Wirtschaftswissenschaftliches Zentrum (WWZ) der Universität Basel

July 2012

The Visible Hand: National Oil Companies, Oil Supply and the Emergence of the Hotelling Rent

WWZ Discussion Paper 2012/11
(B-120)

Markus Ludwig

The Author:

Markus Ludwig, Assistant

University of Basel

Department of Business and Economics

Peter Merian-Weg 6

CH - 4002 Basel

phone: +41(0)61 267 33 59
Fax: +41(0)61 267 32 51

markus.ludwig@unibas.ch

A publication of the Center of Business and Economics (WWZ), University of Basel.

This publication and the research project presented within it have been financially supported by the Förderverein of the WWZ (Center of Economics Sciences of the University of Basel).

Contact:
WWZ Forum | Peter Merian-Weg 6 | CH-4002 Basel | forum-wwz@unibas.ch | www.wwz.unibas.ch

The Visible Hand: National Oil Companies, Oil Supply and the Emergence of the Hotelling Rent*

Markus Ludwig†

Department of Business and Economics, University of Basel, Switzerland

July 22, 2012

Abstract

Using firm-level panel data, this paper exposes differences in the dynamic oil production regime between private and state-owned firms. I find that state-owned firms reduce the oil supply, ceteris paribus, by 3.5 percent each year, but private firms hold output constant. Furthermore, state-owned firms have not followed such stringent policy before 1997. My extension of the Hotelling-model attributes the behavior of state-owned firms to a scarcity rent, whereas private firms produce at their constant capacity limit, owing to possible expropriation. The theory also indicates that state-owned firms will only switch to a Hotelling-regime after a certain lag time, attributable to limited capacity. The data further reveals that contractions in the supply of state-owned oil lead to oil price increases, indicating that state-owned firms do, in fact, generate a scarcity rent. My results therefore suggest that the shift from private towards state-owned oil dominance in the 1970s gave rise to a delayed increasing oil price path.

*I wish to thank Michael Wagner, Hermione Miller-Moser, Matthias Flückiger, the participants of the economics lunch at the Faculty of Business and Economics of the University of Basel for valuable suggestions and Frank Krysiak for valuable comments, advice and time. This work was supported by the Förderverein des WWZ.
Email addresses: markus.ludwig@unibas.ch (M. Ludwig)

†Corresponding author. Tel.:+41 (0)61 267 33 59 ; fax:+41 (0)61 267 32 51 ; Postal address: Peter Merian-Weg 6, Postfach, CH-4002 Basel.

1 Introduction

For nearly a decade now, the sustained crude oil price rally has been fueling the fear that there is no going back to cheap oil in the near future. The price rally originates from the dramatic demand shift, caused by new heavyweight emerging economies with high income elasticities of oil demand like China and India, and from the sluggish oil supply response of the oil producers. In view of this situation, one primarily wonders at what price the supply side will be able and willing to satisfy the rising world oil demand.

Economic implications arise from the risk that the high oil price might hamper economic recovery after the recent recession. Moreover, the peaking oil price in 2008 was arguably a driving force behind the recession itself (Hamilton, 2009a), and as crude oil is the backbone of large areas of economic activity, the oil price affects the economy through various channels (Lee and Ni, 2002). In order to assess the relevance of oil, Figure 1 displays yearly average crude oil expenditure[1] as a share of GDP, in US dollars, for several countries and aggregates. Starting in 2000, the world spent about 2.6 percent of its income on oil. This share increased subsequently with the exploding oil price and peaked at around 5 percent during the financial crisis. The prominent position of oil is based on its low price elasticity and in the case of developing countries, on an income elasticity that is near unity (Hamilton, 2009b). The income elasticity declines with economic development and is thought to be around 0.5 percent for OECD countries.

Scrutinizing the supply side more closely reveals that far more than half of today's oil production is controlled by national oil companies, and almost 90 percent of all proven oil reserves are owned by national oil companies (EIA, 2009). This is in stark contrast to the situation four decades ago, when oil production was predominantly in private hands. Thus, the question at what price oil will be supplied in the future boils down to the ability and the willingness of national firms and their governments.

Given this shift from a private-dominated oil market towards an overwhelming dominance of national firms, I explore in this paper to what extent differences between (multinational) private firms and national firms under government control can explain oil price increases. My regression analysis exploits a firm-level panel data set of the 50 largest oil firms, which accounted on average for nearly 75 percent of the world oil supply during the sample period 1987-2010.

The data reveals three key points. First, by the mid-1990s the Hotelling rule emerged as a dominant factor governing the oil supply of *fully* state-owned firms[2] which provide the bulk of oil to the world market. Second, private firms differ from national firms, since they do *not* follow a Hotelling regime, but produce at a constant level at their capacity limit. Finally, national firms,

[1]The data on the oil consumption is taken from the BP-Statistical Review of World Energy 2011.

[2]From here on, state-owned, refers to 100-percent state ownership. In this study, I use the term national and state-owned interchangeably.

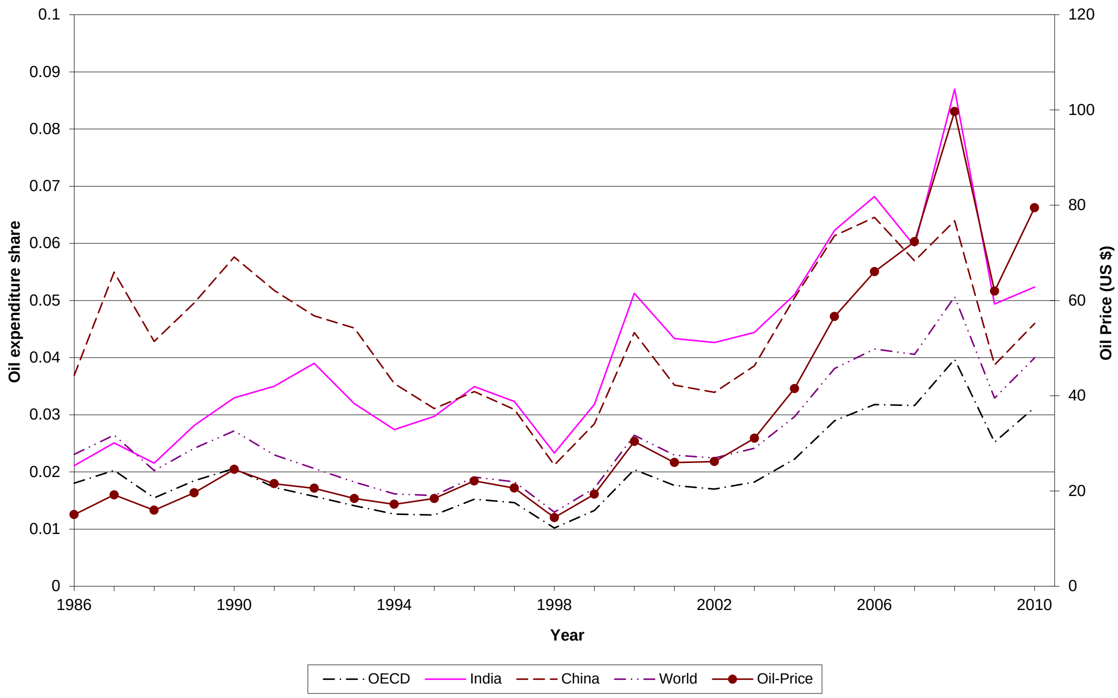

Figure 1: Average yearly expenditure (US $) on oil as share of GDP (US $) (1986-2010)

which in large part emerged through expropriation in the 1970s, did not follow a Hotelling path immediately after formation, but only after a certain lag time of constant oil production. The evidence suggests that it is not the peak-oil effect or the inefficiency of national firms that are the driving forces behind the oil price increase, but instead the shift (in 1970-1984) from private towards state-owned oil dominance and the subsequent emergence of a scarcity rent in case of national firms, which result in an increasing oil price path.

In particular, I find that the sluggish supply response is the result of a 'visible hand on the tap' (The Economist, 2007) policy of national firms, that limit their oil supply in order to generate a Hotelling rent. National firms and their respective governments exacerbate the oil price rally by successively reducing the oil supply by a yearly rate of 3.5 percent according to my regression estimates. On the other hand, I find that national firms did not realized a scarcity rent before the mid-1990s, but produced at their given capacity limit, ceteris paribus. The same holds true for the case of private firms. Here, I show that private firms produce at their capacity limit during the whole sample period and hence do not follow the Hotelling rule at all.

To support the empirical analysis, I present a simple stylized model that builds on Hotelling (1931). My model allows for market decomposition into private firms and state-owned firms, where the former face expropriation, but the latter do not. The theoretical framework facilitates the interpretation of the empirical results. The regression analyses show that private firms produce at a constant rate, ceteris paribus. Within the model, this is due to the expropriation date which limits the time horizon of the firm. The data also reveals that state-owned firms, which do not face an expropriation date, are homogenously[3] on a declining production path from 1997 onwards. According to the theory, this follows from the Hotelling rule, where the shadow price has to increase according to the interest rate. The theory further suggests that national firms initially, after formation, produce at a constant rate before following a Hotelling path. Thus, the model is able to explain why national firms switch to a Hotelling path only after a certain lag time. I also show that starting in the mid-1990s the declining extraction path of national firms successively resulted in a price increase, which is consistent with the theoretical model.

Moreover, the theoretical model allows for the following casual interpretation of the historical oil price development:

In an initial period with private firm dominance, the oil price remains constant (until the 1970s). This is followed by a period of heavy oil supply disruption, as the market dominance shifts from private to state-owned firms (in the 1970s). Finally, after market consolidation and a period of constant oil production, the state-owned firms move towards a Hotelling path and oil price increases (starting from the mid-1990s). Figure 2 in the appendix depicts these mechanisms.[4] This agrees with the well documented fact that the shift from private to state-owned oil indicates a remarkable change within the oil industry (Kobrin, 1984; Victor et al., 2012).

Thus, in the case of the oil industry, the Hotelling rule is a quite recent phenomenon, simply because the state-owned firms of net-exporting countries have evolved more recently.[5] This is in line with the casual conclusion of Hamilton (2009b); and the finding of Lin (2011) that the shadow price has increased in recent years. It is also consistent with the rise in the income share spent on oil consumption starting in 1998 (Figure 1). Thus, the dominant position of national firms in the oil industry combined with the scarcity rent do not raise hope for falling oil prices in the long run.

The key contributions of this study are therefore threefold: **(a)** I show that the Hotelling rule is a dominant factor in the decision process of national oil firms; **(b)** but *not* for private firms; **(c)** I further present theoretical and empirical evidence that national firms did not follow a Hotelling regime before 1997, which explains why a Hotelling price path could not be observed immediately after the shift from private to state-owned oil supply dominance.

My work is related to different strands of literature (empirical work on the Hotelling rule, studies on national oil firms and theoretical work extending the Hotelling model) which will be discussed in the following.

[3] In a statistical sense.

[4] It is important to stress that the model, of course, does not account for short-term oil market shocks like the Iran-Iraq war (1980) or demand contractions, for example, through the European sovereign debt crisis, but depicts the long-run mechanisms.

[5] Most state-owned firms of net-exporter countries evolved in the 1970s and early 1980s, major exceptions are Mexico and Iran. However, both did not provide oil to the world market until the 1970s (Kobrin, 1984).

This study is related to the empirical literature testing the Hotelling model for the non-renewable resource sector. Livernois (2009) gives a thorough review of this topic. However, empirical evidence on the Hotelling rule is mixed. Focusing on a U-shaped price path, evolving through technological progress, Slade (1982) finds support for the Hotelling model. In contrast, Berck and Roberts (1996), using a more sophisticated ecometric technique find no U-shape and hence no support for the Hotelling rule. Looking at the development of the shadow price, Adelman and Watkins (2005) find no rise in the latter and hence reject the Hotelling rule for the oil sector. For a more recent period, however, Lin (2011) demonstrates an increase in the shadow price of oil, indicating support for a scarcity rent. The most convincing evidence on the Hotelling rule stems from data on non-renewable resources outside the oil market (e.g., stumpage prices for Old-Growth forests (Livernois et al., 2006)). However, to the author's knowledge no literature dealing with the Hotelling rule on the firm level in the case of the oil industry exists and, in particular, with the differentiation along the line of state-owned and private firms. Therefore, my results contribute to this branch of literature by identifying the decomposition of the oil sector into private and national firms as a crucial factor for the empirical application of the Hotelling model.

