; Gylfason, 2001a, Papyrakis and Gerlagh, 2004). This negative effect is commonly called the “spending effect”. In addition, the natural resources sector attracts capital and labor from other parts of the economy. As a result, the input production costs of other traditional export sectors such as manufacturing and agriculture increase. This resource reallocation is usually denominated “indirect-deindustrialization” (Corden and Neary, 1982; Corden, 1984) or “resource pull effect” (Humphreys et al., 2007). For African countries, both effects are reflected in the decline of the agriculture sector. Other explanations for the resource curse, often cited in the literature as symptoms of the Dutch Disease, are related to the disincentive for entrepreneurship (Sachs and Warner, 2001), the decrease in savings and physical investment (e.g., Gylfason, 2001a; Papyrakis and Gerlagh, 2007) and lower investment in education and human capital (e.g., Gylfason, 2001b; Birdsall et al., 2001; Bravo-Ortega and Gregorio, 2005). This might explain why one out of three young people in SSA region fail to complete primary school and need alternative pathways to acquire basic skills for employment (UNESCO, 2012)[16].

The second explanation suggests that the resource curse may operate because oil and mineral commodity prices are more volatile than the prices of other manufactured products. **Volatility** increases uncertainty in government revenues, and makes it difficult to conduct effective planning and therefore reduces economic growth (Davis and Tilton, 2005).This situation also explains the debt crisis observed in resource-rich countries during the 1980's (Van der Ploeg, 2011). In order to ensure debt repayment and economic restructuring, the IMF and the WB created the so-called Structural Adjustment Policies (SAPs) for a majority of African countries. Poor countries were forced to reduce spending on health, education and infrastructure, while debt repayment and budget balance became the priority.

The third explanation associates the resource curse with rent seeking behaviors and corruption (Auty 2001). According to Collier and Hoeffler (2005), **Rent-seeking** occurs when "individuals or firms compete to obtain economic rents that arise when government restrictions are imposed" while **corruption** is defined, according to Kaufmann and Vicente (2011), as the abuse of public or private office, position, or power for private gain in contravention of established rules or norms. These two economic challenges are the principal reasons for underdevelopment in many African regimes (Coolidge and Rose-Ackerman 1999). In addition, Ross (2001) concludes that oil abundance hampers **democracy**. More recently, Arezki and Gylfason (2013) examined the impact of the interaction between resource rents and democracy and corruption for a panel of African economies. They found that large resource rents lead to more corruption, but that the effect is lower for more democratic countries. Finally, the literature shows evidence of the negative impact of resources abundance and the **quality of institutions**. For example, Mehlum et al. (2006) have demonstrated, using regression analysis that the resource curse is strongly present in countries with weak institutions but is barely present in countries with strong institutions. Other authors like Isham et al. (2005), Bulte et al. (2005), Robinson et al. (2006) and Collier (2010) conclude that natural resources abundance is a cause of poor institutional quality.

4.2.1 Resource Curse studies using panel data

In order to test the resource curse for a panel of countries, the literature proposes different methodologies. Some authors use cross-sectional analysis while others use panel data analysis. In cross-sectional analysis, an equation is estimated for a number of countries at a specific point of time. The estimation does not incorporate any temporal dynamics. This method has been used by several authors (see Table 4.1). In this case, two problems can rise. The first one may stem from a potential endogeneity of resources abundance proxies with growth variables. The second lies in the control of all country-specific effects. In addition, cross-section estimation is more sensitive to omitted variables that may reflect country specific characteristics. Panel data seem to be a solution for these problems. Compared to cross-sectional data, the advantages of panel data lie in using information for both temporal and individual dimensions and it is possible to estimate the country-

[16] The tenth Education for All Global Monitoring Report, UNESCO (2012)

specific effects. This would reduce the effect of unobserved or omitted variables bias (See Manzano and Rigobón 2001 for comments and justification).

Regarding the results of cross sectional and panel data analysis, a relationship between resources abundance and economic growth might differ. Some authors find evidence of the resource curse while others do not. Based on Torres and Afonso (2013) and Zagozina (2014) surveys and several other studies, Table 4.1 summarizes recent cross sectional and panel studies on the resource curse and their main findings. The major outcomes presented in the table reflect the importance of choosing relevant resource abundance proxies. In the following section, we discuss different proxies used in the literature to measure this concept.

4.2.2 Measures for non-renewable resource abundance

The literature proposes a number of natural resources abundance or dependency proxies. There are at least four measures for natural resources abundance mostly used by authors (see Table 4.1): (i) Ratio of natural resources exports to gross domestic product (GDP), (ii) Share of natural resources exports in total exports, (iii) Ratio of mineral production to gross national product (GNP), and (iv) Rents from natural resources over GDP or per capita. Other proxies are used in the literature. For instance, Stijns (2005) measures natural resources abundance by the present value of mineral reserves and finds no correlation between this variable and economic growth. Lederman and Maloney (2008) use the Leamer index (natural resources net exports/labor force) and find no significant impact with respect to GDP per capita growth.

In this study, we use non-renewable resources rents to GDP, which we note "*Rent*", as a measure of natural resources abundance. We use GDP as a denominator to take into account the country size. As we hope to evaluate the impact of resource rent on agricultural performance, we include only minerals, oil and gas rents and exclude forestry and other agricultural resources rents to deal with a possible endogeneity problem. According to the World Bank, the rent for a given commodity is calculated as the difference between the price of this commodity and it average cost of production. The unit rent is multiplied by the physical quantity extracted and expressed as a share of GDP. The choice of this measure is justified by two reasons. First, the use of production or exports of natural resources tend to overestimate the abundance or dependence as no deduction of production cost is made. Second, there are data availability and homogeneity problems for all selected countries.

Table 4.1: Summary of selected panel and cross-sectional studies and different Natural Resources (NR) proxies

