DISTORTIONS IN OIL CONTRACT ALLOCATION AND THE ROLE OF CORRUPTION IN SPATIAL PRICE TRANSMISSION OF CRUDE OIL PRICES

By

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ABSTRACT

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This dissertation has two papers. The first investigates how distortions stemming from corruption can alter government oil contract allocation decisions. The second examines the role of corruption in influencing crude oil price determination and spatial transmission of crude oil prices across international markets. Both papers have theoretical and empirical components. The first paper focuses on how corrupt behavior influences a government official’s contract allocation decision and increases the likelihood of a high cost efficiency multinational oil company getting the contract ahead of a low cost efficiency but low environmental damage oil company. The government gets a lower payoff with corruption compared to the no-corruption case, creating economic inefficiency. The major implication is that corruption creates economic inefficiency, reduces the official’s concern for environmental damage, and lowers the government payoff. The key model prediction is that oil production is more responsive to price changes when corruption is influencing allocation decisions. The empirical application tests this prediction. The second paper explores the link between crude oil corruption and spatial price transmission using Nigeria as a case study. A key prediction of the model is that, in the presence of corruption, Nigerian oil prices will be more sensitive to changes in world prices than they would be otherwise. Empirical results support that corruption influences Nigerian oil prices and increases the responsiveness of Nigerian prices to changes in world prices.
To my beloved mother
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KEY TO ABBREVIATIONS

BC  Brent Crude
CBN  Central Bank of Nigeria
CNL  Chevron Nigeria Limited
EIA  US Energy Information Administration
EIIC  Euromoney Institutional Investor Company
FOC  First-Order Condition
JOAs  Joint Operating Arrangements
MPEPC  Multinational Petroleum Exploration and Production Companies
MPNU  Mobil Producing Nigeria Unlimited
MPR  Nigerian Monetary Policy Rate
NAOC  Nigerian Agip Oil Company
NNPC  Nigerian National Petroleum Corporation
OPEC  Organization of Petroleum Exporting Countries
PSCs  Production Sharing Contracts
RWB  Reporters without Borders Press Freedom Index
SOC  Second-Order Condition
SPDC  Shell Petroleum Development Company
SPT  Spatial Price Transmission
WEF  World Economic Forum Global Competitiveness Survey
WTI  West Texas Intermediate
Corruption is widely defined by most public, private, and development organizations, such as the World Bank, as “the abuse of public power for private benefit”. Transparency International (2015) defines corruption as “the misuse of entrusted power for private gain”. Tanzi (2002) further classified corruption to include “bureaucratic (or “petty”) or political (or “grand”); …cost-reducing (to the briber) or benefit enhancing; briber-initiated or bribee-initiated; coercive or collusive; centralized or decentralized; predictable or arbitrary; and involving cash payment or not”. Rose-Ackerman (1999) noted that paying to get a benefit, to avoid a cost, and to acquire an official position, are other forms of corruption. Blackburn et al. (2006) gave a succinct definition of corruption as “the abuse of authority by bureaucratic officials who exploit their powers of discretion, delegated to them by the government, to further their own interests by engaging in illegal, or unauthorised, rent-seeking activities.” It is, therefore, evident that corruption abuses well-established government regulatory policies, facilitates illegal activities, and exploits powers of discretion.

There is a large body of research on corruption in the crude oil industry (or oil corruption). According to Karl (2004), countries that are rich in or dependent on oil usually have high corruption leading to a “resource curse”. Arezki and Bruchner (2011) investigated the effects of oil rents on crude oil corruption and state stability and found that an increase in oil rents has a positive effect on crude oil corruption. They concluded that, in countries with large amount of state participation in oil production, the effect of oil rents on corruption is significant unlike in low state-participating countries.

Moreover, Robinson et al. (2006) and Kolstad and Soreide (2009) observed that weak governance and corruption are the two most important factors that cause enormous economic
welfare changes in oil producing countries. Al-Kasim et al. (2013) further examined the relationship between oil production and corruption, with major focus on political accountability. They argued for stronger information disclosure on oil production. Other research that centers primarily on non-crude oil corruption in developing countries is the work done by Olken and Pande (2012), where they focused mainly on corruption prevalence, efficiency, and the determinants of corruption. They found an economic incentive effect of corruption as well as studying the effects of decreasing anti-corruption policy.

While these and many other studies (e.g., Ades and Di Tella, 1999; Al-Kasim et al., 2008; and Katsouris and Sayne, 2013) have enriched the corruption literature, the distortion or economic inefficiency that oil corruption might create, and its effect on environmental damages, have been neglected. Also neglected in the literature is the role oil corruption plays in influencing oil price determination and price transmission performance. Oil corruption can have ripple effects on all aspects of a nation’s welfare, including environmental and other health-related issues, and excluding these concerns would underestimate the actual impact of corruption on crude oil decisions and production.

1.1 Research questions and chapter organization

Therefore, the contributions of this dissertation are to provide theoretical and empirical answers to the following questions:

1. Does oil corruption lead to economic inefficiency (theoretical investigation)?

2. Does oil corruption increase the responsiveness of oil production to price (empirical investigation)?
3. Does corruption play a significant role in influencing price determination and price transmission performance of crude oil prices (theoretical and empirical investigation)?

Specifically, Chapter 2 analyzes a government official’s oil contract allocation procedure, and shows how corruption influences the official’s choices in determining who gets the oil exploration and production contract. It also illustrates the economic inefficiency that corrupt behavior creates and generates a theoretical prediction that oil production will be more responsive to price at higher corruption levels. An econometric application finds support for the model’s prediction.

Chapter 3 links spatial price transmission and crude oil diversion, and develops a model that shows the degree to which price shocks transmit across spatially distinct oil markets when oil corruption may be influencing trade volumes and price determination. A comparative static analysis examines the impact of a change in world oil price on the domestic price level in the presence of corruption. This chapter also provides quantitative estimates of price transmission elasticities, both with and without corruption, and estimates the effect of corruption on spatial price transmission. Chapter 4 provides overall conclusions to the dissertation.
REFERENCES


CHAPTER 2: DISTORTIONS IN OIL CONTRACT ALLOCATION AND ENVIRONMENTAL OUTCOMES IN THE PRESENCE OF CORRUPT BEHAVIOR

2.1 Introduction

Corruption, oil contract allocation, and environmental damage are three bedfellows that have coexisted in many parts of the world. Business activities in the oil industry are generally complex and confidential, opening a wide range of opportunities for corrupt behaviors (see Al-Kasim et al., 2008). For example, oil corruption appears common in Africa (e.g., Osoba, 1996; Shaxson, 2007; Kolstad and Soreide, 2009; Vicente, 2009; Hammond, 2011; and Brook, 2014). Le Billon (2005) discussed the role of corruption in the oil industry and observed that Iraq (Middle East), with the (then) second largest oil reserve in the world, has a history that “points to a pattern of … corruption…”. Oil Change International (2016) also noted that the oil and gas industry in Europe (particularly in the UK) experienced more prosecutions for bribery and corruption than any other sector over kickbacks to other international government entities as well as other payments made abroad. The US is also not exempt from oil corruption. Oil Change International (2016) reported that in the US “regulations and legislation to promote transparency and fight corruption was [were] opposed for years by the oil industry”.

Considerable existing research has focused on identifying the environmental impacts of crude oil production. Crude oil is one of the most commonly spilled petroleum products (e.g., benzene, ethylbenzene, oil mists, xylene, diesel fumes, heavy metals and oil dispersants) causing pollution and other environmental disasters (Irwin et al., 1997). Oil has been found to cause chemical, physical and physiological health hazards, especially to residents living close to the affected areas. O’Rourke and Connolly (2003) examined the impacts of crude oil production and
consumption and the environmental harm, socio-cultural consequences, and health hazards that increased oil production creates. They noted that “the physical alteration of environments from exploration, drilling, and extraction can be greater than from a large oil spill” with major environmental impacts ranging from chemical contamination of land and water, deforestation, and ecosystem destruction. O’Rourke and Connolly also enumerated other harmful impacts of oil production and consumption to include reduced plant and animal populations, human health/safety risks, other occupational hazards, and conflicts over oil ownership.