Due to their dominant position in the oil sector, extensive literature exists on the topic of state-owned oil firms outside the Hotelling literature. Two prominent studies are the PESD study edited by Victor et al. (2012) and the World Bank study of Tordo et al. (2011) which focus on peculiarities of the individual state-owned firm. The World Bank and PESD reports attempt to evaluate the efficiency of different national firms in a broader, not purely economic, context.[6] My study draws heavily on the historical case studies in this literature for the stylized facts presented in Section 2. Both studies stress the point that significant variation between state-owned firms exist, and aim to determine its cause. Even though, state-owned firms come in various forms (Tordo et al., 2011, Vol. I, p. 22), I add to this literature by identifying the Hotelling rule as an underlying economic pattern which is a general mechanism, in a statistical sense, attributable to all state-owned firms. Thus, despite the numerous idiosyncratic features of individual state-owned firms, there is a common economic driver: the Hotelling rent. My study further, in particular the stylized facts in Section 2, draws on Kobrin (1984) who gives a thorough summary of the first wave of expropriation in the 1970s, resulting in the establishment of most national oil firms which provide the bulk of world oil supply today.

That private and state-owned firms differ systematically in terms of production has been noted by Johany (1979) and Mead (1979). Especially, when expropriation is evident, private firms tend to increase oil production. Belonging to this strand of literature, there exist various studies on the efficiency differences between private and state-owned firms. Eller et al. (2010) find that national

[6]The studies move beyond efficiency in a pure economic sense, but also take the multi-dimensional challenges faced by national oil companies into account, such as social contributions.

firms are less efficient than their private counterparts. The empirical analysis conducted below is connected to the empirical study by Wolf (2009), who employs the same dataset, but without the period 2007-2010, and examines the effect of state-ownership on efficiency. In contrast to Wolf (2009), my empirical analysis concentrates on the effect of the market decomposition into private and state-owned firms on the dynamic behavior of the oil production path for the respective firms. That is, I use the qualitative predictions of my theoretical model to test for a Hotelling regime in the case of state-owned firms, which is not addressed in Wolf (2009). He finds that national firms produce at a significantly lower level compared to private firms, using pooled data on the gas and oil supply. In contrast to Wolf (2009), my results for the oil sector suggest that state-owned firms produce at a higher level than private firms, taking the Hotelling rent into consideration.[7] I also include additional country-specific variables (e.g., a corruption index) and time dummies in my analysis.

Further, it has been shown before by Long (1975), that firms facing a limited time horizon will produce at a constant rate. The main difference to the theoretical work by Long (1975) is that my model endogenizes the expropriation decision of the country. Thus, it depicts a complete picture of the decision interactions of the state and the firm and their effect on the oil supply over time. My work is also related to more general discussions of national oil companies (Adelman, 2002; Stevens, 2008).

Finally, my findings relate to studies reporting structural breaks in the price path of natural resources; e.g., Lee et al. (2006).

The paper is organized as follows. In Section 2, I present some historical examples which emphasize that the assumptions of the theoretical model are based on stylized facts found in real life. Section 3 presents the theoretical model. Section 4 presents a casual interpretation of the oil price path. Section 5, Section 6 and Section 7 describe the data and report the empirical findings. Section 8 presents robustness checks of the link between theory and empirics, and Section 9 concludes.

2 Stylized Facts

The stylized facts presented here, serve as the point of departure for the theory and as a tool to evaluate the model assumptions in a historical context of the oil industry. These stylized facts mainly relate to the state-owned firms that emerged with the first wave of nationalizations in the 1970s, and, in the case of Norway in the early 1980s which provide the bulk of world oil supply today.[8] Thus, almost all national firms of this period evolved from some kind of expropriation

[7] In turn, when not controlling for the Hotelling rent effect, my results are similar to Wolf (2009).

[8] Before I proceed, it is necessary to clarify the following concept. In this study, I use the term expropriation (nationalization) in the sense of a transfer of decision-making power in the oil production process from a private firm to the state akin to Stevens (2008) concept of resource nationalism, defined as greater national control over natural

process (Victor et al., 2012, p. 6).[9] However, the pattern outlined below emerges again in the case of national firms in the former USSR. It is further important to stress that I concentrate in this study on national firms of net-exporting countries. In other words, firms that add to the world oil supply and hence affect the world oil price directly.

During the era of the 'seven sisters' (around 1950-1970), most oil was produced by private enterprises. The seven sisters were a cartel of private firms which exerted almost total control over the oil market (Victor et al., 2012, p. 5). In particular, the emergence of a world oil market is closely associated with these private firms, since before WW II international trade in oil was insignificant (Adelman, 2002; Wyant, 1977). However, in the wake of a first wave of resource nationalism, starting in the Middle East during the 1970s, governments began to assume control of their oil production. This has often been achieved by means of a state-owned oil company. In other words, before nationalization in the 1970s, only 1 percent of world oil reserves were in the hands of state-owned firms (Victor et al., 2012, p. 6). Today, almost 90 percent of the world's reserves are owned by state-owned firms (EIA, 2009). After the re-strengthening of private oil firms' market power, due to resource privatization in the former Soviet Union and a surge of consolidations in the oil industry through 'super-mergers', a second expropriation wave hit the oil industry more recently, as Venezuela, Ecuador, Bolivia, and Russia increased the prevalence of state-control by expropriating private owners and investors (Engel and Fischer, 2008). Thus, the history of state-owned oil firms, which add significantly to the world oil supply, is young and commenced in the 1970s (Kobrin, 1984).[10]

I now present two strands of stylized facts: **(i)** case studies of countries, describing the transition from private to state-owned oil production. **(ii)** the knowledge transfer from private to state-owned firms.

(i) The transition from private to state-owned oil production has occurred frequently in the history of the oil industry and explains the origin of almost all national firms today. In Mexico, for example, oil production shifted through expropriation from private hands to the then state-owned oil company Petromex.[11] A similar pattern emerged in the case of Saudi Arabia, when the Arabian American Oil Company (Aramco) started oil production in Saudi Arabia in the 1930s. It was initially owned and privately controlled by Standard Oil of California (Socal), but was

resource development. This shift might take place through outright expropriation of the firm's capital equipment and/or drilling rights, by the financial acquisition of the firm's capital equipment and/or drilling rights or by enforced state participation in the oil producing process (e.g., Norway used enforced production sharing contracts). As the differentiation is not important here, because all that matters is the shift in decision-making power or greater national control, I will not distinguish and use the concept of expropriation as described above.

[9] An exception is, for example, the Brazilian Petrobras (Victor et al., 2012).

[10] Notable exceptions are Mexico and Iran, but neither Pemex nor NIOC supplied oil to the world market before the 1970s (Kobrin, 1984).

[11] Mexico expropriated in the late 1930s, but had no access to the world oil market until the 1970s.

subsequently taken over by the Saudi Arabian government and is today completely state-owned and controlled. More recently, the Russian government incorporated the former private firm Yukos into the national company Rosneft.

Accordingly, it is possible to decompose the oil industry into two parts: on the one hand, private firms that operate in a country under a finite time horizon until expropriation, and which do not expect to fully exhaust the oil reserves of their host country; on the other hand, national firms that operate domestically within a much longer time horizon subsequent to expropriation.

The observations give rise to a simplified two-stage economic order. A country starts to produce oil at a given oil price level. Starting oil production from scratch is difficult and expensive for two reasons. First, large sunk investments (exploration and extraction installations) have to be made. This was especially true in the 1970s, when international private oil companies had a considerable technological advantage (Kobrin, 1984) and is generally true in the case of developing countries which lag in up-front investment. Second, technical and commercial know-how in producing oil has to be acquired, which relates, in particular, to indigenous human capital. Thus, it is much more convenient to employ specialized private firms to explore oil fields and to develop oil production facilities on-site.[12] This is often accomplished by means of a production sharing agreement (PSA).[13] I label this initial period, where a country gives concessions to private firms which make sunk investments and start to produce oil, the first stage in a country's oil producing process. During this initial period the country also accumulates know-how in oil production and the oil business which will be discussed in (ii).

Once this first stage is accomplished, the country starts pushing for increased participation in the oil production process. Finally, the country annexes the control of the oil production process completely or at least extensively. With the shift of control, the second stage is reached. Usually, there is a considerable elapse of time between the commencement of private oil production and the shift to state control; and usually a national oil company is involved in this transfer of control. Norway and Venezuela can be used to exemplify this two-stage process.

Norway initially awarded drilling licenses for the Norwegian Continental Shelf to private firms. In this initial period throughout the 1960s, private companies were fully responsible for the development of the oil fields and the oil production. In 1972, Norway enforced its participation in the oil production process via the newly established NOC Statoil[14] (Øystein Noreng, 1980). The shift from private oil production to state-controlled oil production took much longer in Venezuela. Oil production in Venezuela started in the early 20th century and was conducted by private firms on

[12] Indeed, history delivers few accounts of countries establishing their oil industry, independently, from scratch. One such example is Brazil and its national firm Petrobras (Tordo et al., 2011, Vol. II, p.56)

[13] A PSA is a contract that grants the exclusive right to explore and produce oil in a given area and for a given period. Thus, the time horizon is limited, since extension of the contract is uncertain.

[14] Even today after privatization, 67 percent of Statoil are state-owned.

concession[15] until the nationalization of the oil industry and the creation of Petroleos de Venezuela in 1976 (Wilpert, 2003; Victor et al., 2012, p. 423).

(ii) The transfer of know-how from private firms was fundamental for successful entry into the oil market, for almost all major national firms active today. That is, activity in the oil business requires not only technical but also managerial and organizational capacities which national oil firms to a great extent acquired from private firms (Kobrin, 1984; Marcel and Mitchell, 2006, p. 30). As a consequence, we can associate national firms with a '*learning function*'. Thus, there was usually a period where private firms and state-owned firm activity within a country overlapped and a know-how transfer from private towards national firms took place (Marcel and Mitchell, 2006, p. 29). I now give four examples of this kind of know-how transfer, where an important factor was the accumulation of oil sector-specific human capital:

Algerian's national firm Sonatrach was founded in 1963 and was initially a partner to private firms in major hydro carbonate projects (Victor et al., 2012, p. 561). It was only after several years and its nationalization in 1971 that Sonatrach had accumulated sufficient know-how to operate the Algerian oil sector on its own (Tordo et al., 2011, Vol. II, p. 108).

Similarly, Norwegian Statoil was established in 1972 and acquired its managerial and technical capacity thorough the state enforced partnership with private firms in almost all oil production projects in Norway (Victor et al., 2012, p. 637). This enabled Statoil to accumulate know-how by learning through its interaction with private firms.

Venezuela took a different route in gaining the know-how transfer from private firms. It enforced employment regulations which made sure that private firms hired and trained local workers (know-how transfer). Thus, by the time of nationalization almost all private oil sector employees were Venezuelan which joined the newly established state-owned PDVSA in 1975 (Victor et al., 2012, p. 425). As a consequence, PDSVA draws heavily on its private sector heritage (Victor et al., 2012, p. 425).

The Venezuelan example bears a resemblance to Saudi Arabia. The private oil company Aramco which was active in Saudi Arabia started to train and employ local workers at all organizational levels, as a reaction to nationalization movements in neighboring countries (Victor et al., 2012, p. 179). Furthermore, Aramco helped to jump-start the industrial modernization of Saudi Arabia. All in all, the relations of the private Aramco cooperation with the Saudi Arabian state were positive, enabling a smooth transition from private hands to state-ownership (Saudi Aramco). As a consequence, by the time of Aramco's full nationalization, little changed within the company itself, and most of the company's know-how and staff were retained (Marcel and Mitchell 2006, p. 30; Victor et al. 2012, p. 181).

[15] There was a change in Venezuela's tax policy in the 1940s.