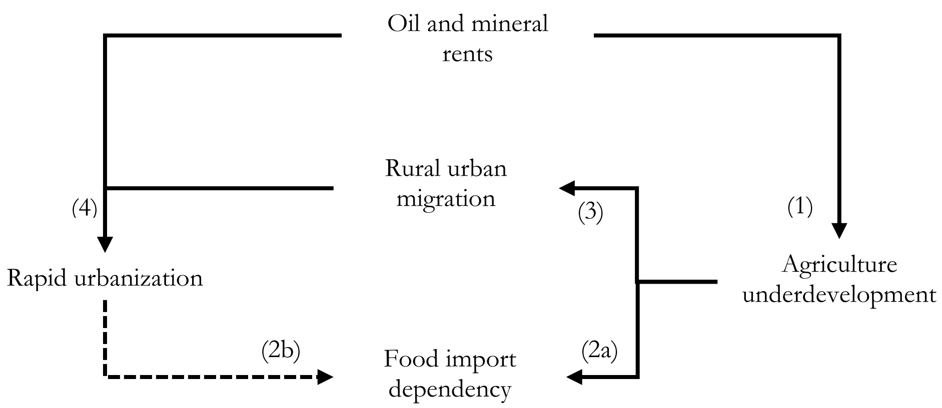
Reference	NR proxy	Panel	Cross-sectional	Main findings
Sachs and Warner (1995)	NR exports over GDP	No	Yes	Negative relationship between natural resources and growth.
Manzono and Rigobon (2006)	NR exports over GDP	Yes	No	No effect or positive effect once fixed effects are introduced into a model.
Arezki and Van der Ploeg (2011)	NR exports over GDP	No	Yes	Negative relationship between natural resources and income per capita, especially in countries with bad rule of law or bad policies.
Boschini et al. (2013)	NR exports over GDP	Yes	Yes	The interaction of ores and metals rents with institutional quality has a negative effect on growth.
Leite and Weidmann (1999)	NR exports over GNP	No	Yes	Natural resources abundance creates opportunities for rent-seeking behaviors and it is an important factor in determining a country's level of corruption.
Davis (1995)	NR exports over total exports	No	Yes	Resource abundance have a positive relationship with economic development.
Dietz al. (2007)	NR exports over total exports	Yes	No	Resource abundance has a negative effect on genuine saving.
Beck(2011)	NR exports over total exports	No	Yes	The paper tested for the existence of a natural resources curse in financial system development. The finance and growth relationship seems as important for resource-based economies as it is for other economies, so that underinvestment in the financial sector will have long-term negative repercussions for economic growth.
Daniele (2011)	NR exports over total exports	Yes	No	Human development is negatively correlated with natural resources dependence, but positively correlated with resource abundance. These effects are particularly significant in countries with comparatively lower institutional quality.
Barajas et al. (2013)	NR exports over total exports	Yes	No	The beneficial effect of financial deepening on economic growth is smaller in oil exporting countries.
Papyrakis and Geragh (2003)	NR production over GDP	Yes	No	Natural resources have a negative impact on growth when considered in isolation, but a positive impact on growth when include in the analysis with other variables such as corruption, investments, openness, terms of trade, and schooling, and treating these variables as independent.
Brunnschweiler (2008)	NR production over GDP	No	Yes	A positive relationship between natural resources abundance and economic growth.
Collier and Hoeffler (2009)	NR rents over GDP	Yes	No	Natural resources abundance considerably increases the potential of violent civil conflict.
Ross (2001)	NR rents over GDP	Yes	No	Oil exports are strongly associated with authoritarian rule; that this effect is not limited to the Middle East; and that other types of mineral exports have a similar antidemocratic effect, while other types of commodity exports (agricultural commodities) do not.
Auty (2001)	NR rents over GDP	Yes	No	The presence of abundant natural resources (especially minerals) leads to rent-seeking behavior and corruption, thereby decreasing the quality of governance, which in turn negatively affects economic performance.
Bhattacharyya and Collier (2013)	NR rents over GDP	Yes	No	Resource rents significantly reduce the public capital stock. The adverse effect on public capital is mitigated by good institutions. The depletion of non-renewable (mineral) resources reduces the public capital stock whereas rents from sustainable sources (forestry and agriculture) do not.
Bhattacharyya and Hodler (2010)	NR rents per capita	Yes	No	The relationship between resource rents and corruption depends on the quality of the democratic institutions.

4.3 Empirical models

4.3.1 Identification

The objective of our empirical study is to evaluate the impact of non-renewable resources abundance on the development of agriculture and urbanization in a sample of African countries. We seek to verify two main hypotheses. The first (H1) suggests that oil and mineral rents can lead to the underdevelopment of the agriculture sector in resource-rich African countries (relation (1) Figure 4.1). The second (H2) indicates that oil and mineral rents are mostly invested in cities to develop infrastructure and services which, in turn, can attract more people and lead to an acceleration of urbanization (relation (4)). We suppose that the link between the two hypotheses is that poor performance of agriculture exposes the countries to two main problems. First, an increase in rural-urban migration (3) since more than 2/3 of Sub-Saharan African people work in the agricultural sector according to the World Bank estimations,. The second problem is the food security. Indeed, faced with the inability of the agricultural sector to satisfy food needs locally, countries cover their deficits through imports (2a). Indirectly, food imports become more attractive for governments in order to feed growing urban populations rather than investing in agriculture[17] (2b).

Figure 4.1: Oil and mineral rents and its relations with agriculture and urbanization.



[17] This policy was supported by World Bank and IMF structural adjustment programs by eliminating government support for agriculture and poor farmers.

We test these hypotheses, using the following models with interaction effects:

$$Agri_{it} = \beta_0^1 + \beta_1^1 Rent_{it} + \sum_{j=3}^{p} \beta_j^1 Controls_{j,it} + \varepsilon_{it}^1 \qquad (4.1)$$

$$Food\_M\_Dep_{it} = \beta_0^2 + \beta_1^2 Agri_{it} + \beta_2^2 \boldsymbol{Agri_{it}} * \boldsymbol{Rent_{it}} + \sum_{j=3}^{p} \beta_j^2 Controls_{j,it} + \varepsilon_{it}^2 \qquad (4.2a)$$

$$Food\_M\_Dep_{it} = \beta_0^3 + \beta_1^3 Urban_{it} + \beta_2^3 \boldsymbol{Urban_{it}} * \boldsymbol{Rent_{it}} + \sum_{j=3}^{p} \beta_j^3 Controls_{j,it} + \varepsilon_{it}^3 \qquad (4.2b)$$

$$Migration_{it} = \beta_0^4 + \beta_1^4 Agri_{it} + \beta_2^4 \boldsymbol{Agri_{it}} * \boldsymbol{Rent_{it}} + \sum_{j=3}^{p} \beta_j^4 Controls_{j,it} + \varepsilon_{it}^4 \qquad (4.3)$$

$$Urban_{it} = \beta_0^5 + \beta_1^5 \boldsymbol{Rent_{it}} + \beta_2^5 \boldsymbol{Agri_{it}} * \boldsymbol{Rent_{it}} + \sum_{j=3}^{p} \beta_j^5 Controls_{j,it} + \varepsilon_{it}^5 \qquad (4.4)$$

The dependent variables are: $Agri_{it}$ agricultural value added per capita used as a measure of sectorial performance for country *i* at time *t;* $Food\_M\_Dep_{it}$ food imports dependency measured by the share of food consumption covered by imports; $Migration_{it}$ rural-urban migration. Ideally, a rural-urban migration estimate can be obtained from a direct survey that gives information on the type of previous residence. This is not the case for Africans countries for which no data are available. Therefore, we opted for an indirect estimation. We assume that the natural population growth (births-deaths) in both urban and rural areas has remained unchanged during the last fifteen years (estimation period) and we assume that the proportion of international migration (people coming from other countries) remain stable. Under these assumptions, we can use simply the ratio of urban population to rural population as a proxy of rural-urban migration. A rise of this ratio would be a result of population movements from rural to urban areas; and $Urban_{it}$ is the ratio of urban population out of the total population.

The explanatory variable of interest is $Rent_{it}$ which is the non-renewable resources abundance measured by the ratio of oil and mineral rents to GDP.

$Controls_{j,it}$ is a set of other explanatory variables that affect the corresponding dependent variable. Theses variables include: $yield_{it}$ which is grain yield as a proxy for agricultural productivity; $land_{it}$ is arable land in percent of total area; $Rural_{it}$ is the percentage of rural population used as a proxy for labor availability. This approximation is justified because Africa's agriculture is characterized by a high percentage of small-scale family farms where each family member has a role to play; $demo_{it}$ is population growth; $Income_{it}$ is the gross domestic product (GDP) per capita measured in constant 2005 US dollars and $Rural\_income_{it}$ is the ratio of agricultural GDP measured in constant 2005 US dollars to rural population and used as a proxy for per capita income in rural area.

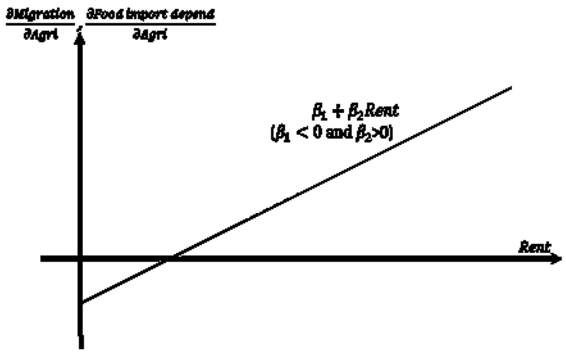
The advantage of an interactive model compared to an additive model resides in the fact that the coefficients in an additive model describe the effects of each independent variable on the dependent variable as constant (*Ceteris Paribus*), regardless of the level of the other independent variables; whereas the coefficients in an interactive model assume that the effects of each independent variable on the dependent variable are varying, depending on the level of the other independent variable. In our case, the interactive model enables us to adequately evaluate the impact of agricultural performance on rural-urban migration, food imports dependency and the urbanization rate in African countries conditional to their dependence level on natural resources revenues.