Other studies have also explored the relationship between corruption, environmental regulatory policies and firm efficiency. Fredrisson et al. (2003), for example, investigated the effect of corruption on foreign direct investment flows as well as environmental policies using a panel of US state-level data from 1977 to 1987. They found that “environmental policy stringency and corruption play a significant role in shaping the spatial allocation of foreign investment into the US” and that “corruption influences the supply of relevant public goods as well as the level of environmental regulation”. Dal Bo and Rossi (2007) also explored the role corruption plays in determining firm efficiency using a panel dataset containing 80 electricity distribution firms from 13 different Latin American countries from 1994 to 2001. They found higher levels of corruption are strongly related to firm inefficiency.

This chapter centers on a neglected aspect of crude oil production that may help explain oil contract award decisions and environmental damage when corruption is influencing the decision-making process. Clearly, oil exploration and production companies vary in their ability to carry out exploration activities with adequate checks on oil spillage and other environmentally harmful by-products. Small oil companies may be cost inefficient but capable of more careful supervision. Multinational oil companies, on the other hand, may be more cost efficient but also
generate greater environmental damage due to poor supervision and larger oil exploration and production potential. In the presence of corruption, officials are incentivized to award the contract to the company that pays a larger amount of bribes, even when the government gets a lower payoff. It is, therefore, important to examine the official’s contract award decisions when corruption misaligns the official’s incentives to allocate oil contracts.

If, as noted by Olken and Pande (2011), oil corruption has an important influence on the official’s decision regarding who gets the oil contract, this may create economic inefficiencies. Consequently, this chapter evaluates how distortions arising from oil corruption can influence the choice of who gets the oil exploration and production contract. The goals of this chapter are to provide a model structure that identifies which of the oil companies get the contract when corruption is influencing the official’s choice, and to provide an empirical analysis of one of the key predictions of the theoretical model.

The model predicts that higher corruption lowers the weight on environmental damage, and increases the likelihood that high cost efficiency multinational oil companies would get the contract. The presence of corruption misaligns the official’s incentives and as the official becomes more and more corrupt their decision changes in favor of the high cost efficiency multinational oil companies. Because of the cost of the bribe, the government gets a lower payoff with corruption than without corruption.

A key prediction of the model is tested empirically using monthly data from six different oil-producing countries. Results are consistent with the model prediction, showing that the responsiveness of oil production to price increases with corruption. This is particularly important because if oil production is more responsive to price with higher corruption levels then corruption makes the low cost multinational oil firm more likely to get the contract.
The remainder of Chapter 2 is organized as follows. Section 2.2 presents the model structure and comparative statics for the first-best case (benchmark). Then the second-best case without corruption is analyzed and compared to the first-best case. Finally, the second-best case with corruption is studied and economic inefficiency resulting from distortion of the oil contract allocation procedure is characterized. Model predictions and payoff comparisons for the first-best, second-best without corruption, and second-best with corruption cases are presented in section 2.3. The empirical implementation, data and results are shown in section 2.4, while conclusions and study limitations are discussed in section 2.5.

2.2 Model structure

There are three entities but two major players in the model: (1) firms \( \theta \) which are the bidding Oil Companies\(^1\) (the third party); and (2) the official (the agent), which represents the government (the principal). Denote \( \theta \in \{H, L\} \) as type \( H \) or \( L \) so that the output of the \( H \)- and \( L \)-type companies are \( Y_H \) and \( Y_L \), respectively, and their cost functions are \( C_H(Y) \) and \( C_L(Y) \).

Assume that the \( H \)-type has high cost efficiency and the \( L \)-type low cost efficiency, which implies that \( C_H(Y) < C_L(Y) \) for any \( Y > 0 \), and that \( C_H(0) = C_L(0) = 0 \) so the cost to the firm for any zero output level is zero. It is also assumed that marginal cost is smaller for the \( H \)-type than for the \( L \)-type, \( C_H'(Y) < C_L'(Y) \), for any \( Y > 0 \), and \( e(Y) \) is the environmental damage as a function of oil output \( Y \).

Assume also that \( C_\theta'(0) = 0 \) and that \( e'(0) = 0 \). That is, the marginal cost function for any firm and the marginal environmental damage function are zero at zero output levels. The

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\(^1\)The firm is defined as any Oil Company applying for crude oil exploration and production contract in the model. These include the multinational oil companies (MNOCs) such as ChevronTexaco, Total, ExxonMobil, Agip, etc.; and other national oil companies.
functions $C_\theta(Y)$ and $e(Y)$ are twice continuously differentiable on $Y$ and are strictly increasing and strictly convex so that $C_\theta'(Y) > 0$, $e'(Y) > 0$, $C_\theta''(Y) > 0$ and $e''(Y) > 0$.

To simplify the analysis, we assume the official can only award the contract to one firm. Let $s \in (0,1)$ be the fixed share that accrues to the government in the form of profit sharing and tax revenue\(^2\) and $1 - s$ be the fixed share the firm gets. The international price of oil is denoted $p$.

2.2.1 The firm

Firms produce oil output $Y$ with cost function $C_\theta(Y)$. The goal is to maximize the firm’s share of profit, $(1 - s)\pi_\theta$, by choosing

$$
(1) \quad \max_{Y \geq 0} (1 - s)\pi_\theta = (1 - s)(pY - C_\theta(Y))
$$

where $\pi_\theta$ is the profit for firm $\theta$.

2.2.2 The official

The government official chooses which firm will be awarded the oil production contract. The official cares about social welfare which can be maximized by keeping costs low but accounting for the environmental damage oil pollution creates. The official also cares about his own welfare and this introduces the possibility of corruption\(^3\) in awarding oil contracts. To understand how distortions arising from (corrupt) contract awards can influence outcomes,

\(^2\) Other types of oil costs such as royalty and signature costs are subsumed in $s$.

\(^3\) While there are many definitions of oil corruption such as shirking and contract awards to undeserved friends and family members with concealed benefits by the government official, our main focus here is on bribes the official might be asking before making contract award decisions. For more on official corruption see Olken and Pande (2011).
consider three major scenarios: the first-best (benchmark) case, second-best case without corruption, and the second-best case with corruption.

2.2.3 First-best outcome

To begin, consider a benchmark case where there is no corrupt behavior between the official and the firm. The official decides which firm should produce and how much so as to maximize a fixed (exogenous) government share of profit $s$ and minimize environmental damage $e(Y)$. In other words, the official maximizes the government objective function $G(\theta, Y)$, which is additively separable in government profit $R(\theta, Y)$ and environmental damage $e(Y)$:

$$\max_{\theta \in \{L, H, \emptyset\}, Y \geq 0} G(\theta, Y) = R(\theta, Y) - \lambda e(Y)$$

where the government profit $R(\theta, Y) = s(pY - C_\theta(Y))$ depends on the firm and firm output, and $\theta = \emptyset$ if no one wins the contract. In $G(\theta, Y)$, the environmental cost resulting from oil pollution depends on the government’s environmental priority $\lambda \in (0, \infty)$. For simplicity, assume the cost and environmental functions are quadratic$^4$: $C_\theta(Y) = \frac{Y^2}{2k_\theta}$ and $e(Y) = \frac{Y^2}{2}$.

Therefore, the first-order condition (FOC) for (2) yields:

$$p = C_\theta'(Y^*) + \frac{\lambda}{s} e'(Y^*)$$

where $Y^*$ is the optimal output choice. Since the convexity of the cost and environmental functions requires that $C_\theta''(Y) > 0$ and $e''(Y) > 0$, by differentiating the FOC with respect to $Y^*$

---

$^4$ We could make other tractable assumptions regarding the cost and environmental damage functions (such as exponential function specification) and still arrive at the same results provided such functions are twice continuously differentiable, strictly increasing and convex.
we obtain $-[sC_\theta''(Y^*) + \lambda e''(Y^*)] < 0$, which satisfies the second-order condition (SOC) for a maximum.