3 The Model

In this section, I develop a simple model to assess the implications of the oil market decomposition into private and state-owned firms. The model is an extension of the basic Hotelling model presented in Hotelling (1931). The main purpose of the theory presented here is to support the argument outlined in this study and to deliver qualitative predictions that can be used for data analysis. Thus, while the model is sophisticated enough to provide useful results for this purpose, it is also sufficiently simple to ensure tractability. Importantly, it is sophisticated enough to carve out an economic theory which is able to, despite being highly abstracted, explain and connect the three key points revealed by the data: **(a)** private firms produce at a constant rate; **(b)** national firms produce initially at a constant rate; and **(c)** national firms switch towards a Hotelling regime only after a certain lag time. The model further abstracts from any idiosyncratic level effects concerning state and national oil firms, since this study is interested in an underlying general economic mechanism and as will be discussed below (Section 6), these effects are accounted for in the econometric analysis.[16]

The model's two key assumptions, which are the existence of a learning function and the fact that most national firms today originated owing to (or are linked to) expropriation, build on the stylized facts presented in Section 2. Before proceeding, it has to be acknowledged that the model is purely descriptive, which allows me to assign a well-founded economic theoretical mechanism to the three key points outlined in this study. However, the model would be overtaxed if one intended to derive predictions of the long-run future oil price, since it does not incorporate demand adaption to oil price increases and further neglects technological progress, affecting both demand and supply.

The model consists of a supply side and a demand side. The demand side is expressed by an isoelastic demand function, which captures the world oil demand. This assumption is based on the fact that crude oil prices around the world are heavily cointegrated (Chen et al., 2009). In the interests of tractability and for simplicity, the world oil reserves are owned by a single country (oil monopoly).[17] Starting at time zero, under a set of predetermined economic and political covariates, the country offers a formal contract to a private firm. This contract includes the unconditional lease of the oil reserves to the firm, the date of expropriation, and the tax rate (not unlike a PSA). The formal expropriation includes the transfer of the firm's sunk investment to the state. There is no informal expropriation, say, for example, in the form of a subsequent tax-rate increase. Thus, there is a commitment to the expropriation date and the tax rate. During the period in which the

[16] Such level effects include corporate governance, cultural identity, historical background as well as the individual scope of objectives (if time invariant).

[17] However, due to the functional form of the model, the equilibria of perfect competition and pure monopoly coincide (Stiglitz, 1976).

private firm is active, the country increases its know-how in oil production and the oil business. The spillover effect is captured by a learning function, which is increasing in time until expropriation.[18] The country's cumulated know-how, in turn, determines the country's capacity limit for oil production and can be treated as a stock variable. More formally, the know-how transfer might be part of the concession contract; e.g., as a training program for the local population, which is a common contractual detail. Hence, the country offers the contract, including expropriation date and tax rate, under perfect information and is aware of the firm's cost function and optimal sunk investment as well as its own covariates.

A single private firm obtains the concession from the country, places its one-time investment (sunk costs) and starts producing oil. This one-time investment can be interpreted as the fixed real capital necessary for oil extraction. It also sets an upper bound on the maximal production capacity in such a way that the private firm cannot extract total oil reserves at once. This assumption is suitable, because production capacity is important in the oil industry, which requires significant lead time to increase (Hamilton, 2009b). The firm is fully aware of the expropriation date (no uncertainty) and the tax rate, but cannot influence these. This lack of bargaining power might be interpreted as a pool of potential contracting parties made up of homogeneous firms, which induces a 'price taking' behavior.[19]

After expropriation, the country produces oil at its own expense by means of a state-owned firm.

3.1 The firm

There is a world demand for oil, given by the inverse isoelastic demand function

$$P(t) = B\, u(t)^{-1/h},$$

with $P(t)$ the price at time t, B is some positive constant, $u(t)$ the oil supply, and $h > 1$ the elasticity of demand.[20] The static isoelastic demand function simplifies the analysis, because the equilibrium prices in a pure monopoly and perfect competition without variable costs coincide (Stiglitz, 1976). Thus, I concentrate in the following on the one-country one-firm case which still allows me to derive implications for the case of perfect competition. It has to be acknowledged, though, that the world oil demand has increased in recent decades. However, the econometric setup

[18] Not strictly increasing though, as will be discussed below.

[19] Since uncertainty is not a model feature, the private firm will only place a one-time investment. Excluding uncertainty in terms of the expropriation date simplifies the analysis considerably, but is a strong assumption which might not hold in reality. Introducing uncertainty might lead to the successive investment behavior of the private firm instead. However, such a model extension lies outside the scope of the present paper.

[20] The isoelastic demand function requires the restriction of $h > 1$ or otherwise no production takes place. This is a caveat of the isoelastic demand, since in reality the long-run oil demand elasticity is thought to be smaller than 1.

below allows me to control for possible demand shifts by holding the oil price constant, so that the assumption of a static demand function does not confer complications affecting the theoretical model's predictions.

World oil reserves are owned by a single country, denoted by the subscript L. Before time zero, there is no oil production and no oil industry in the country. At time zero, the country issues an oil extraction concession to a single private firm, henceforth termed *firm*, identified by the subscript F. The oil supply is given by $u(t) = D\, u_L + (1 - D)\, u_F$, where D is zero in the first stage (private firm producing) and one after expropriation. Furthermore, let $X(t)$ denote the stock of oil remaining in the ground at time t:

$$X(t) = X_0 - \int_0^t u(s)\, ds.$$

The private firm then has to solve the dynamic programming problem, given by

$$\begin{aligned} V_F = \max_{u_F, K_F} \int_0^T & B\, u_F(t)^{1-\frac{1}{h}}\, (1-g)\, e^{-rt}\, dt \; - \; K_F\, \phi \\ \text{s.t.} \qquad & 0 \le u_F(t) \le K_F \\ & \dot{X}(t) = -u_F(t) \\ & X(t) \ge 0 \; \forall\, t \in [0, T] \text{ and } X(0) = X_0, \end{aligned} \tag{1}$$

where V_F is the value function, with the first term of the right-hand side being the discounted profit flow and r the discount rate. g introduces a tax rate relative to the prevailing price, payable to the state. I assume that there are no variable costs, so that revenues after taxes equal profits. There are unit fixed costs given by ϕ. K_F is the one-time sunk investment which determines the upper bound for the extraction rate. Accordingly, line two in Eqs. (1) is the control space restriction faced by the firm. The equation of motion for the oil stock $X(t)$ is associated with the shadow cost of the in-ground unit oil. The initial oil stock is $X(0) = X_0$, and the stock of oil is not allowed to become negative. Finally, the time horizon of the optimization problem is limited by the expropriation date T. In order to obtain the optimal solution to the problem in Eqs. (1), it is first necessary to inspect the interior solution (see Appendix):

Lemma 1. *The interior solution to the problem of Eqs.* (1) *is given by*

$$u_F(t) = \begin{cases} K_F & \forall t \in [0, T_{S(F)}] \\ e^{-h\, r\, t} \left(\frac{B\, Y\, (1-g)}{c_F} \right)^h = e^{-h\, r\, (t - T_{S(F)})}\, K_F & \forall t \in [T_{S(F)}, T], \end{cases} \tag{2}$$

with $Y = \frac{h-1}{h}$, c_F *being a positive constant*[21] *and* $T_{S(F)}$ *being the switching point from constant oil production towards a Hotelling path for the firm's extraction policy.*

[21] Since the price cannot be smaller than zero, the constant has to be positive.

Lemma (1) gives the best feasible extraction policy for the interior of the control domain which has to be compared with the boundary points.

Proposition 1. *Assuming* $X(T) = X_0 - T\,\tilde{K}_F = X_0 - T\,\left(\frac{B\,(1-g)\,Y\,e^{-r\,T}\left(e^{r\,T}-1\right)}{r\,\Phi}\right)^h > 0$ *and* $g < 1$, *where* $\tilde{K}_F$ *is the solution to the capacity limit problem of Eqs.* (1) *and* $Y = \frac{h-1}{h}$, *it is optimal for the firm to produce at the capacity limit* $u(t) = \tilde{K}_F\,\forall\,t \in [0, T]$. *Further,* $g < 1$ *implies that* $V_F > 0$.

Prop. 1 shows, similar to Long (1975), that the firm will produce a constant stream of oil as long as it cannot fully exhaust the oil reserves until T and as long as there are some profits. If $g < 1$ does not hold, the firm will not become involved in the country.

Proof. To prove Prop. 1, it is sufficient to show that the corner solution is superior to the interior solution given by Lemma 1, under the same K_F and T. Economically speaking, the production at the capacity limit must yield higher profits than the extraction policy of the interior solution which induces a declining extraction path. For the proof, define:

$$\begin{aligned} V_F^C &= \int_0^T B(1-g)K_F(t)^{1-\frac{1}{h}}e^{-rt}dt \\ V_F^I &= \int_0^{T_{S(F)}} B(1-g)K_F^{1-\frac{1}{h}}e^{-rt}dt + \int_{T_{S(F)}}^T B(1-g)K_F^Y e^{-r(h(t-T_{S(F)})+T_{S(F)})}dt, \end{aligned} \tag{3}$$

where V_F^C is the value function for the constant extraction until T, and V_F^I is the value function for the interior solution. Here $T_{S(F)}$ indicates the point at which the optimal regime shifts from maximum production K_F to the optimal declining extraction path of the interior solution (Seierstad and Sydsaeter, 1986, p. 69). We require that $V_F^C \geq V_F^I\;\forall\,T_{S(F)} \in [0, T]$. Writing Eqs. (3) as an inequality, evaluating the integrals and substituting $T - i$ for $T_{S(F)}$ results in:

$$B\,(1-g)\,((h-1)\,e^{hir} - h\,e^{(h-1)ir} + 1)\,K_F^Y\,e^{-r((h-1)i+T)} \geq 0.$$

Because $g < 1$, the inequality above is satisfied as long as $(h-1)\,e^{hir} - h\,e^{(h-1)ir} + 1$ $= Y\,e^{hir} - e^{(h-1)ir} + \frac{1}{h} \geq 0$ holds. But this is true $\forall\,i \in [0, T]$. Further, Lemma 2 (Appendix) shows that $V_F > 0$ in this case. □

The firm additionally solves the static problem of the optimal sunk investment, which determines the oil production capacity limit. Substituting K_F for u_F in the value function of Eqs. (1) reveals that V_F is strictly monotone increasing and concave in K_F. Hence, there is only one maximum that is given by the first order condition (FOC)

$$\frac{B(1-g)YK_F^{-1/h}\left(1-e^{-rT}\right)}{r} - \Phi = 0.$$

The FOC for this problem shows that the optimal sunk investment $\tilde{K}_F$ is a strictly increasing function of the expropriation date T. The solution $\tilde{K}_F$ displays a direct link between expropriation date T and the sunk investment of the firm. Increasing T implies a higher constant extraction rate of the firm. On the other hand, increasing the tax rate g will reduce the sunk investment. Following Prop. 1, the firm does not incorporate any form of scarcity rent into its depletion policy and will extract as much oil as possible until the expropriation, given the optimal sunk investment. This ensures maximal profits.

In this situation, we have $g < 1$, a finite expropriation date, constant oil production at the capacity limit, and a strict positive oil stock at T.

In the case that $X|_{T=\infty} = 0$, the state does not expropriate at all. Here, the firm will behave similar to the state-owned firm in the following subsection.

3.2 The state

At time zero, the state basically faces two possibilities, where the outcomes are measured by the value functions $V_L^i,\ i = 1, 2$. Given the learning function and the tax rate g, the state can either:

$$\begin{aligned} &V_L^1 : \text{give a concession to the firm and do not expropriate } (X|_{T=\infty} = 0) \\ &V_L^2 : \text{give a concession to the firm and do expropriate } (X|_{T<\infty} \geq 0). \end{aligned} \tag{4}$$

In order to say something meaningful about the country's optimization problem, it is necessary to specify the learning function:

$$K_L = \min\{a\,T, K_{max}\} \text{ with } K_{max} \leq \tilde{K}_F, \tag{5}$$

where K_L is the capacity limit of the state;[22] a is some learning-multiplicator; and K_{max} is the maximum achievable know-how which might be conditioned on some economic stock variable in the society. The restriction on K_{max} is necessary to ensure the validity of the interior solution below and will be evoked in Prop. 3. Equation (5) also links the capacity limit of the state to the length of time in which the firm is active in the country as well as to the firm's capacity limit $\tilde{K}_F$.