4.3.2 Expected results

Equation (4.1) measures the direct impact of oil and mineral rents on agricultural performance. We test the null hypothesis that resource abundance has no significant effect on agricultural performance ($H_0: \beta_1 = 0$) against the alternative hypothesis that resource abundance negatively affects agricultural performance ($H_1: \beta_1 < 0$). The other explanatory variables are referred to productivity and inputs[18] (land and labor). These variables are: $yield_{it}$, $land_{it}$ and $Rural_{it}$. We expect positive coefficients for these three variables.

Equation (4.2a) evaluates the impact of agricultural performance on food import dependency conditional to oil and mineral rents. We expect $\beta_1 < 0$ and $\beta_2 > 0$ (Figure 4.2).

Figure 4.2: Impact of agriculture performance on rural-urban migration and food import dependency depending on oil and mineral rents level



Equation (4.2b) evaluates the impact of urbanization dynamics on food imports dependency conditional to oil and mineral rents. Since we suppose that food imports become more attractive for decesion makers in resource-rich countries in order to feed growing urban population rather than investing in agriculture, we expect a positive effect of urbanization on food imports dependency. Then, the coefficients β_1 and β_2 in equation (4.3b) should be positive (Figure 4.3).

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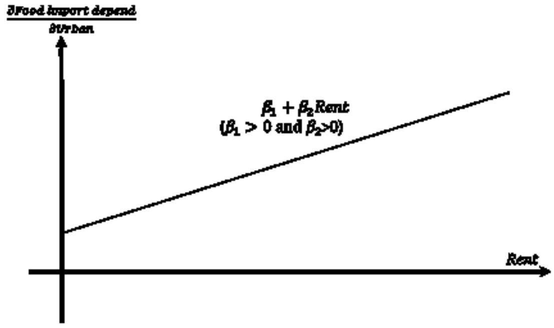
[18] We explicitly ignore other inputs because Africa's agriculture uses minimal levels of fertilizers, pesticides and infrastructure facilities such as irrigation equipments, machinery, transport and communication.

Figure 4.3: Impact of urbanization on food import dependency depending on oil and mineral rents level

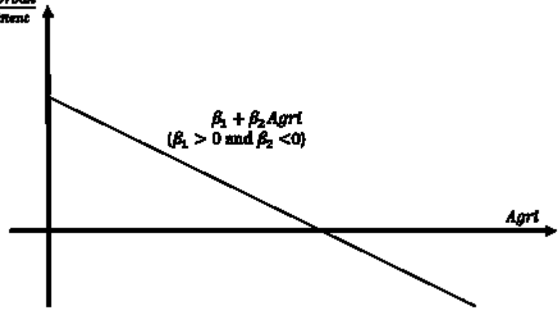


For both equations (4.2a) and (4.2b), we use two additional explanatory variables. First, population growth ($demo_{it}$). Intuitively, more population means more food needs. The sign and significance of the coefficient associated with this variable depend on the capacity of agricultural sector to satisfy additional needs. A significant positive coefficient would reflect that the additional food requirements are covered by imports. The second tested variable is $Income_{it}$ which we expect to have a positive coefficient. In Africa, this phenomenon is very visible in cities where urban population –with a higher income level than in rural areas- is heavily dependent on imported wheat and rice (Tchamda et al. 2015).

Equation (4.3) measures the impact of agricultural performance on rural-urban migration conditional to oil and mineral rents. As illustrated in Figure 4.2, we expect that a marginal increase of agricultural performance to be associated with a decrease in rural-urban migration when a country is none or lowly dependent on oil and mineral rents ($\beta_1 < 0$). The effect becomes positive when the dependence of oil and mineral rents exceeds a given threshold ($\beta_2 > 0$). Therefore, the marginal increase in agricultural performance will be associated with an increase in migration. We use as control variables: population growth ($demo_{it}$) to capture the structural changes (its effect should be positive), and $Rural\_income_{it}$ which hopefully will have a negative and significant effect.

Finally, equation (4.4) tests both the direct effect of oil and mineral rents and the effect conditional to agricultural performance on urbanization dynamics. As shown in Figure 4.4, the coefficient β_1 captures the effect of an increase in oil and mineral rents on the urbanization rate when agricultural performance is absent.

Figure 4.4: Impact of oil and mineral rents on urbanization depending on agriculture performance



Since our hypothesis suggests that oil and mineral rents lead to an acceleration of urbanization, we expect to find a positive sign for β_1. For countries with good agricultural performance, we suppose that the urbanization rate grows at a slowler rate because of low rural-urban migration. Then, the effect of resources rents on urbanization conditional to agricultural performance should be negative ($\beta_2 < 0$).

4.3.3 Estimation strategy

We first estimate a static panel data model to control for the country-specific effects. Secondly, we estimate a dynamic panel data model to deal with missing variables effects.

<u>The Static Panel Data Estimations</u>

We start by estimating a static panel data model spelled as follows (equation 4.5).

$$y_{it} = \beta' X_{it} + \alpha_i + c + v_{it}, \qquad i = 1, \dots, N(country);\ t = 1, \dots, T(time) \qquad (4.5)$$

where y_{it} is the observed dependent variable for country i at time t, x_{it} are regressors, β the parameter vector to be estimated, c the constant term and v_{it} the residual disturbance term with zero mean, constant variance, and supposed to be uncorrelated across time and individuals. The α_i terms represent the country-specific effects and capture the unobserved heterogeneity in the model.

We first test for the presence of panel heterogeneity using the redundant fixed effect test. The null hypothesis of the redundant fixed effect is that the pooled regression model is more appropriate ($H_0: \alpha_1 = \cdots = \alpha_N = \alpha$), with the alternative hypothesis being that the fixed effect model is preferable. Then, we test both fixed and random effects models. The fixed effects model involves estimating a parameter (α_i) for each country, in our case the 39 selected countries. The random effects model assumes that country-specific terms (α_i) are randomly distributed. In this case, we do not need to estimate a parameter for each country and this can be a considerable as an efficiency gains. However, the random effects estimator will be inconsistent due to the presence of correlation between the country-specific effects and one or more independent variables (Baltagi, 1995). We test for random effects estimator consistency in our analysis below by conducting a standard Hausman test. A significant value for the Hausman test statistic would mean that the random effects estimators are inconsistent and that fixed effects estimates are more appropriate. We can easily estimate these models by using standard methods (Least squares dummy variables or LSDV) for fixed effects model and Generalized least squares (GLS) for random effects model or ordinary least squares (OLS) for both, if we can assume heteroskedastic disturbances.