At the optimal output level $Y^*$ the marginal revenue (i.e. the international price of oil $p$) from any additional quantity of oil produced equals the additional cost of production plus the additional cost to the environment, with the marginal environmental cost multiplied by $\frac{\lambda}{s}$, which is the relative weight the government places on environmental priority $\lambda$ for any fixed share $s \in (0,1)$.

Then given the quadratic cost and environmental functions the optimal output level is

\[ Y^* = \frac{sp}{s+\lambda k_\theta} k_\theta = \frac{sp}{k_\theta + \lambda k_\theta} \]

and the maximized government payoff is

\[ G(\theta, Y^*) = s[pY^* - C_\theta(Y^*)] - \lambda e(Y^*) = \frac{(sp)^2}{2(s+\lambda k_\theta)} k_\theta = \frac{(sp)^2}{2\left(\frac{s}{k_\theta} + \lambda k_\theta\right)}. \]

It is straightforward to show that if the official awards the contract to the $H$-type, the government gets a higher payoff\(^5\) than if it is awarded to $L$-type or no one:

\[ \frac{(sp)^2}{2\left(\frac{s}{k_H} + \lambda k_\theta\right)} > \frac{(sp)^2}{2\left(\frac{s}{k_L} + \lambda k_\theta\right)} > 0 \]

since $k_H > k_L$, which occurs because the $H$-type is more cost efficient than the $L$-type. Consequently, in the first-best case, the official will pick the $H$-type for any combination of

\[^5\] Notice that if the official selects $\emptyset$, the maximized payoff function $G(\emptyset, Y^*)$ will be zero since the cost and environmental functions are zero at zero output level.
\( \lambda, s, p \), with the first-best (socially) optimal output choice \( Y^{FB} = \frac{sp}{s+\lambda \xi k_H} k_H \) and maximized government payoff \( (H, Y^{FB}) = \frac{(sp)^2}{2(s+\lambda \xi k_H)} \).

### 2.2.3.1 Comparative statics of the first-best outcome

The first-best case delivers \( \theta^{FB} (\lambda, s, p) \) and \( Y^{FB} (\lambda, s, p) \) where \( \theta^{FB} (\lambda, s, p) = H \), \( \forall \lambda, s, p \). Therefore, the effects of environmental priority \( \lambda \), fixed share of profit \( s \), and oil price \( p \) on the first-best (socially) optimal output choice is obtained in Proposition 1 below.

**Proposition 1**: First-best oil output increases in \( p \) and \( s \) but decreases in \( \lambda \)

Under the first-best output choice any change in \( Y^{FB} \) due to a change in \( \lambda, s \) and \( p \) have the following magnitudes and signs:

\[
\frac{dY^{FB}}{d\lambda} = -\frac{sp\xi k_H^2}{(s+\lambda \xi k_H)^2} < 0, \quad \frac{dY^{FB}}{ds} = \frac{p\lambda \xi k_H^2}{(s+\lambda \xi k_H)^2} > 0 \quad \text{and} \quad \frac{dY^{FB}}{dp} = \frac{sk_H}{s+\lambda \xi k_H} > 0.
\]

The signs of these comparative static effects follow a *priori* expectations as we would anticipate the optimal output choice to be increasing in price and share but decreasing in environmental priority. ■

### 2.2.4 Second-best outcome without corruption

Next consider the second-best case where we continue to assume that oil corruption does not influence firm choice. In this case, however, the uncorrupt official cannot control firm output decisions but chooses which of the firms should produce. The official’s maximization problem is to select \( H, L \) or \( \emptyset \), whichever gives the highest government payoff.

For \( H \) vs \( L \), the official’s choice is to
\[
\max_{\theta \in \{H, L\}} G(\theta, Y^\text{SB}_\theta) = R(\theta, Y^\text{SB}_\theta) - \lambda e(Y^\text{SB}_\theta)
\]

such that \(Y^\text{SB}_\theta = \arg\max_{Y_{\theta} \geq 0} (1 - s)(p Y_{\theta} - C_{\theta}(Y_{\theta}))\)

where \(R(\theta, Y^\text{SB}_\theta) = s[p Y^\text{SB}_\theta - C_{\theta}(Y^\text{SB}_\theta)]\) is the government profit that depends on firm type \(\theta\) and the firm’s second-best output choice \(Y^\text{SB}_\theta\). Obviously, the firm will choose \(Y^\text{SB}_\theta\) such that \(p = C_{\theta}'(Y^\text{SB}_\theta)\) or

(8a) \(Y^\text{SB}_\theta = p k_{\theta}\)

and obtain profit\(^6\):

(8b) \(\pi_{\theta} = \left(p Y^\text{SB}_\theta - C_{\theta}(Y^\text{SB}_\theta)\right) = p^2 k_{\theta} - \frac{(p k_{\theta})^2}{2k_{\theta}} = \frac{p^2}{2} k_{\theta}\).

From (8a) firms are incentivized by the price mechanism to make oil production decisions by setting their respective marginal costs to marginal revenue to get profit \((1 - s)\frac{p^2}{2} k_{\theta}\).

Therefore, the official’s choice between \(H\) and \(L\) is

(9a) \(G(H, Y^\text{SB}_H) = R(H, Y^\text{SB}_H) - \lambda e(Y^\text{SB}_H) \geq R(L, Y^\text{SB}_L) - \lambda e(Y^\text{SB}_L) = G(L, Y^\text{SB}_L)\),

(9b) \(s \pi_H - \lambda e(Y^\text{SB}_H) \geq s \pi_L - \lambda e(Y^\text{SB}_L)\),

(9c) i.e. \(\frac{p^2}{2} k_H(s - \lambda \xi k_H) \geq \frac{p^2}{2} k_L(s - \lambda \xi k_L)\)

where \(R(\theta, Y^\text{SB}_\theta) = s \pi_{\theta}\), with the choice of who wins the contract specifically depending on \(\lambda, s, k_H, k_L\), and \(\xi\) but not on \(p\) (since \(p\) enters identically in both payoffs).

\(^6\) It is obvious that \(Y^\text{SB}_H > Y^\text{SB}_L\) and \(\pi_H > \pi_L\) since the \(H\)-type is more cost efficient than the \(L\)-type.
Also, from (9c), the government’s profit share between the $H$-$L$ indifference line gives the following inequality:

(10a) \[ k_H(s - \lambda \xi k_H) \geq k_L(s - \lambda \xi k_L) \]

(10b) \[ s(k_H - k_L) \geq \lambda \xi (k_H^2 - k_L^2) \]

(10c) \[ s \geq \lambda \xi (k_H + k_L). \]

This is represented in Figure 2.1 below, which shows the graph of the official’s choice in $(\lambda, s)$ space in the absence of corruption. In Figure 2.1, the $H$-$L$ indifference line begins at $(\lambda, s) = (0,0)$ and goes through to $(\lambda_{HL},1)$, where $\lambda_{HL} = \frac{1}{\xi(k_H+k_L)}$ is the environmental priority of the $H$-$L$ indifference line when $s = 1$. The slope of the indifference line is $\xi(k_H + k_L)$.