For the time being, I concentrate on the second case and assume that $X(T) > 0$. The state then faces a two-stage optimization problem where the second stage is a dynamic optimization problem similar to the firm. The state maximizes V_L^2 by choosing an optimal extraction trajectory $\tilde{u}_L(t)$ for the oil residuum $X(T) = X_0 - \int_0^T \tilde{K}_F > 0$, an optimal expropriation date $\tilde{T}$ and an optimal tax rate

[22] It is straightforward to model the capacity limit as a function of the cumulated know-how.

$\tilde{g}$. Using the learning function, the problem of the state becomes:

$$
\begin{aligned}
V_L^2 = \max_{u_L,T,g} S(T) + & \int_T^\infty B\, u_L(t)^{1-\frac{1}{h}}\, e^{-rt}\, dt \\
\text{s.t.} \quad S(T) = & \int_0^T B\, g\, \tilde{K}_F^Y\, e^{-rt} \\
0 \leq & u_L(t) \leq K_L \\
\dot{X}(t) = & - u_L(t) \\
X(t) \geq 0 \text{ and } X(T) = & X_0 - \int_0^T \tilde{K}_F > 0 \\
K_L = & \min\{a\, T, K_{max}\} \text{ with } K_{max} \leq \tilde{K}_F,
\end{aligned}
\tag{6}
$$

where $S(T)$ is the cumulative tax paid to the state. The restriction in the third line of Eqs. (6) gives us the control space restriction for the state's extraction path. This restriction is defined by the learning function in the last line of Eqs. (6).

The state then maximizes its discounted income by choosing an optimal policy at $t = 0$, which simultaneously determines the tax income in the first stage and its own oil extraction path after expropriation in the second stage. The state controls the tax income by choosing the length of the taxing period (expropriation date) and the tax rate. This optimal control, however, must incorporate the effects of the expropriation date and the tax rate on the control space restrictions of the second stage (lines 5-6 in Eqs. (6)). For example, increasing the tax income period results in an increase in the state's capacity limit, but decreases the remaining oil stock.

The state can control its income in the second stage by choosing an optimal extraction path, given the remaining oil stock and the control space restriction. This control space restriction is determined by the capacity limit of the state.

The two stage problem is solved backwards, by first choosing the optimal extraction path for an arbitrary expropriation date and an arbitrary tax rate. Applying the Maximum Principle and using the restrictions from Eqs. (6) gives the optimal extraction path $\tilde{u}_L$ for the second stage problem. The control space restriction in form of the capacity limit again imposes a switching point $T_{S(L)}$ on this optimal program. The oil extraction will be constant until $T_{S(L)}$. Afterwards, the extraction path resembles the 'normal' Hotelling path, although being steeper. Similar to the interior solution of the firm, the optimal extraction rate of the state also involves a constant, denoted as c_L. It describes the shadow price of oil for the state at $t = T$. The two unknowns $T_{S(L)}$ and c_L are determined by exploiting the oil stock restriction $X(T) = \int_T^\infty \tilde{u}_L\, dt$ and the fact that $\tilde{u}_L(T_{S(L)}) =$

K_L. The solution is hence described by the triplet:

$$\tilde{u}_L = \begin{cases} K_L & \forall\, t \in [T, T_{S(L)}] \\ \tilde{u}_L = \left(\frac{B\,Y\,e^{-rs}}{c_L}\right)^h & \forall\, t \in [T_{S(L)}, \infty) \end{cases}$$
$$c_L = B\,Y\,K_L^{-1/h}\,e^{\frac{1}{h}-\frac{rX(T)}{K_L}-rT} \tag{7}$$
$$T_{S(L)} = -\frac{1}{hr} + \frac{X(T)}{K_L} + T.$$

Since this solution of the second-stage problem is similar to a dynamic problem with a control space restriction, I omit the proofs and refer to Seierstad and Sydsaeter (1986, p. 69). However, due to the additional first step (the tax income period) involving the choice of the expropriation date and the tax rate, it is necessary to check for the consistency of the control space restriction of the second stage with the first-stage solutions. In detail, the feasibility of the optimal solution requires that $T_{S(L)} \geq \tilde{T}$. This ensures that the capacity limit (control space) does not expand during the second stage. Thus, the expropriation date imposes an additional restriction on the solution space of the dynamic problem.[23] The optimal extraction path, using the solution of $T_{S(L)}$ and c_L, yields the intertemporal maximized value function V_L^2:

$$V_L^2 = S(T) + \frac{B\,e^{-r\,T}(a\,T)^Y\left(h - (h-1)\,e^{\frac{r(\tilde{K}_F\,T - X_0)}{a\,T}+\frac{1}{h}}\right)}{h\,r} \tag{8}$$

Exploiting the FOC would give the optimal expropriation date $\tilde{T}$. Unfortunately, no explicit solution is available. Hence, it is necessary to establish that such an optimal expropriation date exists in finite time.

Proposition 2. *Under the assumptions of Lemma 3 (Appendix), there exist an optimal $\tilde{T}$ and an optimal $\tilde{g}$ which maximize case two of Eqs.* (4) *and for which $V_L^2(\tilde{T}) > 0$ holds.*

Proof. Given Lemma 3, the value function of Eq. (8) is a continuous function on a closed and bounded domain $T \in [0, \frac{K_{max}}{a}]$. Thus, by the extreme value theorem, there exists at least one $\tilde{T}$ for which the value function achieves its maximum. According to Lemma 4 (Appendix), the maximized value function V_L^2 is non-zero and positive. This holds for a general tax rate. □

Using an additional assumption, Lemma 3 shows whether the state will expropriate.

Corollary 1. *Assuming $K_{max} \geq \tilde{K}_F\, g^{\frac{1}{Y}} \geq \tilde{K}_F|_{T=\infty}\, g^{\frac{1}{Y}}$, the state will expropriate and thus choose V_L^2 of Eq.* (4)*. $\tilde{K}_F|_{T=\infty}$ is the sunk investment under the premise that the state does not expropriate (case one), and $\tilde{K}_F$ is the optimal sunk investment of the firm in case two.*

[23] To maintain the flow of the argument, I shall postpone the proof of this requirement until the end of the section.

Proof. The corollary follows from the same argument as Lemma 3. Note that if $T = \infty$, then case V_L^1 applies, and the optimal extraction program, and thus the optimal tax income path, is the firm's interior solution. This follows from the discount rate. □

Following Lemma 5 (Appendix), an optimal tax rate also exists for the problem in Eqs. (6). The first assumption of Lemma 3 guarantees that when the maximal know-how level of the state is reached, the state always succeeds better on its own. The second assumption ensures that the state reaches its maximal know-how level before the oil reserves are exhausted by the firm. Under these conditions an expropriation date exists in finite time which maximizes the discounted income of the state and guarantees oil production under state regime. The optimal expropriation date has to satisfy a tradeoff. On the one hand, postponing the expropriation date increases tax income, the boundary of the state capacity limit[24] K_{max}, and the actual capacity limit K_L. On the other hand, it decreases the remaining oil reserves owing to the duration of operation and the capacity limit of the firm. Because the optimal expropriation date holds for all tax rates, it also holds for the optimal tax rate. The optimal tax rate is determined by the following interrelations: The tax rate increases the tax income in the first stage. On the other hand, the tax rate governs the depletion rate of the firm through its effect on the firm's capacity limit, which affects the remaining oil stock and the feasible boundary of the state capacity limit.

Following this argument, it is optimal for the state to give a concession (contract) to the firm in the first stage, and then in a second stage, after expropriation, to produce oil on its own. In this second stage, optimality requires that the state produces oil according to a Hotelling path. This implies an oil supply contraction. The next proposition recaps the situation which prevails in the second stage.

Proposition 3. *Under the assumptions of Lemma 3, the optimal extraction policy of the state is given by Eqs. (7). That is, the state will first produce, after expropriation at time T, at its capacity limit K_L, and then switch at time $T_{S(L)}$ to a declining extraction path in order to generate a Hotelling rent.*

Proof. By Eqs. (7) it remains to be shown that $T_{S(L)} \geq T$. Substituting the solution of Eqs. (7) for $T_{S(L)}$ and expanding yields

$$\frac{X_0}{\tilde{K}_F} - T \geq \frac{K_L}{\tilde{K}_F}\frac{1}{hr}.$$

Estimating T by $T \leq \frac{K_{max}}{a}$ gives the following inequalities:

$$\frac{X_0}{\tilde{K}_F} - T \geq \frac{X_0}{\tilde{K}_F} - \frac{K_{max}}{a} \geq \frac{1}{hr} \geq \frac{K_L}{\tilde{K}_F}\frac{1}{hr},$$

[24] As long as the equality $K_{max} = \tilde{K}_F$ holds.

where $\frac{K_L}{\tilde{K}_F} \leq 1$ by definition and the last inequality follows by the assumption $\frac{X}{\tilde{K}_F} \geq \frac{\tilde{K}_F}{a} + \frac{1}{hr}$ of Lemma 3. □

Thus, according to Props. 2-3 the state will first give a concession to the firm in order to generate tax income and to increase its own know-how (capacity limit) by learning from the private firm. The state is not able to conduct oil extraction from scratch, as oil production requires know-how. During this first stage, the state has to share the oil revenues with the firm or otherwise the firm will not operate in the country. Then after the expropriation date is reached the state can obtain higher revenues by conducting oil extraction on its own without splitting the oil revenues with the firm. Further, the state will eventually follows a Hotelling extraction path, after an era of constant oil supply, which induces an exponentially increasing oil price.

3.3 Summing up

The preceding theoretical model incorporates stylized facts found in the literature into a Hotelling setup. In the model analysis I show, assuming a sunk investment, a finite expropriation date, and a learning function of the state, and how the oil supply decomposes naturally into a two-stage process. In the first stage, a private firm produces oil, and after expropriation in the second stage, the state produces on its own account. Proposition 1 shows that a firm will produce oil at a constant rate under the assumption that the expropriation takes place in finite time, and it cannot fully exhaust the oil reserves of the host country.[25] Consequently, oil output and price will be constant during this period. The size of the sunk investment, and hence of the extraction rate, depends directly on the expropriation date, the oil stock size and the prevailing tax rate. Here, the model attributes the constant extraction rate of the firm to the finite expropriation date. In reality, additional forces that contribute to such a behavior might exists; e.g., incentive of short-run profit maximization of CEOs. This, however, does not affect the basic model mechanisms.

The expropriation date chosen by the state is characterized in Prop. 2. The model analysis further shows that the optimal extraction program of the state after expropriation is given by a constant extraction rate, owing to the capacity limit constraint, followed by an eventually declining extraction rate. Hence, eventually, the state's extraction rate will follow a Hotelling path, giving rise to a constant relative price increase. The model, thus, implies a break in the production pattern of the state-owned firms, at the point of constant output towards the Hotelling path. This latter point depends, among other things, on the expropriation date and the oil stock size. This is crucial, because a market dominated by national firms does not necessarily imply a Hotelling price path immediately after expropriation, but only after a certain lag time.

[25] It seems plausible that private firms do not expect to fully exhaust the oil reserves in the host country.

The result, in case of a one-firm-one-state setup, indicates how the market decomposition separates the price process into a period of a constant oil price followed by a period of an exponentially increasing oil price. The analysis further shows that this behavior is optimal to both firm and state. Under these conditions the oil produced by private firms is cheaper.