<u>The dynamic Panel Data Estimations</u>

In addition to the static approach, we also test for dynamic effects in the models. A dynamic approach may be particularly relevant to evaluate the influence of natural resources rents on agricultural development and urbanization trends. Dynamic panel data models use the lags of the dependent variable as explanatory variables (See equation 4.6).

$$y_{it} = \gamma y_{it-1} + \beta' X_{it} + \alpha_i + c + v_{it}, \qquad i = 1, \dots, N;\ t = 1, \dots, T \qquad (4.6)$$

It is evident that the model suffers from an endogeneity problem, because y_{ti-1} is correlated with α_i. In this case, the standard estimators (GLS and OLS) would be inappropriate. To solve this problem, we use the generalized method of moments (GMM) approach proposed by Arellano and Bond (1991). We start by transforming the equation into first differences to eliminate the bias arising from individual heterogeneity (equation 4.7) and then we estimate the transformed equation through the GMM method using lagged values of the endogenous variables as instruments.

$$\Delta y_{it} = \gamma \Delta y_{it-1} + \beta' \Delta X_{it} + \Delta v_{it}, \qquad i = 1, \dots, N;\ t = 1, \dots, T \tag{4.7}$$

The consistency of the GMM estimator depends on the validity of the assumption that the error terms do not exhibit serial correlation and on the validity of the instruments. To address these issues, we use two specification tests suggested by Arellano and Bond (1991) and Sargan (1958). The first one, commonly called "m-test" examines the presence of serial correlation in error terms. As, we run the test on the differenced equation, we only report the test for second-order serial correlation. The second one, commonly called "J-test" of over-identifying restrictions, regresses the residuals from a GMM regression on all instruments and test if all instruments are uncorrelated with the error term. For both tests, we should not reject the null hypothesis to confirm the consistency of the GMM estimators. We note that Arellano and Bond (1991) compared, using simulations, the performance of GMM, OLS, and Within-Group (WG) estimators and they found that GMM estimators exhibit the smallest bias and variance.

4.4 Data and statistical analysis

4.4.1 Data description and sources

The data are gathered from the World Bank (World Development Indicators), the Food and Agriculture Organization of the United Nations (FAO) and the World Urbanization Prospects and Millennium Development Goals (United Nations). All these sources are characterized by considerable lack of data, forcing us to make an arbitrage concerning the number of countries in the sample, the number of variables to include in the equations and the estimation period. In fact, according to the United Nations, the total number of African countries is 54. Out of this group, 15 countries were excluded due to missing data, both on the dependent and the control variables. We assume that the resulting panel of countries is not endogenous. The estimation is based on annual data span from 2000 to 2013. The selected variables are summarized in Table 4.2 and the list of selected countries is presented in Table 4.3.

Table 4.2: Data description and sources

Variable	Abbreviation	Description	Source
Oil and Mineral rents dependency indicator	*Rent*	We include the sum of oil rents, natural gas rents, coal rents (hard and soft) and mineral rents. According to the World Bank, the estimates of a resource rents are calculated as the difference between the price of a commodity and its average cost of production. This is done by estimating the world price of units of specific commodities and subtracting estimates of average unit costs of extraction or harvesting costs (including a normal return on capital). These unit rents are then multiplied by the physical quantities countries extract or harvest to determine the rents for each commodity as a share of gross domestic product (GDP).	Estimates based on sources and methods described in "The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium" (World Bank, 2011).
Agriculture performance	*Agri*	Agriculture value added (VA) divided by total population. Agriculture VA is the net output of agriculture sector after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources.	World Bank national accounts data, and OECD National Accounts data files.
Cereal yield	*yield*	Cereal yield, measured as kilograms per hectare of harvested land, includes wheat, rice, maize, barley, sorghum and others grains.	FAO
Arable land	*land*	Arable land as defined by the FAO measured as a % of total land area.	FAO
Rural population	*Rural*	Rural population refers to people living in rural areas as defined by national statistical offices. It is calculated as % of total population.	World Bank estimates based on United Nations, World Urbanization Prospects.
Food import dependency	*Food_M_Dep*	Share of food imports in total food consumption. Total food consumption is derived from a Demand/Supply equilibrium equation.	World Bank estimates from the Comtrade database, United Nations Statistics Division.
Population growth	*demo*	Annual population growth rate.	World Bank from United Nations Population Division, World Population Prospects
Prosperity indicator	*Income*	GDP converted to 2005 constant international dollars using Purchasing power parity (PPP) rates divided by total population.	World Bank, WDI
Rural area standard of living indicator	*Rural_income*	Agriculture value Added expressed in constant 2005 US$ and divided by rural population.	World Bank, WDI
Urban Population	*Urban*	Share of people living in urban areas as defined by national statistical offices on total population.	United Nations, World Urbanization Prospects.

Table 4.3 : Selected countries

n°	Country	Rent to GDP	n°	Country	Rent to GDP	n°	Country	Rent to GDP
1	**Libya**	**54,78**	14	Tunisia	5,87	27	Senegal	0,88
2	**Angola**	**52,31**	15	Ghana	5,60	28	Burundi	0,54
3	**Gabon**	**43,73**	16	South Africa	4,58	29	Liberia	0,49
4	**Algeria**	**37,59**	17	Zimbabwe	4,58	30	Ethiopia	0,40
5	**Mauritania**	**31,14**	18	Mozambique	4,50	31	Swaziland	0,37
6	**Nigeria**	**30,91**	19	Eritrea	4,17	32	Sierra Leone	0,34
7	**Equatorial Guinea**	**29,25**	20	Burkina Faso	3,74	33	Madagascar	0,28
8	**Chad**	**25,65**	21	Botswana	3,45	34	Uganda	0,13
9	**Sudan**	**15,87**	22	Tanzania	2,43	35	Rwanda	0,09
10	**Zambia**	**11,14**	23	Morocco	2,05	36	Kenya	0,07
11	Guinea	9,78	24	Niger	2,03	37	Central African Rep.	0,06
12	Cameroon	8,27	25	Namibia	1,57	38	Benin	0,06
13	Mali	6,63	26	Togo	1,46	39	Malawi	0,03

Table 4.4 presents descriptive statistics (i.e. mean value, maximum and minimum values, standard deviation and number of observations) for the selected variables. For each variable, we compare computed averages for the whole sample with the average of the top 10 resource-rich Africans countries. It is evident from the data, that natural resources dependency is high for the top 10 group with an average rate close to 33%, compared to the sample average (10.4%). In addition, the top 10 group has a lower agricultural performance in terms of value added per capita, yield and availability of land and labor compared to the whole sample. The Urbanization rate is also higher in the top 10 group (48.6%) compared to the sample average (37.6%).

Table 4.4: Descriptive statistics of selected variables (2000-2013)

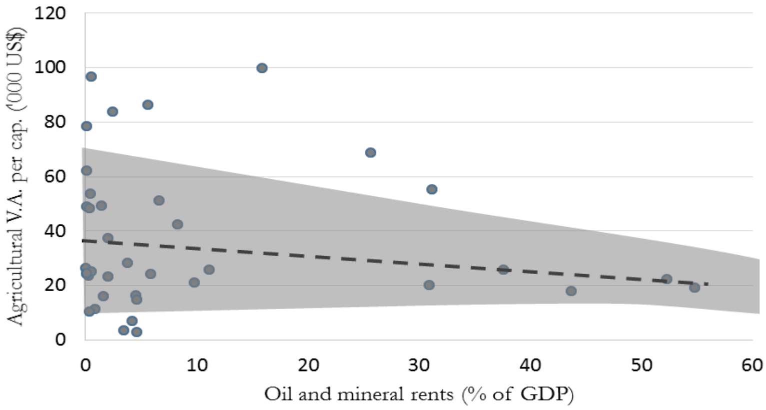
Variable	**Unit**	**Mean**		**Max**	**Min**	**Std. Dev.**	**Obs.**
		All	**Top 10[a]**				
Rent	%	10,4	33,2	84,7	0,0	17,2	546
Agri	000'$/cap.	35,2	32,9	163,2	1,5	30,8	478
yield	Kg/hect.	1252,4	1107,3	4412,6	130,7	627,9	532
land	%	13,5	6,7	48,7	0,3	12,4	542
Rural	%	62,4	51,4	91,8	13,3	17,4	546
Food_M_ Dep	%	28,0	25,7	101,1	0,0	22,4	355
demo	%	0,5	0,3	6,6	-3,0	1,1	546
Income	US$/cap.	1778,9	3661,8	16847,6	132,6	2700,3	546
Rural_income	US$/cap.	324,5	529,4	2889,8	20,3	418,2	498
Urban	%	37,6	48,6	86,7	8,2	17,4	546

(a) Top 10 highly resource dependent countries (see table 3)

4.4.2 Correlation between oil and minerals rents and agriculture

Figure 4.5 shows that on average over the period from 2000 to 2013, agricultural value added per capita is negatively correlated with oil and minerals rents (in percentage of GDP). These two variables have a correlation coefficient of -0.10. In other words, when a country strongly depends on revenues from extractive industries, there is a probability that its agricultural production will be lower and vice versa. However, this chart does not mean that there is a causal link between resources rents and agricultural performance.