Figure 2.1: The official’s choice as a function of $\lambda$ and $s$ in the absence of corruption
Similarly, the official’s preference between $L$ and $\emptyset$ is given as:

\[(11a) \quad G(L, Y_L^{SB}) = R(L, Y_L^{SB}) - \lambda e(Y_L^{SB}) \geq 0 = G(\emptyset, Y_\emptyset^{SB})\]

\[(11b) \quad s\pi_L - \lambda e(Y_L^{SB}) \geq 0\]

\[(11c) \quad \frac{p^2}{2}k_L(s - \lambda\xi k_L) \geq 0\]

with firm choice depending on $\lambda$, $s$, $k_L$, and $\xi$ but not on $p$ (which cancels out in the inequality) and the $L$-$\emptyset$ indifference line gives the following inequality:

\[(11d) \quad k_L(s - \lambda\xi k_L) \geq 0\]

\[(11e) \quad s \geq \lambda\xi k_L.\]

From Figure 2.1, the $L$-$\emptyset$ indifference line also begins from $(\lambda, s) = (0,0)$ all through to $(\lambda_{L\emptyset},1)$, where $\lambda_{L\emptyset} = \frac{1}{\xi k_L}$ is the environmental priority of the $L$-$\emptyset$ indifference line when $s = 1$. The slope of the $L$-$\emptyset$ indifference line now becomes $\xi k_L$, which is smaller than $\xi (k_H + k_L)$.

Therefore, the official’s allocation procedure in the $(\lambda, s)$ space is as follows: in region $H$, the $H$-type will be chosen since $H > L > \emptyset$; in region $L$, the $L$-type is chosen since $L > H, \emptyset$; and in region $\emptyset$, no contract will be chosen since $\emptyset > L > H$, otherwise the government gets a negative payoff if the contract is awarded.

**Proposition 2:** Environmental damage in the second-best case is higher for the high efficiency firm, $e(Y_H^{SB}) > e(Y_L^{SB})$

Recall that $e(Y_\emptyset) = \xi \frac{Y_\emptyset^2}{2}$. Therefore, $e(Y_H) = \xi \frac{(p_{kH})^2}{2} > \xi \frac{(p_{kL})^2}{2} = e(Y_L)$ since $k_H > k_L$.

This means that the environmental damage of the $H$-type is greater than that for the $L$-type in the second-best case. $\blacksquare$
The official’s decision can be summarized as follows. The government gets a higher profit but with a higher environmental damage if the $H$-type wins the contract, and gets a lower profit but with a lower environmental damage if the $L$-type wins the contract. The government gets nothing if the official chooses not to award the contract to anyone. So, the choice of who wins the contract will ultimately depend on environmental priority $\lambda$. Therefore, as $\lambda \to 0$ so that the government’s environmental prioritization becomes more and more irrelevant, the $H$-type wins the contract (since $k_H > k_L$), and as $\lambda \to \infty$ so that environmental priority becomes extremely important in making contract award decisions, no one wins the contract.

2.2.4.1 Comparative statics of the second-best outcome without corruption

In this section, we investigate how the firm choice $\theta$ and output $Y_{\theta}^{SB}$ change as $\lambda$, $s$ and $p$ change when there is no corruption.

2.2.4.1.1 Environmental priority

First, consider the effect of environmental priority $\lambda$ on firm choice $\theta$ and output $Y_{\theta}^{SB}$, holding $s$ and $p$ fixed. For any $\lambda \in \left(0, \frac{1}{\xi(k_H+k_L)}\right)$, $\theta = H$ and $Y_{\theta}^{SB} = pk_H$; for any $\lambda \in \left(\frac{1}{\xi(k_H+k_L)}, \frac{1}{\xi k_L}\right)$, $\theta = L$ and $Y_{\theta}^{SB} = pk_L$; and for any $\lambda \in \left(\frac{1}{\xi k_L}, \infty\right)$, $\theta = \emptyset$ and $Y_{\theta}^{SB} = 0$. That is, as $\lambda$ increases, the official’s choice switches from $H$ to $L$ to $\emptyset$, and production $Y_{\theta}^{SB}$ declines in a step-wise fashion. This production decline produces less environmental damage. Therefore, for any $\lambda \in \left(0, \frac{1}{\xi k_L}\right)$, a profit-environmental damage trade-off must be reached by the official in determining who wins the contract.
2.2.4.1.2 Government share of revenue

Next consider the effect of government share $s$ on firm choice $\theta$ and output $Y^\theta_{SB}$, holding $\lambda$ and $p$ fixed. In this case, there are three regions in $(\lambda, s)$ space. As $s$ increases, the official’s choice (1) switches from $\emptyset$ to $L$ if $\lambda \in \left(0, \frac{1}{\xi(k_H+k_L)}\right)$; (2) switches from $\emptyset$ to $L$ if $\lambda \in \left(\frac{1}{\xi(k_H+k_L)}, \frac{1}{\xi k_L}\right)$; and (3) remains $\emptyset$, regardless of $s$, if $\lambda \in \left(\frac{1}{\xi k_L}, \infty\right)$. Production increases in a step-wise fashion and (1) switches from $0$ to $pk_L$ to $pk_H$ if $\lambda \in \left(0, \frac{1}{\xi(k_H+k_L)}\right)$; (2) switches from $0$ to $pk_L$ if $\lambda \in \left(\frac{1}{\xi(k_H+k_L)}, \frac{1}{\xi k_L}\right)$; and remains at $0$, again, regardless of $s$, if $\lambda \in \left(\frac{1}{\xi k_L}, \infty\right)$.

2.2.4.1.3 Price of crude oil

Finally, by holding $s$ and $\lambda$ fixed, it can be observed that changes in oil price $p$ have no effect on the official’s firm choice $\theta$. To see why, refer to (9c) and (11c) and notice that oil price drops out in the inequalities, implying that who gets chosen depends on the location in $(\lambda, s)$ space and not on $p$. In this case, the $H$-type will be chosen in region $H$, the $L$-type in region $L$ and no one in region $\emptyset$.

However, changes in $p$ do affect production $Y^\theta_{SB}$: if $(\lambda, s)$ fall in region $H$, $Y^H_{SB} = pk_H$ and $\frac{\partial Y^H_{SB}}{\partial p} = k_H$; if $(\lambda, s)$ fall in region $L$, $Y^L_{SB} = pk_L$ and $\frac{\partial Y^L_{SB}}{\partial p} = k_L$; and if $(\lambda, s)$ fall in region $\emptyset$, $Y^\emptyset_{SB} = 0$ and $\frac{\partial Y^\emptyset_{SB}}{\partial p} = 0$.

In summary, in the no-corruption second-best case the official is assumed to allow the firms make their own production decisions but chooses which firm should produce. The official’s decision reduces to comparing between the government payoff of $H$ vs $L$ and $L$ vs $\emptyset$, and an environmental damage trade-off must therefore be reached in determining who gets the
contract. An important aspect of the no-corruption second-best case is that, though it is not as efficient as the first-best outcome (where the official makes both firm choice and optimal output decisions), it does provide a point of comparison for the payoff structure when corruption is introduced.

**2.2.5 Second-best outcome in the presence of corruption**

In this section, we relax the assumption that the government official is not corrupt when making contract award decisions, allowing the official to care about his own welfare. In the presence of corruption, the conventional wisdom is that the official would award the contract to the “highest bidder” ignoring the resultant effect on the environment. Consequently, the study places major emphasis on how distortions arising from oil corruption can influence the official’s choice of who gets chosen, and what environmental damage would prevail in a corrupt environment.

First, the bargaining power model in the presence of corruption is introduced which shows that the official will extract the maximum willingness to pay (or a bribe) from the firm in awarding the contract. Next, we examine how corruption distorts the contract allocation procedure by making a comparison between the second-best case with and without corruption. Thereafter, model predictions, econometric analysis, and overall chapter summary are provided.