The functional form of the model, ensures that the dynamic extraction policy in the case of a pure monopoly (described here) and perfect competition coincide (Stiglitz, 1976). Thus, the qualitative predictions of the model apply, for example, to a market structure dominated by a private firm monopoly as well as to a market structure dominated by state-owned firms under perfect competition.[26] Furthermore, the isoelastic demand function ensures that national firms are able to generate an analogous scarcity rent through supply contraction even in a market including private firms.[27]

Empirical Investigation

In the next section, I first present a casual discussion of the world oil price path along the arguments of the theoretical model and then present empirical evidence, by using a firm-level micro-panel dataset and employing the fixed-effects panel data estimation procedure, that national oil companies limit their oil supply to generate a Hotelling rent, but private firms not. The data also reveals that national firms exhibit a break in the oil extraction policy by switching from constant oil supply to a Hotelling path in 1997. Thus, the main predictions of the theory indeed carry over to the data.

4 A First Look at the Price Data

From the model which describes long-run economic mechanisms, it is to be expected that in an era which is dominated by a private firm monopoly, the oil price will be constant.[28] Figure 2 shows that the oil price is constant and even declines, given short-run shocks, during the period of the private firms oil monopoly. The first period of constant oil supply is then followed by heavy disruption in the oil market structure, as dominance shifted from private to state-owned oil supply. In particular, within a decade, world oil reserves owned by national firms increased from 1 percent to 60 percent

[26] This might not hold in the case of static variables, like the fixed investment and expropriation date, but holds for the dynamic extraction policy under given fixed variables. Due to the fixed effects estimator procedure, the econometrical analysis does not depend on these static variables.

[27] This holds true as long as the demand curve lies above the constant part of the supply curve (private firm supply) which seems uncontroversial, since national firms provide the bulk of the world oil supply.

[28] That the seven sisters exerted near perfect control over world oil supply (outside USA) and behaved like a monopolist until the 1970s is uncontroversial (Wyant, 1977; Victor et al., 2012, p. 5).

in 1980 (Victor et al., 2012, p. 6) and are now at almost 90 percent (EIA, 2009). It is important to note, that by 1984 the oil market was no longer dominated by a monopoly of private firms but by competitive state-owned firms.[29] In the model, this shift leads to a level oil supply contraction,[30] giving rise to a jump in the oil price. After, consolidation of the oil market, the price path remained more or less constant during a period of constant oil supply provided by national firms. The price path then indicates a break in 1998. The theoretical model above attributes this break to a shift from constant oil extraction to Hotelling behavior in the case of national firms which dominate world oil supply.

5 Data

For a more detailed analysis of the theoretical model, firm level data is needed. Unfortunately, such data is not available before 1987. However, the oil market structure during the era of the seven sisters and the shift from private to state-owned oil is well documented. Thus, the data analysis below concentrates on the more recent era, where the transition from private to state-owned oil supply dominance has been completed.

The Petroleum Intelligence Weekly (PIW) publishes a compilation of the Top 50 oil-producing firms in an annual supplement to its publication. These 50 firms make up the bulk of the world oil supply with a market share of about 75 percent during the sample period. The ranking is based on six operational criteria, including oil and gas reserves and production, refinery capacity and product sales volumes. The annual supplement provides data on the six operational variables and data on the number of employees, revenues, net incomes and total assets for each firm. Additionally, the dataset provides information about the share of state-ownership for each listed firm and information on the country of origin. This makes it possible to assign country-specific covariates to each firm.[31] The country-specific covariates include real GDP in current international dollars,[32] taken from the World Development Indicators; the Quality of Government Index (QoGI)[33] from ICRG; the Political Rights Index (PRI) from the Freedom House Dataset; and OPEC membership. The PRI is normalized to lie between 0 and 1, where higher values signify better institutions. The data on the gross oil price in US dollars (Cushing, OK WTI Spot Price FOB (dollars per barrel)) is taken from the U.S. Energy Information Administration (EIA).

For the analysis, I obtained firm data for 1987-2010. I define a firm as state-owned when the

[29]That the oil market today is competitive in the case of national firms, at least for the relevant period in this study, will be addressed below in more detail.

[30]The disruption of the oil market was also accompanied by short run-supply shocks.

[31]In the case of Royal Dutch Shell, which is located in the United Kingdom and the Netherlands, I average the country-specific variables over both countries.

[32]Real GDP refers to PPP adjusted GDP.

[33]The data is provided by Samanni et al. (2008)

Table 1: State-owned and Private Firms Characteristics

Characterstic	No. of Obs.	Oil Reserves in mill bbls	Oil Production in 1,000 b/d	Refinery Capacity in 1,000 b/d	GDP p. Capita Host Country
Fully state-owned	445	45,074	1,656	741	13,215
Fully/partly private	712	3,801	717	1,229	23,397

Notes: The table shows the sample averages for fully state-owned (100 percent state ownership) and fully/partly private (not 100 percent state-owned) firms. The sample covers the period 1987-2010. In the case of the refinery capacity, the sample is limited to 612 observations for private firms. The variable in the last column gives the GDP per capita in PPP-adjusted international dollars for the respective country in which each firm is located.

state ownership is 100 percent. Thus, state-owned is indicated by a dummy variable which is one if state-owned, and zero otherwise. The sample also possesses enough within (intra) firm variation to assess the impact of a switch to full state ownership. In the case of national firms, I only include the countries of net-exporters. This excludes national-firms from India, Austria, Italy, Peru, Spain and Turkey; and Chinese national-firms since 1993 and Petrobras before 2006, since they do not contribute directly to the world oil supply.

Exploiting variation at firm level allows me to decompose the oil supply market into national and private firms, in contrast to the usual country-level assessments. This facilitates a more in-depth insight into the dynamic behavior of the oil supply, because oil is produced at firm level.

The composition of the panel changes continuously as firms leave and enter the Top 50 ranks, and results in an unbalanced panel. To broaden within-firm variation, I combined the firm data for BP-Amoco and Arco, which merged in 2000, for the years 1998 and 1999.[34] All in all, the sample contains 103 firms allocated across 42 countries. The average firm remains in the sample for 11.2 years.

Table 1 reports an average breakdown of state-owned and not fully state-owned firms, labeled private firms from here on, for the years 1987-2010. The table reveals significant differences within the sample. While state-owned firms own oil reserves that are usually roughly ten times larger than those of private firms, they only produce roughly twice as much oil. The private firms, in turn, exhibit a much higher downstream involvement, which is evidenced by their refinery capacity. The last column of Table 1 displays the average GDP per capita in international dollars for the respective countries in which each firm is located. The data reveals significant differences in the average per capita income for the set of countries possessing state-owned firms and the set of host countries of private firms. These sets are not disjoint. For example, private and state-owned firms coexist in Russia.

Unfortunately, there is no per unit oil production cost available at firm level. Thus, the analysis below may capture the effect of higher per unit oil production costs for national firms. In gen-

[34] Treating these private firms separately does not alter the subsequent results.

eral, this caveat should be inconsequential, due to the availability of cheap oil in the Middle East (national) and the high costs of offshore production (mostly private firms) and production from tar sands (mostly private firms). Nevertheless, given the available data, I was not able to lift this caveat. Using total output, revenues and net income is not feasible because of the downstream business.

For the analysis, I construct two panels. The first contains the observations from 1998 to 2010, and the second contains the full sample. This separation is based on the literature, which notes that the scarcity rent in the oil market is a more recent phenomenon. For example, Hamilton (2009b) hypothesizes that scarcity rent became a significant issue in 1998.

6 Econometric Setup

The information on the firm's ownership facilitates the decomposition of the sample into two subgroups of private and national firms, respectively. This allows me to account for statistical differences between these two groups in terms of their oil production policy, and hence to test the qualitative predictions of the model.

Being able to track firms over time makes the application of panel data techniques feasible. Moreover, using within-firm variation in the data eliminates the problem of firm-specific effects, which might be correlated with the explanatory variables. This is achieved by employing the fixed effects procedure, which wipes out the between-firm variation. Here, all time-constant firm specific effects are captured by firm dummies. These effects include inter-firm differences in technology, oil reserves, production efficiency and, of course, the information on state ownership as long as there is no change within the sample period. This comes in handy, as it is reasonable to assume that firms differ significantly with regard to these characteristics (Tordo et al., 2011, Vol. I, p.xiii). The fixed effects estimator also wipes out any level effects concerning cultural differences, historical background and corporate governance. In turn, the estimator makes use of all information regarding time variation. Thus, if a firm increases its oil reserves during the sample period, the fixed effects procedure will capture the effect of this on the firm's oil production. As each firm is attributable to a specific country, between-country variation will be excluded, and the firm location does not matter.

It is possible, though, to assess the influence of within-country variation on the oil production for firms located in that country. It is to be expected that within-country variation is particularly important in the case of national firms, which are directly influenced by country-specific features. It is empirically troublesome that the data availability of the selected variables is not homogeneous. Adding additional variables to the regression model usually leads to a sample size reduction. However, all setups are robust to the sample reduction, meaning that if all the regression setups were run on the smallest sample, similar results would be obtained.[35]

7 Empirical Evidence

My model identifies some qualitative features of an oil industry which is decomposed into private firms and national firms. Proposition 1 suggest that a private firm, under the assumption of static demand and fixed oil reserves, produces at a constant rate. The constant supply is induced by the expropriation date, and the level of the extraction rate depends on the production capacity. Further, it is to be expected that any demand shift will be captured by the crude oil price, since oil markets are cointegrated (Chen et al., 2009), and accordingly the firms face price processes which move simultaneously. Thus, controlling for the price takes care of fluctuations in demand; e.g., the recent European sovereign debt crisis.

Hence, the model suggests that private firms produce a constant output when controlling for price effects and changes in oil reserves; in other words, holding oil price (and hence oil demand) and oil reserves constant. This is an important point then, because the private oil supply might vary with the oil price and oil reserve changes, but is constant conditional on these covariates and any fixed effects. The model further suggests that the capacity limit of private firms depends, among other things, on the fixed tax rate and the expropriation date. However, the fixed effect estimator removes time invariant level effects.

From Prop. 2 in the theoretical model, the national firm will produce at a constant rate (the constant phase) initially, and subsequently, after crossing the switching point, will give in to a declining extraction trajectory (Hotelling path). Again, this behavior is conditional on the oil price (oil demand) and covariates, but does not imply that national firms effectively reduce output on the Hotelling path. For example, given a positive demand shock and a resulting demand-driven oil price increase, national firms might even increase output. However, such an output increase would fall short to the extent of the Hotelling rent, or in other words, we would observe a supply decrease conditional on the oil price; that is, holding oil price and hence oil demand constant.

In particular, from Eq. (7) we have for $t > T_{S(L)}$ (switching point), taking the log:

$$\begin{aligned} \ln(\tilde{u}_L) &= -h\,r\,t + h\,r\left(\frac{X(T)}{K_L} + T\right) - 1 \\ \dot{\tilde{u}}_L &= -h\,r\,t \end{aligned} \tag{9}$$

where t is a time index, $\tilde{u}_L$ denotes the optimal oil production of a state-owned firm, and $\dot{\tilde{u}}_L$ is the differential with respect to time. Thus, holding oil reserves and the oil price constant, we expect

[35] The results are further robust to the pooling of the national and the private firms sample. In other words, the results are similar when the empirical analysis is conducted on the samples separately.

that national firms will reduce their output at a rate similar to the adjusted discount rate $h\,r$, labeled discount rate from here on.[36]

Given these conditions, the question arises as to whether the national firms on average follow a Hotelling path and, if so, whether it is possible to identify a switching point where national firms on average shifted from a constant towards a declining oil supply? The answer depends heavily on the market structure of the oil sector, because the model is only applicable if the oil sector consists of competitive national firms,[37] and national firms are indeed able to cause a price increase through supply contraction. I will address these issues in the robustness section (Section 5). The theoretical model further suggests that the oil output of the state-owned firm declines, conditional on the covariates, by a percentage rate similar to the discount rate on the Hotelling path. The reason for this is the price increase, arising from the supply restriction.