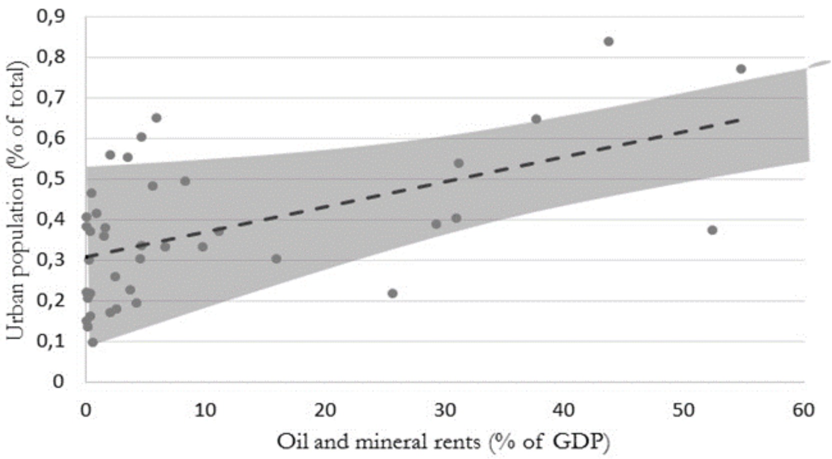
Figure 4.5: Natural resources rents and Agricultural performance



4.4.3 Correlation between oil and mineral rents and urbanization

Similarly, Figure 4.6 shows that on average over the period 2000-2013, the urbanization rate in Africa is positively correlated with oil and minerals rents. These two variables have a correlation coefficient of 0.54. This result suggests that countries highly dependent on natural resources revenues tend to have a higher proportion of urban population. However, this chart does not confirm a causal link between natural resources dependency and urbanization levels.

Figure 4.6: Natural resources rents and Urbanization



In addition, the positive correlation between urbanization and natural resources rents does not mean that urban people live in better conditions. Indeed, if we classify the African countries according to the share of resources rents in GDP (Table 4.5), we can see that the group of countries heavily dependent show higher percentages of urban population living in unhealthy housing (with less access to water and sanitation) compared to the group of countries less dependent.

Table 4.5 : Natural resources rents and urbanization conditions.

	Country groups by Oil and Mineral rents (% of GDP)			
	Group 0	*Group 1*	*Group 2*	*Group 3*
	<5%	[5-10%[	[10-25%[	>=25%
	Less dependent	…………………………		*Highly dependent*
Urban population (% of total)	*47,58*	*36,75*	*35,21*	*50,81*
Improved water source, urban (% of urban population with access)	*95,1*	*89,8*	*90,8*	*80,6*
Improved sanitation facilities, urban (% of urban population with access)	*71*	*43,7*	*42,7*	*50,6*
Population living in slums, (% of urban population), 2009	*45,3*	*60,7*	*61,7*	*63*

Source: World Bank and United Nation Millennium Development Goals database

4.5 Empirical results

4.5.1 Econometric validation of static and dynamic panel data estimations

Table 4.6 presents the results of the static panel regressions and Table 4.7 reports the results of the dynamic panel regressions. Each column, in tables 4.6 and 4.7, presents the best specification for the corresponding equation.

In order to validate the model, we run some important specification tests. For static panel regressions, we first conduct the redundant fixed effect test (R-test) for each regression. The result shows that the R-test statistic is significant for all regressions, suggesting a presence of a country specific effect. Moreover, we run the Hausman test to check if this specific effect is fixed or random. The result suggests a fixed effect specification for all regressions as the test is strongly significant (Prob(H-test)<5%). For dynamic panel regressions, we conduct two specification tests (m-test and J-test) to validate our results. As we can see, for all estimated regressions, the m-test is insignificant suggesting the absence of second order serial correlation in residuals, whereas, the J-test of over-identifying restrictions provides support for our choice of instruments.

4.5.2 Analysis of the Static Panel Data Estimations

Column 1 in table 4.6 presents the estimated coefficients for equation (4.1) using panel fixed effects. The results show that oil and minerals rents have a negative and significant effect on agricultural performance. These findings are in line with the first hypothesis (H1), which suggests that oil and minerals rents can lead to the underdevelopment of the agricultural sector in resource-rich African countries. Looking at the control variables, as expected, the two main production factors (arable land and work force) as well as cereal yields are significant and positive determinants of agricultural performance in African countries. Columns (2) and (3) report the estimated coefficients for equation (4.2a) and (4.2b) respectively. The result shows a negative and significant effect of agricultural performance on food import dependency at 1% level when the conditioning variable (resources rents) is absent. The coefficient is equal to -0.27. Therefore, a one-percentage point increase in agricultural performance leads to a decrease in food imports dependency of 0.27

percentage points, on average, in the selected panel of African countries. The effect becomes positive when we include the conditioning variable. The coefficient of the interaction term between agricultural performance and resource rents is positive and significant at the 10% level. This result can be interpreted as follow: the marginal increase in agricultural performance leads to an increase - i.e. becomes more positive – in food import dependency when a country in highly resource rent dependent. Urbanization is a significant and positive determinant of food import dependency. The estimated coefficient is equal to 0.65 when we include the interaction between agriculture performance and resource rents (column 2), and 0.67 when we include the interaction between urbanization and resource rents (column 3). The interaction between urbanization and resource rents (column 3) is also significant and positive, suggesting that urbanization leads to more food import dependency in countries with high resource rents. The estimation results for equation (4.3) are shown in column (4). Agricultural performance has a negative and significant effect on rural-urban migration, but in terms of magnitude the effect is only 0.05. This would suggest that a one-percentage point increase in agricultural performance leads to a decrease in migration flows by only 0.05%. The interaction between agricultural performance and resources rents is positively significant at the 1% level. This means that agricultural performance plays the opposite role in countries highly dependent on resources rents. Perhaps this is becausethe agriculture sector, in resource rich-countries, cannot offer more job opportunities and better living standards than in the oil and minerals sector. The control variables used in equation (4.3) show evidence that population growth affects positively rural-urban migration and is statistically significant at level of 1%; and rural revenue effect is, as expected, negative but not significant. The estimated coefficients for equation 4 are presented in column (5). Our findings support the second hypothesis (H2), which indicates that oil and minerals rents are mostly invested in cities in order to develop infrastructures and services. This can attract more people and lead to an acceleration of urbanization as the coefficient associated with resource rents is positive and significant at level of 1% (0.16). When we introduce agricultural performance as a conditioning variable, the effect becomes negative (-0.217). This can imply that the effect on the urbanization rate is positive in countries highly dependent on resources rents but with poor agriculture performance.