**2.2.5.1 Model set-up with corruption**

To begin, define $\gamma \in (0,1)$ as the incorruptibility parameter and the official’s objective as a weighted function:

\[
\max_{\theta \in \{H,L,0\}} G_b(\theta, Y^{SB}_\theta; \gamma, b_\theta) = \gamma G(\theta, Y^{SB}_\theta) + (1 - \gamma)b_\theta
\]
where \( G(\theta, Y^{SB}) = R(\theta, Y^{SB}) - \lambda e(Y^{SB}) \) is the government’s objective function that depends on firm type and the firm’s second-best optimal output choice (as in the previous section), and \( b_\theta \) is the bribe the firm pays the official to win the contract. The exogenous parameter \( \gamma \in (0,1) \) captures the presence of corruption and puts weight on the government’s objective function \( G(\theta, Y^{SB}) \). For example, if \( \gamma \rightarrow 0 \), where the official is heavily corrupt, then the official will choose to maximize \( b_\theta \); and as \( \gamma \rightarrow 1 \), in which case the official becomes more and more incorruptible, he will maximize \( G(\theta, Y^{SB}) \). Thus, \( \gamma \) shows how much the official weighs his enrichment vis-a-vis the government objective.

2.2.5.2 The bargaining power model in the presence of corruption

The official makes a take-it-or-leave-it offer to firm \( \theta \) and so extracts the maximum willingness to pay, \( WTP_\theta = (1 - s)\pi_\theta \). To see why, suppose the official makes an offer of \( WTP_\theta = (1 - s)\pi_\theta + \epsilon \), then the firm will choose not to bid for the contract since the bribe it is being asked to pay is greater than the after-share profit \( (1 - s)\pi_\theta \). If \( WTP_\theta = (1 - s)\pi_\theta - \epsilon \), then the firm will fully participate in corruption but the official can increase his gains by an additional \( \epsilon \) amount. Therefore, the official will make a take-it-or-leave-it offer of \( (1 - s)\pi_\theta \) in awarding the contract to firm \( \theta \).

The payoff to the official if he awards the contract to \( \theta \) is therefore

\[
13) \quad \gamma G(\theta, Y^{SB}_\theta) + (1 - \gamma) b_\theta = \gamma G(\theta, Y^{SB}_\theta) + (1 - \gamma)(1 - s)\pi_\theta.
\]

Similar to the second-best case in the absence of corruption, the official’s maximization problem is to compare the government payoff of \( H \) vs \( L \) and \( L \) vs \( \emptyset \), now in the presence of corruption.

For \( H \) vs \( L \), the official’s choice or preference is given as:
(14a) \( \gamma G(H, Y_H^{SB}) + (1 - \gamma)(1 - s)\pi_H \geq \gamma G(L, Y_L^{SB}) + (1 - \gamma)(1 - s)\pi_L \),

which can be rewritten as:

(14b) \( \gamma \left( s\pi_H - \lambda e(Y_H^{SB}) \right) + (1 - \gamma)(1 - s)\pi_H \geq \gamma \left( s\pi_L - \lambda e(Y_L^{SB}) \right) + (1 - \gamma)(1 - s)\pi_L \).

Multiply the official’s payoff through by a fraction, \( \frac{s}{\gamma s + (1 - \gamma)(1 - s)} \), as follows:\(^{7}\):

(14c) \( \iff \frac{s}{\gamma s + (1 - \gamma)(1 - s)} \left[ (\gamma s + (1 - \gamma)(1 - s))\pi_H - \gamma \lambda e(Y_H^{SB}) \right] \geq \frac{s}{\gamma s + (1 - \gamma)(1 - s)} \left[ (\gamma s + (1 - \gamma)(1 - s))\pi_L - \gamma \lambda e(Y_L^{SB}) \right] \)

(14d) \( \iff s\pi_H - \frac{\gamma s}{\gamma s + (1 - \gamma)(1 - s)} \lambda e(Y_H^{SB}) \geq s\pi_L - \frac{\gamma s}{\gamma s + (1 - \gamma)(1 - s)} \lambda e(Y_L^{SB}) \)

(14e) \( \iff s\pi_H - \omega \lambda e(Y_H^{SB}) \geq s\pi_L - \omega \lambda e(Y_L^{SB}) \)

(14f) \( \iff R(H, Y_H^{SB}) - \omega \lambda e(Y_H^{SB}) \geq R(L, Y_L^{SB}) - \omega \lambda e(Y_L^{SB}) \)

(14g) i.e. \( \frac{p^2}{2} k_H(s - \omega \lambda \xi k_H) \geq \frac{p^2}{2} k_L(s - \omega \lambda \xi k_L) \)

where \( \omega \in (0,1) = \frac{\gamma s}{\gamma s + (1 - \gamma)(1 - s)} \) is a corruption-adjusted weight on environmental damage, with the official’s choice of who wins the contract depending on \( \lambda, s, k_H, k_L, \xi \) and most importantly \( \gamma \). It is as if the official is comparing the two payoffs in (14g), as was the case without corruption, but now places a lower weight on environmental damage than what the government actually prescribes (i.e., \( \omega \lambda \) rather than \( \lambda \)).

Similar to the no-corruption second-best case, the \( H-L \) indifference line in the presence of corruption gives the following inequality:

(15a) \( \frac{p^2}{2} k_H(s - \omega \lambda \xi k_H) \geq \frac{p^2}{2} k_L(s - \omega \lambda \xi k_L) \)

---

\(^{7}\) This will not change the comparison even though the levels change.
\[(15b) \quad s(k_H - k_L) \geq \omega \lambda \xi (k_H^2 - k_L^2)\]

\[(15c) \quad s \geq \frac{\gamma s}{\gamma s + (1 - \gamma)(1 - s)} \lambda \xi (k_H + k_L)\]

\[(15d) \quad s\gamma + (1 - \gamma)(1 - s) \geq \gamma \lambda \xi (k_H + k_L)\]

\[(15e) \quad s(2\gamma - 1) \geq \gamma \lambda \xi (k_H + k_L) - (1 - \gamma),\]

which gives

\[(15f) \quad s \geq \frac{\gamma \lambda \xi (k_H + k_L) - (1 - \gamma)}{2\gamma - 1} \text{ if the official is less corrupt } (\gamma > \frac{1}{2}) \text{ and}\]

\[(15g) \quad s \leq \frac{\gamma \lambda \xi (k_H + k_L) - (1 - \gamma)}{2\gamma - 1} \text{ if the official is more corrupt } (\gamma < \frac{1}{2}).\]

This is represented in Figure 2.2 below, which shows the graph of the official’s choice in \((\lambda, s)\) space in the absence and presence of corruption when \(\gamma > \frac{1}{2}\). Rather than \((\lambda, s) = (0,0)\), as was the case in the absence of corruption, the \(H-L\) indifference line now begins at \((0, -\frac{1 - \gamma}{2\gamma - 1})\) and continues to \((\lambda_{HL}, 1)\). However, the \(H-L\) indifference lines with and without corruption intersect at \((\lambda_{HL}, 1)\). With corruption, the slope of the \(H-L\) indifference line becomes

\[
\frac{\gamma}{(2\gamma - 1)} \xi (k_H + k_L)\]

and the point where this indifference line intersects the \(\lambda\)-axis is \(\lambda_{HL}^L = \frac{1 - \gamma}{\gamma \xi (k_H + k_L)}\).

For \(L\) vs \(\emptyset\), the official’s choice is

\[(16a) \quad \gamma G(L, Y_{LSB}^L) + (1 - \gamma)(1 - s)\pi_L \geq 0,\]

which can be rewritten as:

\[(16b) \quad \Leftrightarrow \gamma \left( s\pi_L - \lambda e(Y_{LSB}^L) \right) + (1 - \gamma)(1 - s)\pi_L \geq 0\]

and multiplying through by \(\frac{s}{\gamma s + (1 - \gamma)(1 - s)}\) and rearranging gives:

\[(16c) \quad R(L, Y_{LSB}^L) - \omega \lambda e(Y_{LSB}^L) \geq 0\]
(16d) \[ s\pi_L - \omega\lambda e(Y^S_B) \geq 0 \]

(16e) i.e. \[ \frac{n^2}{2}k_L(s - \omega\lambda k_L) \geq 0, \]

and so the choice of who wins the contract will depend on \( \lambda, s, k_L, \xi \) and \( \gamma \).