Using the following regression model, where i is the firm index and t a yearly time index, I set out to test whether the qualitative effects predicted by the theory are evidenced by the data.

$$O_{i,t} = \beta_0 + \beta_1 D_{i,t} + \beta_2 D_{i,t} Y_t + \beta_3 (1 - D_{i,t}) Y_t + \beta' \mathbf{X}_{i,t} + v_{i,t}, \tag{10}$$

with the error term $v_{i,t} = \mu_i + u_t + \epsilon_{i,t}$, where μ_i is a country-specific effect, u_t a time effect and $\epsilon_{i,t}$ an idiosyncratic error term. $O_{i,t}$ is the log (logarithm) of the average daily oil production; $D_{i,t}$ is the dummy variable for state-owned firm, which is one if state-owned and zero otherwise; Y_t is a time trend; and $\mathbf{X}_{i,t}$ is a set of control variables. The control variables include firm-specific as well as country-specific measures. The firm specific measures, all in log, include oil reserves, refinery capacity, product sales volume, number of employees, revenues and the net income. The data on refinery capacity and product sales volume and the data on revenues and employees allow me to control for downstream involvement and efficiency, respectively. The country specific measures[38] include log GDP, OPEC membership, the polity variables QoGI and PRI, and time dummies.

The time dummies serve as crude oil price control variables in Eq. (10). These dummies capture any movements in the oil price, which is the same for all firms, due to cointegrated oil markets (Chen et al., 2009). Adding the crude oil price into the setup results in an insignificant coefficient for the oil price and in dropping one time dummy. The coefficients β_2 and β_3 can be interpreted as oil production growth rates and have the function of capturing the oil production behavior over time for national firms and private firms, respectively, everything else held constant.

[36] From the discussion in the model (Section 3), it is known that the isoelastic demand requires $h > 1$ or otherwise no oil production takes place. Thus, the interpretation of h at this point is difficult, and a separation between h and r not possible.

[37] Additionally, the model also is applicable to a pure monopoly. However, it is not likely that all national firms collude as a whole.

[38] Because population does not enter significantly into the regression model and does not influence the coefficients of the other variables, I dropped population in order to increase the sample size.

’Everything else’ includes any firm fixed effects which includes the expropriation date, the oil price, the oil reserves, downstream involvement, changes in country income and changes within political institutions. Thus, the model predictions will be captured by these two coefficients. The model above predicts $\beta_2 < 0$ in the magnitude of some discount rate and β_3 to be insignificant. A negative β_2 would imply a declining production path over time. The magnitude of the coefficient can be interpreted as the yearly percentage change in oil output (oil output growth rate). Equation (10) includes the dummy for state-owned as a separate variable. This is necessary because some firms exhibit state-owned within-firm variation.

7.1 The Years 1998-2010

By using the observations of the years 1998-2010, I restrict the panel to the period for which, according to the literature (Hamilton, 2009b) and by judging the price path in Figure 2, an oil extraction regime dictated by a Hotelling rent seems plausible. The data restriction is necessary, since the break in the oil extraction policy of national firms, predicted by the theory, is unknown ex-ante.[39] My model further suggests that the Hotelling rent should matter only in the case of the state-owned firms.

Before going into details, as the quintessence of this subsection, I find that, under the full set of control variables, national firms reduce output by about 3.5 percent each year, and private firms produce at a constant rate for the sample period 1998-2010. This indicates strong support for my model and highlights that the main qualitative features of the model carry over to the data of the restricted period.

The results of the regression models, including only log oil reserves and log real GDP as covariates, are presented in Table 2, column 1. In columns 2-5, additional firm-level covariates and the country-specific political institution measures are added. In columns 1-4, the sample is restricted to 1998-2010, whereas column 5 uses the full sample. The dependent variable is the average daily oil production in log. The table reports the coefficients of fixed effects estimator regressions including time dummies and robust standard errors clustered at the firm level in all columns. In the following, I will discuss the regression results for the restricted sample period, starting with the base setup and subsequently add further control variables.

The first column shows the base regression with oil reserves, the state-owned dummy, real GDP and separate time trends for private firms and state-owned firms. The results for the dummy variable, which enters significant in most specifications with a positive coefficient, are not reported here.

The time trend for the state-owned firms enters negative and significant at the 1 percent level.

[39] I will evaluate this break by proper statistical means below in Section 7.2.

Table 2: Fixed Effects Estimations - Sample Period 1998-2010

Dependent variable: Log oil production	(1)	(2)	(3)	(4)	(5)
Log oil reserves	0.561** (0.060)	0.550** (0.063)	0.583** (0.074)	0.524** (0.062)	0.390** (0.041)
Time trend state-owned	-0.041** (0.008)	-0.038** (0.007)	-0.039** (0.010)	-0.035** (0.007)	-0.015** (0.004)
Time trend private	0.009 (0.005)	0.007 (0.005)	0.007 (0.006)	0.006 (0.005)	0.001 (0.004)
Log real GDP (Int $)	0.334** (0.061)	0.200** (0.036)	0.236** (0.045)	0.190** (0.038)	0.199** (0.038)
Log refinery capacity		0.204** (0.046)	0.205** (0.050)	0.207** (0.046)	0.124** (0.037)
Log product sales		0.170** (0.047)	0.183** (0.052)	0.157** (0.047)	0.159** (0.037)
Political institutions			-0.452 (0.327)	-0.355 (0.218)	-0.341** (0.125)
Obs.	622	530	453	530	947
adj.-R^2	0.956	0.960	0.955	0.960	0.957
F-Statistic	18.522	22.547	17.209	21.913	15.257

Notes:* $p < 0.05$, ** $p < 0.01$. FE estimator regressions in all columns with country dummies, time dummies and robust standard errors clustered at firm level in parentheses. Also included, but not reported, is a state-owned dummy. This dummy is one, if state ownership is 100 percent and zero otherwise. Columns 1-5 refer to the restricted sample period 1998-2009. Column 6 uses the full sample period. Log real GDP is in PPP adjusted international dollars. Political institutions are measured by the Quality of Government Index in column 4 and by the Political Rights Index in columns 5-6. Both are normalized to lie between 0 and 1, where higher values signify better institutions.

The coefficient of -0.041 states that on average a state-owned firm decreases its output by 4.1 percent per year, holding price and oil reserves constant. Within the model, this 4.1 percent would correspond to the discount rate faced by the state-owned firms. This ballpark figure is the upper bound as the coefficient of the state-owned firms' time trend varies between -0.035 and -0.041 across the different regression setups of the restricted sample. However, the 4.1 percent is within the spectrum that one would expect for an average discount rate faced by states owning national firms. From the model, we know that national firms reduce their oil supply in order to induce an oil price increase and accordingly generate a Hotelling rent.[40]

Column 1 displays an insignificant time trend coefficient for private firms, which implies that private firms, conditional on the covariates, produce at a constant level. Thus, given, for example, the crude oil price, private firms behave as predicted by the theoretical model which states that private firms will not adjust their oil supply in order to generate a Hotelling rent. This behavior is consistent with the assumption that private firms are not able to fully exploit the oil reserves in their host countries, due to the limited time horizon.

Further, the hypothesis that the slopes of the time trends for private firms and state-owned firms

[40] I will show in the robustness section that the oil price does, in fact, react to the supply reduction.

are the same can be rejected at the 5 percent significance level in all regression specifications in this study.

I find a positive and significant relationship between log oil reserves and log oil production. Following the point estimates in Table 2, column 1, a 1 percent increase in oil reserves leads to an oil production increase of 0.56 percent. This first benchmark is robust to different specifications, and the effect of a firm's oil reserves increase on the oil output remains at an elasticity of around 0.4-0.6. As the regressions exploit within-firm variation, this relates directly to successful oil reserve exploration or acquisitions conducted by a firm. On these terms, a declining reserve discovery rate would translate into a production decrease. The declining time trend for national firms, conditional on the oil reserves, is quite interesting, especially in the context of the Hubbert-Peak debate. As Table 1 shows, there is no oil reserve shortage for these firms in absolute terms. Yet, national firms display a declining oil production path over time, conditional on the oil price and oil reserves. This is an important point here, since it implies that national firms, despite their access to vast and extremely cheaply producible[41] oil reserves, curb their oil production at a yearly rate, holding the oil price constant. On the other hand, private firms which are to a great extent confined to lower and more inaccessible oil reserves, produce at a constant rate (at the capacity limit), holding the oil price constant. They do not curb oil supply. Within an economic context, assuming for the moment no Hotelling regime, it would be expected that national firms would first fully exhaust their cheap oil reserves, before private firms would exploit their expensive oil reserves. However, we do not observe such a behavior. On the contrary, we observe that national firms reduce their (cheap) oil supply at 4.1 percent each year, while private firms produce at their capacity limit, despite their higher extraction costs. My theory above attributes these observations to a Hotelling regime in the case of national firms, but not for private firms. Thus the model is able to give economic meaning to patterns revealed by the data.

The relationship between log real GPD and oil production is significantly positive. It is important to stress that causality is not clear-cut in this case, as more oil production is likely to increase GDP. Nevertheless, GDP is able to explain quite a share of the within-firm variation in oil production. One argument might be that GDP is correlated with technological progress in the respective country.

In columns 2-5, measures for downstream involvement are included. Refinery capacity and product sales enter significant and positive, implying a positive relationship between the expansion of downstream involvement and oil production within a firm.[42] Adding these firm-specific covariates helps to control for firm-specific changes over time.[43]

[41] Especially the national firms in the Middle-East.

[42] See Eller et al. (2010) for further discussion.

[43] In regressions not reported here, I also add the logarithm of employees and revenues as control variables. Adding these variables does not affect the coefficients of interest, but only reduces the sample size considerably. Hence they

The inclusion of the Quality of Government Index (QoGI) as a political institution measure in column 3 does not affect the results above. Hence, I conclude that the estimation results, which indicate a Hotelling regime for national firms but not for private firms, do not depend on institutional variation. The same effect is observed by the inclusion of the Political Rights Index (PRI) in column 4, which is highly correlated with the QoGI, but allows a greater sample size.

According to the results in column 4, national firms realize a policy of oil stringency by curbing the yearly output by about 3.5 percent, whereas private firms produce at a constant rate. Thus, the data exhibits a significant reduction of the state-owned oil supply and a constant supply by private firms, holding all else constant. These findings closely match the predictions of the theoretical model for the sample period 1998-2010; that is, private firms produce at their constant capacity limit, but national firms generate a Hotelling rent.

The regression in column 5 exploits the full sample period 1987-2010. The results reveal a considerable decline in the coefficient size for the time trend of national firms. The reason for this is a structural break in the data for the state-owned time trend. From the theoretical model above this is to be expected, since national firms will initially produce at a constant rate and switch afterwards to a Hotelling path.

7.2 A Structural Break in National Oil Production in 1997

In order to identify the switching point in the oil supply regime of national firms in a proper way, it is necessary to test for a structural change in the time trend over time. I implement the test proposed by Emerson and Kao (2000). Due to the nature of the test and because there seems no singular structural break (no significant time trend) in the case of the private firms, the sample is restricted to state-owned firms for the following regression setup,

$$\widehat{O}_{i,t} = \alpha + \beta\, Y_t + v_{i,t}, \tag{11}$$

where Y_t is a time trend and $v_{i,t} = \mu_i + \epsilon_{i,t}$ is a composite error term with a firm-specific effect and an idiosyncratic part. $\widehat{O}_{i,t}$ are the residuals of a first-step regression on the state-owned firms sample similar to the specification of Table 2, column 5, but without time trend. The null hypothesis is

$$H_0 : \beta_t = \beta \,\forall\, t \;\text{ against }\; H_1 : \beta_t = \begin{cases} \beta_1 \text{ for } t = 1, ..., k-1 \\ \beta_2 \text{ for } t = k, ..., T. \end{cases} \tag{12}$$

I use the *sup*W_1 asymptotic test statistic proposed by Emerson and Kao (2006), because the time structure of the data is I(0).[44] The results for the structural break test are depicted in Table 3. I

are dropped from the subsequent analysis.

[44] I can reject an augmented Dickey-Fuller test that all panels contain unit root at the 1 percent significance level.