Table 4.6 : Static Panel Estimations

	Production	Food dependency		Migration	Urbanization
Dependent variable	*Agri*	*Food_M_Dep*		*Migration*	*Urban*
	(1)	(2)	(3)	(4)	(5)
Agri		-0,272***	-0,266***	-0,047**	0,172***
		(0,031)	(0,035)	(0,019)	(0,032)
Agri×Rent		0,080*		0,223***	-0,217***
		(0,046)		(0,029)	(0,044)
Urban		0,655***	0,667***		
		(0,031)	(0,031)		
Urban×Rent			0,137***		
			(0,025)		
Rent	-0,354***				0,160***
	(0,091)				(0,036)
Constant	-0,103***	0,086**	0,064*	0,042	0,123***
	(0,037)	(0,035)	(0,033)	(0,030)	(0,029)
Land	0,545***				
	(0,078)				
Rural	0,479***				
	(0,143)				
Yield	0,104**				
	(0,047)				
Rural_income				-0,050	
				(0,040)	
Income					1,076***
					(0,048)
Demo				0,561***	
				(0,055)	
Adj, R2	0,582	0,415	0,421	0,394	0,612
F-Statistic	17,009	76,209	78,036	78,466	188,862
Prob(F-Stat)	0,000	0,000	0,000	0,000	0,000
Redundant fixed effect test (H_0: Pooled regression model is more appropriate)					
R-Statistic	18,182	34,380	34,206	269,781	442,398
Prob(R)	0,000	0,000	0,000	0,000	0,000
Hausman test (H_0: Random effect test is more appropriate)					
H-Statistic	9,090	18,817	18,091	17,672	20,587
Prob(H)	0,059	0,000	0,000	0,001	0,000
Obs.	461	319	319	478	478
N	37	30	30	38	38

***, **, and * indicate significance level at 1%, 5%, and 10%, respectively, against a two sided alternative, figures in parentheses are cluster standard errors and they are robust to arbitrary heteroskedasticity and arbitrary intra-group correlation.

4.5.3 Analysis of the Dynamic Panel Data Estimations

Table 4.7 reports the estimation results of a dynamic panel using the GMM method with instruments to deal with measurement errors in dependent variables and potential omitted variable bias. Instruments are taken from lags dated from t-2 to t-5. We observe a positive and statistically significant effect of the lagged dependent variable for all regressions. This means that the omitted variable bias is now reduced. Similar to result obtained from the static panel specification, we find a significant negative impact of resource rents on agricultural performance (column 1). We also find a positive impact of agricultural performance on food imports dependency that is statistically significant at the 1% level (columns 2 and 3). The impact of resources rents on food imports dependency is positive whether it interacts with agricultural performance (column 2) or with urbanization (column 3). As obtained in the static estimation, agricultural performance is a determinant for rural-urban migration. The impact becomes positive and significant when we introduce an interaction with resources rents (column 4) but the estimated coefficient values is way smaller than the one obtained in a static specification. This may be due to the introduction of a lagged dependent variable. Our estimation indicates a positive and significant effect of resource rents on urbanization at level of 1% (column 5). We do not find the expected sign for the interaction between agriculture and resources rents. The coefficient is positive but too small as it only equals 0.014.

Table 4.7: Dynamic panel estimations

	Production	Food dependency		Migration	Urbanization
Dependent variable	*Agri*	*Food_M_Dep*		*Migration*	*Urban*
	(1)	(2)	(3)	(4)	(5)
lag	0,687***	0,137***	0,170***	0,959***	1,009***
	(0,0889)	(0,0150)	(0,0069)	(0,0001)	(0,0035)
Agri		-0,248***	-0,113***	-0,017***	0,009***
		(0,0565)	(0,0396)	(0,0001)	(0,0009)
Agri×Rent		0,195***		0,004***	0,014***
		(0,0431)		(0,0001)	(0,0012)
Urban		1,911***	-0,475***		
		(0,1734)	(0,0740)		
Urban×Rent			0,133***		
			(0,0373)		
Rent	-0,607***				0,012***
	(0,1720)				(0,0012)
Land	1,617**				
	(0,7354)				
Rural	6,377***				
	(0,9439)				
Yield	0,406***				
	(0,0855)				
Rural_income				-0,009***	
				(0,0004)	
Income					
Demo					0,012***
					(0,0017)
Adj, R2	0,454	0,433	0,449	0,835	0,808
J-Statistic	23,790	21,455	24,123	30,263	28,423
Prob(j)	0,162	0,612	0,512	0,651	0,442
m-Statistic	1,205	-0,564	-0,404	0,877	0,984
Prob(m)	0,228	0,573	0,686	0,381	0,325
Obs.	376	285	285	405	405
N	35	29	29	37	37

***, **, and * indicate significance level at 1%, 5%, and 10%, respectively, against a two sided alternative, figures in parentheses are cluster standard errors and they are robust to arbitrary heteroskedasticity and arbitrary intra-group correlation.

4.6 Conclusion

This chapter examines the mechanism through which natural resources lead to poor agricultural performance and rapid urbanization in African countries. Using static and dynamic panel models covering the period 2000-2013 and 39 African countries, we show that resources rents affect negatively agricultural value added and positively food imports dependency. At the same time, results show a positively significant impact of resources rents on rural-urban migration and therefore the urbanization rate. These findings imply that resource-rich countries indeed have a tendency to neglect agriculture that can be justified by attractive world food commodity prices. However, since 2007-2008, food prices have shown a higher volatility and this situation can present a food security risk for millions of Africans.

The positive impact of natural resources rents on the urbanization rate can be interpreted as both a cause and a consequence of policy choices. On the one hand, as policy-makers in resource-rich nations tend to invest in extractive industries to the detriment of other sectors like agriculture, they create a *push factors* for rural migration. On the other hand, as these policy-makers allocate the rents in priority to develop infrastructures in urban area (generally in port cities), they create some *pull factors* to rural population looking for a better life. In fact, this could explain the massive rural-urban migration which contributes to the ongoing debate about the inequality of resource rents distribution in a society.

Generally, urbanization and economic growth are closely linked. The strong positive correlation between these two indicators has been numerously documented[19]. There is no doubt that much of the causation goes from economic growth to increased urbanization. However, as countries grow, they undergo structural changes. Labor forces are reallocated from rural agriculture to urban manufacturing and services sectors (Michaels et al., 2012) and when urbanization occurs without industrialization, serious urban and development problems can arise (Gollin et al, 2013). This is particularly the case for most African countries. The statistical analysis presented in table 5 shows evidence that the urbanization in rich-resource African countries is associated with huge social problems (Expansion of urban slums, limited access to improved water and sanitations facilities).

Further research is needed to focus on this complex causal link between urbanization problems and resource dependence in rich-resources African countries. Future studies should also evaluate the final impact of rapid urbanization in many resource-rich African countries. A time-series analysis of this group of countries, over a longer period, will also allow for more conclusive results.

[19] See for instance World Bank (2009) and Henderson (2002, 2010).