---

**Figure 2.2:** The official’s choice as a function of \( \lambda \) and \( s \) in the absence and presence of corruption when \( \gamma > 1/2 \)
Also, the indifference line between $L-\emptyset$ gives the following inequality in the presence of corruption:

\[(17a) \quad \frac{p^2}{2}k_L(s - \omega \lambda \xi k_L) \geq 0 \]
\[(17b) \quad s \geq \frac{\gamma s}{\gamma s + (1-\gamma)(1-s)} \lambda \xi k_L. \]
\[(17c) \quad s\gamma + (1 - \gamma)(1 - s) \geq \gamma \lambda \xi k_L. \]
\[(17d) \quad s(2\gamma - 1) \geq \gamma \lambda \xi k_L - (1 - \gamma) \]

which also gives

\[(17e) \quad s \geq \frac{\gamma \lambda \xi k_L - (1-\gamma)}{2\gamma - 1} \text{ if the official is less corrupt } (\gamma > \frac{1}{2}) \text{ and} \]
\[(17f) \quad s \leq \frac{\gamma \lambda \xi k_L - (1-\gamma)}{2\gamma - 1} \text{ if the official is more corrupt } (\gamma < \frac{1}{2}). \]

Notice that in the presence of corruption the $L-\emptyset$ indifference line also begins at $(\lambda, s) = (0, -\frac{1-\gamma}{2\gamma - 1})$ as in $H-L$ and continues to $(\lambda, s) = (\lambda_{L\emptyset}, 1)$, where the indifference lines (with and without corruption) also intersect at $(\lambda_{L\emptyset}, 1)$. The slope of the $L-\emptyset$ indifference line is \( \frac{\gamma}{(2\gamma - 1)} \xi k_L \)
and the point where this line intersects the $\lambda$-axis is \( \lambda_{L\emptyset}^c = \frac{1-\gamma}{\gamma \xi k_L} \) (See Figure 2.2 for the less corrupt case, $\gamma > \frac{1}{2}$).

This yields a similar comparison to the case without corruption but now with a lower corruption-adjusted environmental priority $\omega \lambda$. If $\gamma \to 1$ so that the official is incorruptible then $\omega \to 1$ which gives the second-best case in the absence of corruption. If, on the other hand, $\gamma \to 0$ so that the official is highly corrupt, then $\omega \to 0$. In this case, the corruption-adjusted

---

8 Notice that the share inequality in (15f) is exactly the same as (10c), and the share inequality in (17e) is also the same as (11e) as $\gamma \to 1$ (i.e., no corruption case).
environmental concern, \( \omega \lambda \), becomes more and more irrelevant, which means it will be optimal for the official to award the contract to the \( H \)-type since \( k_H > k_L \). Hence, the choice of who wins the contract will, in this case, depend on the corruption-adjusted environmental priority \( \omega \lambda \), rather than \( \lambda \) in the no-corruption second-best case.

### 2.2.5.3 Economic inefficiency due to corruption

In this section we examine how corruption influences the official’s choice, enlarges the official’s bribe, and increases the parameter space over which the \( H \)-type is chosen. The presence of corruption basically shifts the \( H-L \) and \( L-\emptyset \) indifference lines farther to the right and so misaligns the official’s decision-making incentives. To see the effect of corruption, compare the official’s choice in the second-best case with and without corruption. In Figure 2.2, in addition to region \( H \) the official now awards the contract to the \( H \)-type in triangles \( a \) and \( b \), which would have been awarded to the \( L \)-type (triangle \( a \)) or to no one (triangle \( b \)) in the absence of corruption. The space for which the \( L \)-type gets the contract is now adjusted to the shape of a kite \( c \) and triangle \( L \), which was originally triangles \( a \) and \( L \) in the absence of corruption. And the space for which the official would award the contract to no one now reduces by \( b \) and \( c \) in the presence of corruption.

Also, notice the discrepancies or economic inefficiencies that occur regarding the official’s corrupt choice in \((\lambda, s)\) space where the official now selects a payoff that is strictly lower than the optimal government payoff. At \( H \) the optimal and the misaligned government payoff is \( G(H, Y_H^{SB}) \) and the official picks \( H \) and so receives a bribe of \((1 - s)\frac{p^2}{2}k_H \); at \( a \), the optimal government payoff is \( G(L, Y_L^{SB}) \) but the official picks \( H \) with a bribe of \((1 - s)\frac{p^2}{2}k_H \) and the government gets \( G(H, Y_H^{SB}) < G(L, Y_L^{SB}) \); at \( b \), the optimal government payoff is zero.
but the official still picks $H$, gets a bribe of $(1 - s) \frac{p^2}{2} k_H$ and the government gets $G(H, Y^{SB}_H) < G(L, Y^{SB}_L) < 0$; at $c$, the optimal government payoff is zero but the official picks $L$ and receives a bribe of $(1 - s) \frac{p^2}{2} k_L$ with the government getting $G(L, Y^{SB}_L) < 0$; at $L$, the optimal as well as the misaligned government payoff is $G(L, Y^{SB}_L)$ and the official picks $L$ with a bribe of $(1 - s) \frac{p^2}{2} k_L$; and at $\emptyset$, the government gets nothing and the official selects no one and receives a bribe of zero.

Though there is no distortion (only redistribution with some bribe payment from the firm to the official) in regions $H, L$ and $\emptyset$, there are misaligned firm choices and government payoffs in regions $a, b$ and $c$ due to corruption. This is summarized in Table 2.1 below, which shows the official’s corrupt choices and the associated bribe.
Table 2.1: The official’s corrupt choices and bribe

<table>
<thead>
<tr>
<th>Regions</th>
<th>Optimal government payoff</th>
<th>Misaligned government payoff</th>
<th>Optimal firm choice</th>
<th>Misaligned firm choice</th>
<th>Official’s bribe</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>$G(H, Y_H^{SB}) &gt; G(L, Y_L^{SB}) &gt; 0$</td>
<td>$G(H, Y_H^{SB})$</td>
<td>$\theta = H$</td>
<td>$\theta = H$</td>
<td>$(1 - s) \frac{p^2}{2} k_H$</td>
</tr>
<tr>
<td>a</td>
<td>$G(L, Y_L^{SB}) &gt; G(H, Y_H^{SB}), 0$</td>
<td>$G(H, Y_H^{SB})$</td>
<td>$\theta = L$</td>
<td>$\theta = H$</td>
<td>$(1 - s) \frac{p^2}{2} k_H$</td>
</tr>
<tr>
<td>b</td>
<td>$0 &gt; G(L, Y_L^{SB}) &gt; G(H, Y_H^{SB})$</td>
<td>$G(H, Y_H^{SB})$</td>
<td>$\theta = \emptyset$</td>
<td>$\theta = H$</td>
<td>$(1 - s) \frac{p^2}{2} k_H$</td>
</tr>
<tr>
<td>c</td>
<td>$0 &gt; G(L, Y_L^{SB}) &gt; G(H, Y_H^{SB})$</td>
<td>$G(L, Y_L^{SB})$</td>
<td>$\theta = \emptyset$</td>
<td>$\theta = L$</td>
<td>$(1 - s) \frac{p^2}{2} k_L$</td>
</tr>
<tr>
<td>L</td>
<td>$G(L, Y_L^{SB}) &gt; G(H, Y_H^{SB}), 0$</td>
<td>$G(L, Y_L^{SB})$</td>
<td>$\theta = L$</td>
<td>$\theta = L$</td>
<td>$(1 - s) \frac{p^2}{2} k_L$</td>
</tr>
<tr>
<td>$\emptyset$</td>
<td>$0 &gt; G(L, Y_L^{SB}) &gt; G(H, Y_H^{SB})$</td>
<td>$0$</td>
<td>$\theta = \emptyset$</td>
<td>$\theta = \emptyset$</td>
<td>$0$</td>
</tr>
</tbody>
</table>

Note: In regions $H$, $L$ and $\emptyset$, the optimal and misaligned government payoffs are the same irrespective of corrupt behavior, and in regions $a$, $b$ and $c$, the official chooses $H$, $H$, and $L$ respectively (against the optimal firm choice of $L$, $\emptyset$ and $\emptyset$) and obtains a higher bribe since $k_H > k_L > 0$. 