Table 3: Time Trend Structural Break

The sample is restricted to state-owned firms only

$sup\mathrm{W}_1$ (1)	Critical value (1%) (2)	Estimated break year (3)	Pre-break (4)	Post-break (5)
9.47	4.36	1997	.008	-.043**
			(.019)	(.011)

Notes: I use the test for a structural break in the time trend proposed by Emerson and Kao (2006). I employ the $sup\mathrm{W}_1$ test statistic and its correspondent asymptotic critical value for the 1% significance level. Because of the test characteristics, I perform the test on the residuals that are obtained from a regression similar, but without time trend, to Table 2, column 6. The sample is restricted to the state-owned firms only. In the regression estimates of columns 4-5: * $p < 0.05$, ** $p < 0.01$ and robust standard errors clustered at firm level in parentheses.

can reject the null hypothesis at the 1 percent significance level in the case of 1997, which implies that the time trends before and after these break points differ statistically in the case of state-owned firms. Indeed Table 3 reveals that the coefficients differ in sign and size before and after the break points. In particular, the insignificant and small coefficient of the time trend for the period 1987-1997 implies that there is no Hotelling regime observable for these early years in the case of the national firms. Thus, the statistical test places the date of the shift from constant extraction towards a Hotelling path, in fact, near to 1998, which is reported in the literature (Hamilton, 2009b) and is suggested by the price path in Figure 2.[45]

I have, thus, established the three key points in this study in theoretical and empirical terms: **(a)** private firms produce at a constant rate, holding everything else constant; **(b)** national firms curb their oil supply at a yearly rate of approximately 3.5 percent since 1997 in order to generate a Hotelling rent; **(c)** the Hotelling rent played no role before 1997 when national firms shifted from constant supply towards a Hotelling regime. For (b) to hold true, it is necessary that the reduction in oil supply of national firms does in fact affect the oil price, which I demonstrate below.

8 Robustness Checks

In this section, I first establish that the results above are robust to the differentiation in oil reserves between national and private firms. I then show that the Hotelling behavior of national firms is not driven exclusively by the OPEC members, but is attributable homogeneously to national firms. The latter point also helps to evaluate whether OPEC exerts market power by exclusive supply reduction. That would complicate the translation of the analytic results to the data.[46] Finally, I

[45] Note, that the match between price path and the break in the time trend is not trivial, since the data captures yearly oil production rates.

[46] Since the model results are not applicable to a market with some market power; e.g., Stackelberg competition, but only to a competitive market or a pure monopoly.

deliver empirical support for a crucial condition that has to be met, in order to assure that my theoretical model is applicable to the data. That is, the supply contraction needs to have an effect on the oil price or otherwise no Hotelling rent can be generated.

8.1 Differences in Oil Reserves

It might be that differences in the time trend between state-owned and private firms is driven by some cross effect, due to diverging reactions to changes in oil reserves.[47] For example, state-owned firms might develop their oil reserves at a slower pace. Table 4, column 1 (labeled oil reserves), shows that the separation of oil reserves for national and private firms do not affect the coefficients of the time trends. National firms still successively reduce their oil supply by 3.4 percent each year, and private firms produce at a constant rate. Nevertheless, the log oil reserves coefficient of private firms exceeds its national counterpart, indicating that private firms produce at a higher pace. However, it is not possible to reject the Wald-test that both coefficients are equal at the 5 percent level, which does not support the separation of the coefficients on statistical grounds.

8.2 OPEC

In this subsection, I extend the data analysis by investigating whether the observed behavior of the national firms is determined solely by the sub-group OPEC, which would imply that the variance in the OPEC observations drives the results of the national firms and would imply a considerable market power of the OPEC.

To this end, I separate the OPEC group of firms, which consists throughout of state-owned firms, from the rest of the state-owned firms. Thus, for now, the state-owned group does not contain the firms within the OPEC group. Then both groups are endowed with a separate time trend. Table 4, column 2, shows the results. Here the time trend coefficient of the OPEC group tops its state-owned counterpart quantitatively, implying a greater discount rate for the OPEC group. However, following the Wald-test, it is not possible to reject the hypothesis that the coefficients of these two groups are the same. The same holds true in column 3, where, additionally, a separate slope for OPEC oil reserves is introduced. Indeed, the time trends between OPEC and state-owned firms converge considerably in column 3, indicating differences in the pace of oil reserve development. I cannot reject the hypothesis that the OPEC firms differ with respect to the oil reserves of the other oil firms marginally at the 5 percent level, even though the OPEC coefficient is greater in quantitative terms. I conclude that the OPEC group of firms behaves similar to other state-owned firms by reducing their oil supply at a yearly rate of about 3.5 percent, but might differ at the rate

[47] I do not report the results for control variables already discussed in Section 7.1. These coefficients mostly enter into the regression in a manner similar to Table 2.

Table 4: Regression Results - Oil Reserves and OPEC (1998-2010)

Dependent Variable: Log Oil Production	(1)		(2)	(3)
Time trend state-owned	-0.034**		-0.039**	-0.038**
	(0.007)		(0.011)	(0.010)
Time trend private	0.006		0.006	0.006
	(0.005)		(0.005)	(0.005)
Oil reserves		*OPEC*		
		Time trend OPEC	-0.028**	-0.035**
			(0.008)	(0.009)
State-owned oil reserves	0.455**	OPEC oil reserves		0.856**
	(0.083)			(0.216)
Private oil reserves	0.607**	Non-OPEC oil reserves		0.417**
	(0.063)			(0.061)
Obs.	530		530	530
adj.-R^2	0.961		0.961	0.963
F-Statistic	26.780		23.855	24.691

Notes: * $p < 0.05$, ** $p < 0.01$. FE estimator regressions in all columns with country dummies, time dummies and robust standard errors clustered at firm level in parentheses. The sample period is 1998-2010. In all columns a state-owned dummy, log Refinery Capacity, log Product Sales, the PRI measure and log GDP (int $) are included, but not reported. The models of columns 2-3 include an OPEC dummy, and column 2 also the log oil reserves (not reported). For the columns 2-3 I cannot reject, at the 10% level, the H_0: *the coefficients are the same* in case of the time trends for OPEC and state-owned firms.

of development of their oil reserves, holding all else constant. The latter point also might reflect the more easily accessible oil reserves of the OPEC.

Respectively, by reversing the argument, I find that the Hotelling path of a declining oil supply is characteristic for state-owned firms in general, and not characteristic for a special sub-group. It is not characteristic of private firms as the results confirm. This is good news, since it also implies that OPEC does *not* act as a monopolist and, hence, indicates a market structure of competitive national firms.[48] Thus, in the following, the OPEC group of firms is included into the set of state-owned firms again.

8.3 National Oil Supply and Oil Price

A further possibility to test the consistency of the theoretical and empirical findings is to reverse the argument of the relation between the Hotelling rent and the oil supply of national companies. The Hotelling rent in the model can only be realized by a reduction in supply and the resulting increase in the oil price. Following this line of reasoning, the data should exhibit a negative relationship between the oil supply provided by national firms and the oil price for the post-1997 years. A reduction in the state-owned oil supply, holding everything else constant, should result in an observable price effect which generates the Hotelling rent. In the context of the regression setup in

[48] This results coincides with the findings of Lin (2011) who finds no OPEC market power after 1990.

Table 5: The Oil Price and Oil Supply

	Obs.	Explanatory Variables	
		State-owned price effect	Private price effect
Sample restricted to post 1997	574	-.004**	0.000
		(0.001)	(0.000)
Sample restricted to pre 1998	373	0.002	-.008
		(0.005)	(0.005)

Notes: * $p < 0.05$, ** $p < 0.01$. The dependent variable is log oil production. FE estimator regressions in all columns with country dummies and robust standard errors clustered at firm level in parentheses. The post 1997 sample is restricted to 1998-2010 in row 1. The sample in row 2 is restricted to 1987-1997. In all columns, a state-owned dummy, log refinery capacity, log product sales, the PRI measure and log GDP (int dollars) are included, but not reported. I can reject, at the 1% level, the H_0: *the coefficients are the same* in case of the price effects in row 1, but cannot reject the hypothesis at the 10% level for row 2.

Eq. 10, the price effect would become noticeable, when removing the time dummies which control for the average yearly oil price.

On the other hand, the effect should not be observable before 1997, because state-owned firms shifted towards a Hotelling regime after 1997 and produced at a constant level before. Thus, reversing the argument, I substitute separate oil price effects for private and state-owned firms for the respective time trends in Eq. 10 and drop the time dummies. Table 5, row 1, confirms a negative covariance for the oil price and the oil supply for national firms in the sample 1997-2010. Utilizing the Wald-test, I can reject the hypothesis that the coefficients of the private and the national firms are the same at the 1 percent level. In turn, restriction of the sample to pre-1997 in column 2 reveals that the effect vanishes, and I cannot reject the hypothesis of similar coefficients. Hence, I conclude that national oil firms affect the oil price and thereby generate a scarcity rent after 1997, but do not follow such a regime before 1997. This closes the argument lined out in this study.

9 Conclusions

Oil is fundamental in large areas of economic activity. As the oil price rises and demand from developing economies, like China and India, increases, the question of supply is at hand. This paper identifies differences between private and national firms in terms of oil production as the major determinant driving the dynamic behavior of the world oil supply. I find that national firms have pursued a policy of oil supply stringency since 1997 in order to generate a Hotelling rent, whereas private firms have not. Thus, national firms restrict their oil supply to induce an oil price increase. Given that national firms provide the major share of the world oil supply and own more than 90 percent of all proven oil reserves, this finding contributes to a deeper understanding of the oil market and oil price development. I further present empirical evidence that the Hotelling regime is a more recent phenomenon and was not observable before 1997.

Guided by my extension of the Hotelling model that allows for differentiation with respect to private and state-owned firms, I present evidence that state-owned firms reduce their output at a yearly rate of about 3.5 percent. The data does not reveal that private firms adopt this behavior, but exhibits, ceteris paribus, a constant output for this group. In the model, the behavior of state-owned firms is driven by the scarcity rent, which plays no role in the behavior of private firms, because the latter face an expropriation date and hence do not expect to fully exhaust the oil reserves of their host countries. Thus, national firms generate revenues by limiting their output, which increases the oil price. I demonstrate that this carries over to the data, which confirm that a reduction in the oil supply by national firms raises the oil price.

My theory also suggests that national firms do not immediately switch towards a Hotelling regime after formation, but initially produce at a constant rate, due to the capacity limit constraint. That is reflected in the data, which show that national firms, which mostly emerged owing to expropriation in the 1970s, did not follow a Hotelling regime before 1997. These results are robust when controlling for firm- and country-specific variables. Due to the heterogeneous nature of their behavior, a shift from private to state-owned firms' oil market dominance has lead eventually (in 1997) to a shift from cheap to expensive oil. I conduct several robustness checks that show that the empirical results do not depend on specific regression setups and that the theory is applicable to the data.

References

Adelman, M. and G. Watkins (2005). Oil and natural gas reserve prices- addendum to CEEPR WP 03-016, including results for 2003 and revisions to 2001. *Massachusetts Institute of Technology, Working Papers 0513*.

Adelman, M. A. (2002). World oil production & prices 1947-2000. *The Quarterly Review of Economics and Finance 42(2)*, 169–191.

Berck, P. and M. Roberts (1996). Natural resource prices: Will they ever turn up? *Journal of Environmental Economics and Management 31(1)*, 65–78.

Chen, K., S. Chen, and L. Wu (2009). Price causal relations between China and the world oil markets. *Global Finance Journal 20(2)*, 107–118.

EIA (2009, January). Energy in brief: Who are the major players supplying the world oil market? http://tonto.eia.doe.gov/energy_in_brief/world_oil_market.cfm.

Eller, S., P. Hartley, and K. Medlock (2010). Empirical evidence on the operational efficiency of national oil companies. *Empirical Economics 40(3)*, 623–643.

Emerson, J. and C. Kao (2000). Testing for structural change of a time trend regression in panel data. *Center for Policy Research Working Papers 15, Center for Policy Research, Maxwell School, Syracuse University*.

Emerson, J. and C. Kao (2006). Testing for structural change in panel data: GDP growth, consumption growth, and productivity growth. *Economics Bulletin 3(14)*, 1–12.

Engel, E. and R. Fischer (2008). Optimal resource extraction contracts under threat of expropriation. *NBER Working Paper 13742*.

Hamilton, J. D. (2009a). Causes and consequences of the oil shock of 2007-08. *NBER Working Paper 15002*.