4.7 References

- Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies, 58(2),* 277-297.
- Arezki, R., & Gylfason, T. (2013). Resource rents, democracy, corruption and conflict: Evidence from sub-Saharan Africa. *Journal of African Economies*, *22*(4), 552-569.
- Auty, R. M. (1986). Resource-based industrialization and country size: Venezuela and Trinidad and Tobago. *Geoforum, 17(3-4),* 325-338.
- Auty, R. M. (Ed.). (2001). *Resource abundance and economic development*. Oxford University Press.
- Badeeb, R. A., Lean, H. H., & Clark, J. (2017). The evolution of the natural resource curse thesis: A critical literature survey. *Resources Policy*, *51*, 123-134.
- Baltagi, B. H. (1995). *Econometric analysis of panel data* (Vol. 2). New York: Wiley.
- Barajas, M. A., Chami, M. R., & Yousefi, M. R. (2013). *The finance and growth nexus re-examined: Do all countries benefit equally?* (No. 13-130). International Monetary Fund.
- Beck, T. (2011). Finance and Oil: Is there a resource curse in financial development?. *European Banking Center Discussion Paper*, (2011-004).
- Bhattacharyya, S., & Collier, P. (2013). Public capital in resource rich economies: Is there a curse?. *Oxford Economic Papers*, *66*(1), 1-24.
- Bhattacharyya, S., & Hodler, R. (2010). Natural resources, democracy and corruption. *European Economic Review, 54(4),* 608-621.
- Birdsall, N., Pinckney, T., & Sabot, R. (2001). Natural resources, human capital. *Resource abundance and economic development*, *57*.
- Boschini, A., Pettersson, J., & Roine, J. (2013). The resource curse and its potential reversal. *World Development, 43*, 19-41.
- Bravo-Ortega, C., & De Gregorio, J. (2005). *The relative richness of the poor? Natural resources, human capital, and economic growth*. The World Bank.
- Brunnschweiler, C. N. (2008). Cursing the blessings? Natural resource abundance, institutions, and economic growth. *World development, 36(3),* 399-419.
- Bulte, E. H., Damania, R., & Deacon, R. T. (2005). Resource intensity, institutions, and development. *World development, 33(7),* 1029-1044.
- Byerlee, D. (1974). Rural-urban migration in Africa: Theory, policy and research implications. *The International Migration Review, 8(4),* 543-566.
- Collier, P. (2010). *The plundered planet: Why we must--and how we can--manage nature for global prosperity*. Oxford University Press.
- Collier, P., & Hoeffler, A. (2005). Resource rents, governance, and conflict. *Journal of conflict resolution, 49(4),* 625-633.
- Collier, P., & Hoeffler, A. (2009). Testing the neocon agenda: democracy in resource-rich societies. *European Economic Review, 53(3),* 293-308.
- Coolidge, J., & Rose-Ackerman, S. (1999). *High-level rent-seeking and corruption in African regimes: Theory and cases*. The World Bank.
- Corden, W. M. (1984). Booming sector and Dutch disease economics: survey and consolidation. *oxford economic Papers*, *36*(3), 359-380.
- Corden, W. M., & Neary, J. P. (1982). Booming sector and de-industrialisation in a small open economy. *The economic journal, 92(368),* 825-848.

- Daniele, V. (2011). Natural Resources and the 'quality'of economic development. *The Journal of Development Studies, 47(4),* 545-573.
- Davis, G. A., & Tilton, J. E. (2005, August). The resource curse. In *Natural resources forum* (Vol. 29, No. 3, pp. 233-242). Blackwell Publishing, Ltd..
- Dietz, S., Neumayer, E., & De Soysa, I. (2007). Corruption, the resource curse and genuine saving. *Environment and Development Economics, 12(01)*, 33-53.
- Duranton, G. (2015). Growing through cities in developing countries. *The World Bank Research Observer, 30(1),* 39-73.
- Englebert, P. (2002). *State legitimacy and development in Africa*. Lynne Rienner Publishers.
- Frankel, J. A. (2010). *The natural resource curse: a survey (No. w15836).* National Bureau of Economic Research.
- Gollin, D., Jedwab, R., & Vollrath, D. (2013). Urbanization with and without Structural Transformation. *mimeograph, George Washington University*.
- Gylfason, T. (2001a). Nature, power and growth. *Scottish Journal of Political Economy, 48(5),* 558-588.
- Gylfason, T. (2001b). Natural resources, education, and economic development. *European economic review, 45(4),* 847-859.
- Henderson, V. (2010). Cities and development. *Journal of Regional Science,50(1),* 515-540.
- Henderson, V. (2002). Urbanization in developing countries. *The World Bank Research Observer, 17(1),* 89-112.
- Humphreys, M., Sachs, J., & Stiglitz, J. E. (Eds.). (2007). *Escaping the resource curse*. New York: Columbia University Press.
- Iimi, A. (2006). *Did Botswana Escape from the Resource Curse? (No. 2006-2138).* International Monetary Fund, Washington DC.
- Isham, J., Woolcock, M., Pritchett, L., & Busby, G. (2005). The varieties of resource experience: natural resource export structures and the political economy of economic growth. *The World Bank Economic Review, 19(2)*, 141-174.
- Kaufmann, D., & Vicente, P. C. (2011). Legal corruption. *Economics & Politics,23(2),* 195-219.
- Lederman, D., & Maloney, W. F. (2008). In search of the missing resource curse. *Economía, 9(1),* 1-56.
- Manzano, O., & Rigobon, R. (2001). *Resource curse or debt overhang? (No. w8390).* National bureau of economic research.
- Mehlum, H., Moene, K., & Torvik, R. (2006). Institutions and the resource curse. *The economic journal, 116(508),* 1-20.
- Michaels, Guy, Ferdinand Rauch, and Stephen J. Redding. (2012). Urbanization and structural transformation. *Quarterly Journal of Economics 127(2)*:535–586.
- Papyrakis, E., & Gerlagh, R. (2003). Natural resources: a blessing or a curse?.
- Papyrakis, E., & Gerlagh, R. (2004). The resource curse hypothesis and its transmission channels. *Journal of Comparative Economics, 32(1),* 181-193.
- Papyrakis, E., & Gerlagh, R. (2007). Resource abundance and economic growth in the United States. *European Economic Review, 51(4),* 1011-1039.
- Robinson, J. A., Torvik, R., & Verdier, T. (2006). Political foundations of the resource curse. *Journal of Development Economics, 79(2),* 447-468.
- Ross, M. L. (2001). Does oil hinder democracy?. *World politics, 53(3),* 325-361.

- Sachs, J. D., & Warner, A. M. (1995). *Natural resource abundance and economic growth* (No. w5398). National Bureau of Economic Research.
- Sachs, J. D., & Warner, A. M. (1997). Sources of slow growth in African economies. *Journal of African Economies, 6(3),* 335-376.
- Sachs, J. D., & Warner, A. M. (1999). The big push, natural resource booms and growth. *Journal of development economics, 59(1),* 43-76.
- Sachs, J. D., & Warner, A. M. (2001). The curse of natural resources. *European economic review, 45(4),* 827-838.
- Sargan, J. D. (1958). The estimation of economic relationships using instrumental variables. *Econometrica: Journal of the Econometric Society*, 393-415.
- Sarraf, M., & Jiwanji, M. (2001). *Beating the resource curse: the case of Botswana.* Environment Department, World Bank, Washington DC.
- Stijns, J. P. C. (2005). Natural resource abundance and economic growth revisited. *Resources policy, 30(2),* 107-130.
- Torres, N., Afonso, Ó., & Soares, I. (2013). *A survey of literature on the resource curse: critical analysis of the main explanations, empirical tests and resource proxies* (No. 1302). Universidade do Porto, Faculdade de Economia do Porto.
- Van der Ploeg, F. (2011). Natural resources: Curse or blessing?. *Journal of Economic Literature, 49(2),* 366-420.
- World Bank. (2009). *World Development Report 2009: Reshaping Economic Geography*. Washington dc: World Bank.
- Zagozina, M. (2014). *The resource curse paradox: natural resources and economic development in the former Soviet countries* (Doctoral dissertation, Helsingin yliopisto).

General conclusion

Management of non-renewable resources provides a broad field for research. I have tried in this thesis to look at a subset of issues. The field allows researchers to engage in a wide range of topics, each with its own particularities, issues and interesting features. I focused my researcher on phosphate rock- a finite and non-renewable resource- for three reasons: first, the resource is mostly used in food production and, to this date, there is no known substitute for it. Second, global reserves are unequally distributed, with only few countries controling the global market. Third, phosphate prices rose significantly and have become more volatile during the last decade, prompting a debate on its future availability.

This thesis is divided into four chapters. Since each chapter starts with a section summarizing the main results and ends with a concluding section, this general conclusion will then be brief.