Proposition 3 emphasizes the point further.

**Proposition 3**: *The parameter space over which the H-type is chosen increases with corruption*

Recall that in (15e) the share inequality of the $H\,-\,L$ indifference line was given as

$$s(2\gamma - 1) \geq \gamma \lambda \xi (k_H + k_L) - (1 - \gamma)$$

or by rearranging,

$$\lambda = \frac{s(2\gamma - 1) + 1 - \gamma}{\gamma \xi (k_H + k_L)},$$

(18a) \quad \Rightarrow \quad \left. \frac{\partial \lambda}{\partial \gamma} \right|_{H\,-\,L \text{ indifference}} = \frac{\gamma \xi (k_H + k_L)(2s - 1) - [s(2\gamma - 1) + 1 - \gamma] \xi (k_H + k_L)}{\gamma^2 [(k_H + k_L)]^2}, $$

(18b) \quad = \frac{\gamma (2s - 1) - [s(2\gamma - 1) + 1 - \gamma]}{\gamma^2 (k_H + k_L)},

(18c) \quad = \frac{s - 1}{\gamma^2 \xi (k_H + k_L)} < 0 \text{ since } s \in (0, 1).

A similar sign is obtained by considering the $L\,-\,\emptyset$ indifference line. This suggests that, by fixing $s$, environmental prioritization decreases with corruption. In other words, the indifference lines shift to the left as corruptibility decreases (and approaches the second-best case in the absence of corruption) and to the right as corruptibility increases. \[\square\]

This is also represented in Figure 2.3 for a more corrupt scenario, where the $H\,-\,L$ and $L\,-\,\emptyset$ indifference lines pivot around $(\lambda, s) = (\lambda_{HL}, 1)$ and $(\lambda, s) = (\lambda_{L\emptyset}, 1)$, respectively. Specifically, as $\gamma \to 0$ regions $a$ and $b$, which is the parameter space for which the official now selects the $H$-type, enlarge dramatically; and as $\gamma \to 1$ we return to the second-best case without corruption in Figure 2.1. In other words, the regions where the government payoff is harmed ($a$, $b$ and $c$) enlarge when $\gamma$ is smaller (more corruption) and shrinks when $\gamma$ is higher (less corruption). Therefore, *higher corruptibility strictly enlarges the parameter space over which the H-type is chosen.*
Figure 2.3: The official’s choice as a function of $\lambda$ and $s$ in the absence and presence of corruption when $\gamma < 1/2$

Similar to the second-best case without corruption, we could also investigate the comparative static analysis of how the firm choice $\theta$ and output $Y^S_{\theta}$ will behave as $\lambda$, $s$ and $p$ change in the presence of corruption. However, this is omitted since these effects remain the same as was the case without corruption.
2.3 Predictions, payoff comparison and implications

2.3.1 Model predictions

The model, which shows how corruption distorts the oil allocation procedure, predicts the following:

1. Corruption increases the amount of environmental damage;
2. Higher corruption implies that the $H$-type firm is more likely to be chosen; and
3. The $H$-type is more responsive to price (since $Y^s_B = pk_\theta$ and $k_H > k_L$).

Therefore, a key model prediction is that oil production is more responsive to price when corruption is higher.

2.3.2 Comparing government payoffs for different cases

In the first-best case the official controls who gets the contract and how much is produced. If the official picks the $L$-type, the government gets a lower payoff than if the $H$-type is selected since $k_H > k_L$ (Refer to inequality 6), and so the first-best optimization delivers $\theta^{FB}(\lambda, s, p) = H$ over the entire $(\lambda, s)$ space.

Because of the official’s inability to enforce the optimal output level in the second-best no-corruption case, the official now selects $H, L$ and $\emptyset$ depending on the spot in the $(\lambda, s)$ space (see Figure 2.1.). In region $\emptyset$, no one is chosen since $\emptyset > L > H$ and the government gets nothing, whereas the government gets a positive payoff no matter the value of $\lambda$ and $s$ in the first-best case. In region $L$, the $L$-type is chosen in the second-best no-corruption case since $L > H, \emptyset$ and the government payoff is $G(L, Y^s_L)$. However, in this case, the government gets a payoff with a lower profit and lower environmental damage, whereas in the first-best case the
government gets a higher payoff over the entire \((\lambda, s)\) space by awarding the contract to the \(H\)-type. In region \(H\), the official selects the \(H\)-type with a government payoff of \(G(H, Y_H^{SB})\) in the second-best case, similar to the first-best where the official also selects \(H\) with a government payoff of \(G(H, Y^*)\). However, in the second-best case the government gets a higher profit but with a higher environmental damage, whereas in the first-best case, the government gets a higher profit but with a lower environmental damage over the entire \((\lambda, s)\) space.

To see the effect of corruption, compare the second-best cases with and without corruption in Figure 2.2. In regions \(H, L\) and \(\emptyset\), the no-corruption second-best case produces exactly the same outcome with corruption. However, in region \(a\), the official selects the \(H\)-type even when the government gets a higher payoff from the \(L\)-type without corruption; in region \(b\), the official still picks the \(H\)-type even when the government prefers \(\emptyset\) without corruption; and in region \(c\), the official selects the \(L\)-type even when the government still prefers \(\emptyset\) without corruption (see Table 2.1). Therefore, due to misaligned incentives, in regions \(a, b\) and \(c\), the government is strictly worse-off with corruption than without corruption. In general, the second-best case without corruption is weakly better than the second-best case with corruption.

Interestingly, corruption makes the oil market look more like the first-best case in one dimension. Figure 2.3 shows that, as the official becomes more corrupt, the region for which the \(H\)-type would get the contract increases dramatically. And as the official becomes extremely corrupt (i.e., \(\gamma \rightarrow 0\)), the \(H\)-type will be chosen in the entire parameter space, similar to the first-best case. The difference is that the government payoff in the first-best case is strictly greater than the second-best case with corruption. However, while the official’s choice is \(H\) the output choice of the \(H\)-type firm in the second-best case is strictly greater than the first-best case.
because production decisions are made by the firm at the point where marginal revenue just equals private marginal cost, and not the full social marginal cost.

Consequently, the first-best outcome is strictly more efficient than the second-best case without corruption, which is weakly more efficient than the second-best case with corruption. The use of the term “weak” is due to the fact that in regions $H$, $L$ and $\emptyset$, the choice of who gets the contract is the same in the second-best case with and without corruption.

2.3.3 Implications and theoretical findings

This section provides the major implications and findings of the theoretical section:

1. Oil corruption leads to economic inefficiency by making the official select the firm with a higher bribe but with a lower payoff to the government;
2. Oil corruption implies that the official will ultimately weigh damage to the public less and oil revenues more;
3. The $H$-type is more likely to get the contract when the official is extremely corrupt (similar to the first-best case), and the $H$-type, $L$-type or no one will be chosen depending on the spot in the parameter space when the official is not corrupt; and
4. Oil production is more responsive to price when corruption is higher.

2.4 Econometric analysis

The empirical implementation, data, and results are presented in this section.

2.4.1 Empirical implementation

Consider the following linear econometric model for country $i$ at time $t$:
\[(19) \quad Y_{it} = a_i + \beta_{1i}t + \beta_{2i}OILPRICE_t + \beta_{3i}CORRUPT_{it} + \beta_{4i}(CORRUPT_{it} \times OILPRICE_t) + \nu_{it}\]

where \(Y_{it}\) is crude oil production and the right-hand side variables include a linear time trend \((t)\), the international (world) oil price \((OILPRICE_t)\), a measure of corruption in different countries \((CORRUPT_{it})\), where a higher value means more corruption, and \(\nu_{it}\) are error terms representing other unobservable oil production shocks. The constant parameters \(a_i\) include all time-invariant unobserved heterogeneity in country \(i\) that might affect oil production such as political instability and other institutional factors, and \(a\) and \(\beta\)'s are parameters to be estimated.