Hamilton, J. D. (2009b). Understanding crude oil prices. *The Energy Journal 30(2)*, 179–206.

Hotelling, H. (1931). The economics of exhaustible resources. *The Journal of Political Economy 39(2)*, 137–175.

Johany, A. D. (1979). OPEC and the price of oil: Cartelization or alteration of property rights. *Journal of Energy and Development 5(1)*, 72–80.

Kobrin, S. J. (1984). The nationalization of oil production: 1919-1980. In *Risk and the Political Economy of Resource Development*. David W. Pearce and Horst Siebert and Ingo Walter.

Lee, J., J. A. List, and M. C. Strazicich (2006). Non-renewable resource prices: Deterministic or stochastic trends? *Journal of Environmental Economics and Management 51(3)*, 354–370.

Lee, K. and S. Ni (2002). On the dynamic effects of oil price shocks: A study using industry level data. *Journal of Monetary Economics 49(4)*, 823–852.

Lin, C.-Y. C. (2011). An empirical dynamic model of OPEC and non-OPEC. *Mimeo, University of California at Davis*.

Livernois, J. (2009). On the empirical significance of the Hotelling rule. *Review of Environmental Economics and Policy 3(1)*, 22–41.

Livernois, J., H. Thille, and X. Zhang (2006). A test of the Hotelling rule using old-growth timber data. *Canadian Journal of Economics 39(1)*, 163–186.

Long, N. V. (1975). Resource extraction under the uncertainty about possible nationalization. *Journal of Economic Theory 10(1)*, 42–53.

Marcel, V. and J. V. Mitchell (2006). *Oil Titans: National Oil Companies in the Middle East*. Brookings Institution & Chatham House.

Mead, W. J. (1979). An economic analysis of crude oil price behavior in the 1970s. *Journal of Energy and Development 4(2)*, 212–228.

Samanni, M., J. Teorell, S. Kumlin, and B. Rothstein (2008). The qog social policy dataset, version 4nov08. Online. http://www.qog.pol.gu.se.

Seierstad, A. and K. Sydsaeter (1986). *Optimal Control Theory with Economic Applications (Advanced Textbooks in Economics)*. North Holland.

Slade, M. E. (1982). Trends in natural-resource commodity prices: An analysis of the time domain. *Journal of Environmental Economics and Management 9(2)*, 122–137.

Stevens, P. (2008). National oil companies and international oil companies in the Middle East: Under the shadow of government and the resource nationalism cycle. *Journal of World Energy Law & Business 1(1)*, 5–30.

Stiglitz, J. E. (1976). Monopoly and the rate of extraction of exhaustible resources. *American Economic Review 66(4)*, 655–661.

The Economist (2007, July). The visible hand on the tap. July 19th 2007. http://www.economist.com/node/9523371.

Tordo, S., B. S. Tracy, and N. Arfaa (2011). National oil companies and value creation. *World Bank Working Paper Series 18*.

Victor, D. G., D. R. Hults, and M. C. Thurber (Eds.) (2012). *Oil and Governance: State-owned Enterprises and the World Energy Supply*. Cambridge University Press.

Wilpert, G. (2003). The economics, culture, and politics of oil in Venezuela. http://venezuelanalysis.com/analysis/74.

Wolf, C. (2009). Does ownership matter? The performance and efficiency of state oil vs. private oil (1987-2006). *Energy Policy 37(7)*, 2642–2652.

Wyant, F. R. (1977). The role of multinational oil companies in world energy trade. *Annual Review of Energy 2*, 125–151.

Øystein Noreng (1980). *The oil industry and government strategy in the North Sea*. International Research Center for Energy and Economic Development.

Proof of Lemma1 We see that $\frac{\partial u_F(t)}{\partial t} < 0$ and $\exists\, t = T_{S(F)} : u_F(t) = K_F$. The latter point has to be true in order for K_F to be optimal. It follows, by continuity of the interior solution, that $u_F(t) = K_F \;\forall t \in [0, T_{S(F)}]$ and, because $u_F(t)$ decreases with $e^{-h\,r\,t}$, it is possible to write $u_F(t) = e^{-h\,r\,(t - T_{S(F)})}\, K_F \;\forall t \in [T_{S(F)}, T]$. Thus, the point $T_{S(F)}$ is a switching point for the firm.

Lemma 2. *The value function V_F is positive as long as $g < 1$ holds.*

Proof. To prove this Lemma, it is sufficient to substitute the solution for the sunk investment $\tilde{K}_F = \left(\frac{B\,(1-g)\,Y\,e^{-r\,T}\left(e^{r\,T}-1\right)}{r\,\Phi}\right)^h$ and the extraction rate in $V_F > 0$. This leads to

$$B^h\,(1-g)^h\,r^{-h}\,Y^h\,\Phi^{-h}\left(1 - e^{-r\,T}\right)^h > 0, \tag{13}$$

which is true for $g < 1$. □

Lemma 3. *Assuming that $K_{max} \geq \tilde{K}_F|_{\inf\{T: T = \frac{X_0}{\tilde{K}_F}\}}\, g^{\frac{1}{Y}}$ and $\inf\{T : T = \frac{X_0}{\tilde{K}_F}\} > \frac{K_{max}}{a} + \frac{1}{h\,r}$, where $\tilde{K}_F|_{\inf\{T: T = \frac{X_0}{\tilde{K}_F}\}}$ is the maximum value $\tilde{K}_F$ can assume for a finite expropriation date and $\frac{K_{max}}{a}$ is the time until K_{max} is reached, then it follows that $\tilde{T} \in [0, \frac{K_{max}}{a}]$ and thus the domain of Eq. (8) is bounded on $T \in [0, \frac{K_{max}}{a}]$.*

Proof. To prove Lemma 3, it is sufficient to show that if it is not optimal to expropriate until K_{max} is reached, the state will expropriate at $T = \frac{K_{max}}{a}$. This becomes obvious by comparing the following integrals:

$$V_L^2 \geq \overline{V}_L^2 = \int_{\frac{K_{max}}{a}}^{T = \frac{X_0}{\tilde{K}_F}} B\,K_{max}^Y\,e^{-r\,t}\,dt \geq \widehat{V} = \int_{\frac{K_{max}}{a}}^{T = \frac{X_0}{\tilde{K}_F}} B\,g\tilde{K}_F^Y\,e^{-r\,t}\,dt, \tag{14}$$

where the first integral is the discounted income from state-owned oil extraction, starting at time $t = \frac{K_{max}}{a}$ until the expropriation date $T = \frac{X_0}{\tilde{K}_F}$. The second integral denotes the discounted 'tax-only' income over the same interval. At $T = \frac{X_0}{\tilde{K}_F}$, the oil stock is exhausted for $\widehat{V}$. Because of the assumptions of Lemma 3 and $K_{max} \leq \tilde{K}_F$, $\widehat{V}$ is always feasible by expropriating at $t = \frac{K_{max}}{a}$. However, optimality requires a declining extraction path and thus $V_L^2 \geq \overline{V}_L^2$, due to the discount rate. Note that the inequality of Eq. (14) holds for an arbitrary expropriation date $T > \frac{K_{max}}{a}$. Thus, the domain is bounded. Lemma 3 also shows that optimality requires $X|_{T<\infty} > 0$. □

Lemma 4. *There exists a $\tilde{T}$ for which $V_L^2(\tilde{T}) > 0$ is true.*

Proof. It is sufficient to show that at least $\exists\, T : V_L^2(T) > 0$. Substituting for $T = \frac{X_0}{K_F}$ in Eq. (8) yields:

$$g \geq 0 \;\wedge\; h > e^{\frac{1}{h}}(h-1) \implies V_L^2(\frac{X_0}{K_F}) > 0, \tag{15}$$

which is true as long as h does not tend to infinity. □

Lemma 5. *There exists an optimal g which maximizes Eq.* (8).

Proof. The domain of Eq. (8), with respect to g, is bounded on $g \in [0, 1]$, because outside this interval neither the state nor the firm will participate. Furthermore, the value function is continuous and differentiable in g, $V_L^2|_{g=0} = V_L^2|_{g=1} = 0$, and it can be shown that the derivative $V_L^2|_{g=0} > 0$. Thus, by the interior extremum- and Rolle's theorem, the maximum $\tilde{g}$ is reached in the interior of the interval and exists. □

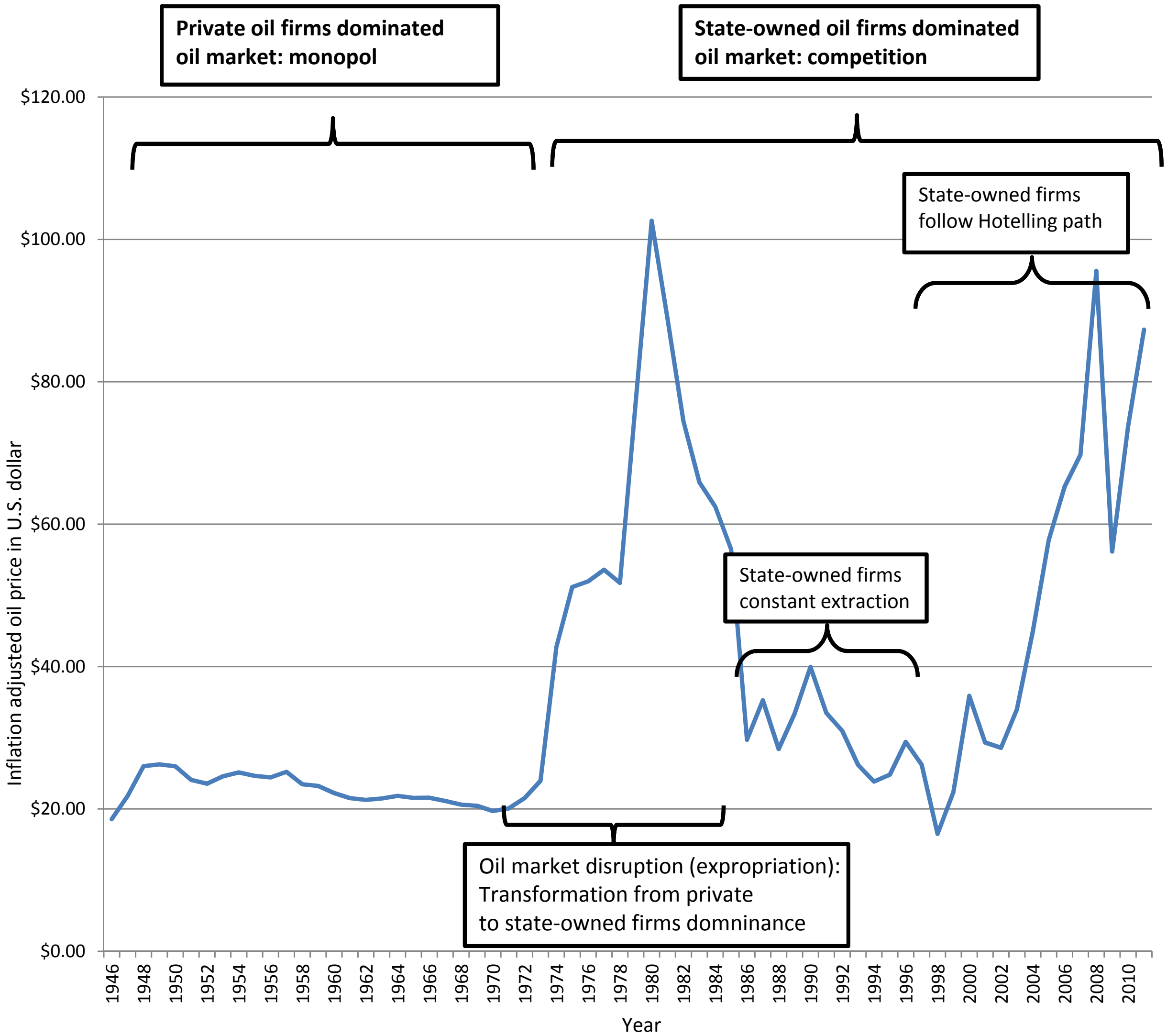

Figure 2: Casual interpretation of the historical oil price in the contex of the theoretical model