In chapter 1, I provided an introduction to the global phosphate rock market. I showed, based on the last USGS data, that world phosphate rock reserves are concentrated in few countries mainly in the MENA region and global trade is concentrated, since some major producing countries are also among the major users. I discussed the "peak phosphorus" hypothesis and I demonstrated that, contrary to recent published articles predicting a peak of phosphate production in the nearest future, current available data show no clear indications that phosphate rock deposits are facing depletion any soon. In addition, as recent studies have predicted that Morocco is moving towards a near-monopoly position in phosphate production and this might potentially create a price-setting behaviour, I also discussed the political, technical and environmental risks that can seriously affect future supply.

In chapter 2, I proposed a strategic game model to examine how phosphate producers, facing a growing demand, make their investment decisions in order to meet their optimal market share. The results show that the phosphate rock market will become, in the future, more concentrated than it is today. World phosphate rock will be produced by 11 countries and just 8 countries will provide more than 90% of global PR production by 2100 (China excluded). Besides China, long-term supply will mainly come from Morocco (about 37% of global production), Syria (11%), Australia (10.8%), Algeria (7.8%), Tunisia and Saudi Arabia (7.7% each) and Kazakhstan (6.9%). In terms of capacities, the results suggest that new capacities will come from Morocco, with a capacity multiplied by 370% (from a present capacity of 36 Mt/y to over 133Mt/y by 2100). Additional capacities will mainly come from Australia, Syria and Algeria. Since all major PR producing countries are moving towards vertical integration, where mining companies will also produce fertilizers, phosphoric acid and other derivatives of phosphate rock, phosphate rock producers will face two options: exporting phosphate rock or exporting fertilizers. The proposed model could similarly be used to examine the equilibrium state and compute the equilibrium quantities of PR to be exported with or without transformation.

Chapter 3 attempted to evaluate the macroeconomic impact arising from OCP's activities within the overall economy using an Input-Output Analysis model. I have combined the detailed Profit and Loss (P&L) statements from OCP Group with the latest Moroccan I-O table to bring out OCP activities and to split them into two sectors: "OCP-Mining" and "OCP chemical". I estimated the direct, indirect and induced effects of a change in final demand for OCP products on national output, income and employment. The results indicate that OCP-chemical has a high production-inducing effect and a high income and employment-inducing effect compared to OCP-mining. In addition, the results show that OCP-chemical has more capacity to generate employment opportunities on a large scale compared to OCP-mining. The linkage analysis shows that OCP-chemical is strongly backward linked compared to OCP-mining which is intermediately backward linked with the others sectors of the economy. However, I noted that both OCP sectors have a low forward linkage effect. Finally, OCP Group is engaged in an important investment program during the period 2010-2020 to increase production capacity, reduce production costs and increase flexibility by introducing new production tools and technologies. The Group announced that this investment program would have a positive impact on the environment and local communities (OCP Group Activity Report, 2013). A future extension of the framework presented in this paper will involve introducing a time dimension in the model (dynamic I-O model) in order to measure the socio-economic and environmental impacts of OCP's investment program.

The purpose of chapter 4 was to examine the mechanism through which non-renewable resource abundance leads to poor agricultural performance and rapid urbanization in African countries. Using static and dynamic panel models covering the period 2000-2013 and 39 African countries, I showed that non-renewable resources rents affect negatively the agricultural sector performance and positively rural-urban migration and therefore the urbanization rate. These findings imply that resource-rich countries have indeed a tendency to neglect agriculture that can be justified by attractive world food commodity prices. However, since 2007-2008, food prices have shown higher volatility and this situation can present a risk for food security for millions of Africans. The positive impact of natural resources rents on the urbanization rate can be interpreted as both a cause and a consequence of policy choices. On the one hand, as policy-makers in resource-rich nations tend to invest in extractive industries to the detriment of other sectors like agriculture, they create *push factors* for rural migration. On the other hand, as these policy-makers allocate in priority the rents to develop infrastructures in urban areas (generally in port cities), they create some *pull factors* for rural populations looking for a better life. In fact, this could explain the massive rural-urban migration which contributes to the ongoing debate about the inequality of resource rents distribution in society. In addition, the statistical analysis presented in this chapter shows evidence that urbanization in resource rich African countries is associated with huge social problems (expansion of urban slums, limited access to improved water and sanitations facilities). Further research is needed to focus on this complex causal link between urbanization problems and resource dependence in resource rich African countries. Future studies should also evaluate the final impact of rapid urbanization in many resource-rich countries in Africa. A time-series analysis of this group of countries, over a longer period of time, will also allow for more conclusive results.

RÉSUMÉ

Cette thèse a pour objet l'examen de la gestion durable des ressources non renouvelables en général et du phosphate naturel en particulier.

Le premier chapitre expose l'état, les perspectives et les enjeux économiques et géopolitiques du marché mondial des phosphates. Il s'attache à mettre en exergue de cette analyse un important déficit, à long terme, de l'offre mondiale par rapport à la demande incitant les producteurs des phosphates, qui ont suffisamment des réserves, à investir dans des nouvelles capacités.

Le deuxième chapitre développe un modèle Stackelberg à plusieurs joueurs, calibré sur des données effectives du marché des phosphates et permet de calculer les capacités optimales à mettre en place par les producteurs selon leurs niveaux de réserves et leurs coûts de développement. Les résultats de ce modèle montrent que le marché deviendrait plus concentré, en 2100, qu'il est aujourd'hui avec une dominance du Maroc, le pays qui détient les trois quarts des réserves mondiales.

Le troisième chapitre vise à évaluer les effets d'entraînement que le Maroc dégage de son exploitation des phosphates. En utilisant le modèle Input-Output, l'analyse empirique proposée compare les impacts socio-économiques de l'extraction à ceux liés à la valorisation ou à la transformation. Les résultats de cette analyse montrent que la transformation des phosphates est plus reliée en amont avec les autres branches de l'économie et génère plus de valeur ajoutée, de revenues et d'emplois.

Le dernier chapitre s'évertue à traiter à de nouveaux frais la question de la malédiction des ressources naturelles en reliant la performance agricole et l'urbanisation à l'abondance de ces ressources. L'étude empirique, basée sur un panel de pays africains, exhibe un lien significatif entre l'abondance de ressources minières, le sous-développement du secteur agricole et l'explosion urbaine.

MOTS CLÉS

Phosphate ; Modèle Stackelberg ; Modèle Entré-Sorties ; Malédiction des ressources naturelles ; Performance agricole ; Urbanisation

ABSTRACT

The purpose of this thesis is to examine the sustainable management of non-renewable resources in general and phosphate rock in particular.

The first chapter presents the current situation, future trends and geopolitical issues pertaining to the global phosphate market. The analysis shows a large deficit in world phosphate supply in the future, inciting producers with sufficient phosphate reserves to invest in new capacities.

The second chapter develops a multi-leader-multi-follower Stackelberg model, calibrated using real data from the phosphate market. This model derives the optimal future capacities for different producers according to their reserve levels and their development costs. The results show that the market would become more concentrated in 2100, with Morocco being the dominante country wich already holding three quarters of the world's reserves.

The third chapter presents and calculates the linkage effects generated by Morocco's phosphates exploitation. Using the Input-Output model, the proposed empirical analysis compares the socio-economic impacts of extraction to those related to transformation or valorization. The results of this analysis show that phosphates transformation is more linked to the other sectors and generates higher socio-economic impacts in terms of added value, income and employement.

The last chapter contributes to the literature on the natural resources curse by linking agricultural performance and urbanization to the abundance of resources. The empirical study, based on a panel of African countries, shows a significant link between the abundance of mineral resources, the underdevelopment of the agricultural sector and urban explosion.

KEYWORDS

Phosphate; Stackelberg model; Input-Output Model; Natural resources curse; Agricultural performance; Urbanization