The effect of price on oil production in country \(i\) is given by:

\[(20a) \quad \frac{\partial Y_{it}}{\partial P_t} = \beta_{2i} + \beta_{4i}CORRUPT_{it},\]

and the effect of a change in corruption on price responsiveness is given by:

\[(20b) \quad \frac{\partial^2 Y_{it}}{\partial P_t \partial C_{it}} = \beta_{4i} > 0.\]

In other words, the key model prediction that oil production is more responsive to price when corruption is higher boils down to the hypothesis that \(\beta_{4i} > 0\).

Six oil-producing countries (Australia, Brazil, China, Nigeria, Russia, and US) were selected for analysis based on location, total quantity of oil produced and perceptions about corruption levels. According to EIA (2015), 2013 world oil production in million barrels per day (MBD) shows the US (with 12.34 MBD) producing the most and Russia (with 10.76 MBD) coming in second. These are the top oil producers in the world. Next is China with 4.5 MBD (upper middle producer category), Brazil and Nigeria with 2.7 and 2.4 MBD (lower middle producer category), Brazil and Nigeria with 2.7 and 2.4 MBD (lower middle producer category).
producer category), respectively, and Australia with 0.52 MBD (lowest producer category).

These countries are also from many different parts of the world and differ in the degree of perceived corruption surrounding their oil industries.

2.4.2 Data

Monthly data from February 1994 to December 2008 were collected on crude oil production in thousand barrels per day (TBD); international price of oil in dollars per barrel; corruption, which ranges from 0 (honest) to 6 (highly corrupt)\(^{10}\); and per capita gross domestic product (GDPPC) in current US dollars. The variables were obtained from the following sources: (1) US Energy Information Administration for crude oil production, (2) Quandl.com\(^{11}\) for world oil price, (3) International Country Risk Guide (ICRG)\(^{12}\) for the corruption variable, and (4) World Bank for per capita gross domestic product, which was used as an additional covariate in some versions of the model. The ICRG corruption variable is a measure computed for the entire country but we assume corruption in the oil industry is highly correlated with the level of corruption in the country as a whole. Variable definitions are presented in Tables 2.2.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Definitions and Units</th>
</tr>
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<tr>
<td>(Y)</td>
<td>Crude oil production in thousand barrels per day</td>
</tr>
<tr>
<td>(OILPRICE)</td>
<td>International price of oil in dollars per barrel</td>
</tr>
<tr>
<td>(CORRUPT)</td>
<td>Corruption (From 0 (honest) to 6 (highly corrupt))</td>
</tr>
<tr>
<td>(CORRUPT*PRICE)</td>
<td>Corruption-price interaction</td>
</tr>
<tr>
<td>(GDPPC)</td>
<td>Per capita gross domestic product (GDPPC) in current US dollars</td>
</tr>
</tbody>
</table>

\(^{10}\)The corruption variable was originally 0 (highly corrupt) to 6 (honest) but was re-scaled to 0 (honest) to 6 (highly corrupt) by generating a new variable which subtracts the original corruption value from 6 so a higher value means a more corrupt country. For another approach that multiplies the corruption value by -1, see Fredriksson and Svensson (2003) and Mendez and Sepulveda (2006).

\(^{11}\)Quandl.com provides information for other crude oil price variables. For more on this visit https://www.quandl.com/data/ODA/POIWTI_USD-WTI-Crude-Oil-Price

\(^{12}\)For other country risks including corruption visit https://www.prsgroup.com/about-us/our-two-methodologies/icrg
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<th>Variable</th>
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</table>

Summary statistics are provided in Table 2.3. On average, the US has the highest amount of oil production followed by Russia, with Australia producing the least. On average, Australia is
the smallest producer at 615.8827 TBD but it also has the least corruption (sample average of 1.1927, with minimum and maximum values of 1 and 1.5).

Nigeria has the highest mean corruption value of 4.5810, with minimum and maximum values of 4 and 5, indicating that corruption is relatively high in this country. Russia is the second largest crude oil producer (7694.849 TBD on average) and it has a relatively high sample average corruption index of 4.1481, suggesting that production should be more responsive to oil price changes in Russia compared to Australia and the US.

2.4.3 Results

In order to give a general overview of oil production and corruption effects, we first report the results of estimating equation (19), reporting standard errors which are robust to heteroscedasticity. Next, we check for autocorrelation in the residuals for each country and discuss the results of the autocorrelation-corrected framework, which gives consistent estimates in the presence of autocorrelation.

2.4.3.1 Oil production and corruption effects

Table 2.4 presents results from regressing oil production against the world price, corruption, and its interaction with price for different countries (equation (19)). Results show that at a zero corruption value, a one dollar increase in price would increase oil production by 84.0532 TBD in Russia, 37.8883 TBD in the US, 3.1058 TBD in China, but decrease production by 10.9762 TBD in Brazil. At a corruption value of 1, a one dollar increase in price would increase production by 129.61023 TBD in Russia, 46.9922 TBD in US, 14.6171 TBD in Nigeria, and 3.5506 TBD in China. Each additional movement up the corruption scale adds 45.5571 TBD to price responsiveness in Russia, 9.1039 TBD in the US, and 7.4251 TBD in Nigeria. This price
effect is statistically insignificant in Australia and China, perhaps because there is little variation over time in the corruption index for these countries. Goodness of fit is high for Brazil, Russia and China, intermediate for the US and Nigeria, and low for Australia.

While these results are interesting, least squares estimation assumes that the residuals are serially uncorrelated. However, the Ljung Box Q statistics in Table 2.4 show empirical evidence of autocorrelation in the residuals in all countries. This implies least squares estimates of (19) may have standard errors that are inconsistent leading to inference problems (Engle and Granger, 1987; and Fackler and Goodwin, 2001). Autocorrelation in the residuals leads to underestimation of variances thus invalidating the usual $t$ statistics.

One approach to dealing with this problem is to estimate (19) and then test the residuals for autocorrelation. If autocorrelation is found an autocorrelation-correction procedure is used to get consistent estimates. The residual $\hat{\nu}_{it}$ is first obtained after estimating (19) with least squares and Ljung-Box Q tests are conducted to check for autocorrelation. If autocorrelation is confirmed we incorporate lagged residuals, $\hat{\nu}_{i,t-1}$, into the oil production estimation framework to correct for autocorrelation:

\[(21) \ Y_{it} = a_i + \beta_1 t + \beta_2 OILPRICE_t + \beta_3 CORRUPT_{it} + \beta_4 (CORRUPT_{it} * OILPRICE_t) + \rho_i \hat{\nu}_{i,t-1} + \kappa_{it}\]

where $\rho_i$ is a parameter to be estimated for each country $i$, and $\kappa_{it}$ is an independent and identically distributed (i.i.d) error term. The next section presents results from the autocorrelation-correction framework with robust standard errors to correct for heteroscedasticity.
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Oil production in Australia</th>
<th>Oil production in Brazil</th>
<th>Oil production in Russia</th>
<th>Oil production in Nigeria</th>
<th>Oil production in China</th>
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</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors in parenthesis
2.4.4 Autocorrelation correction

Table 2.5 presents the corrected results with the Ljung Box statistics now showing no evidence of remaining autocorrelation in the residuals in any country. Similar to Table 2.4, results show that at zero corruption value, a one dollar increase in oil price would significantly increase production by 70.6837 TBD in Russia, 47.2518 TBD in the US and 10.2471 TBD in Nigeria, but decrease production by 10.0784 TBD in Brazil. And each additional movement up the corruption scale also increases price sensitivity by 38.5193 TBD in Russia, 11.7145 TBD in the US, 9.0859 TBD in Nigeria and 2.0426 TBD in Australia.

The hypothesis that oil production is more responsive to price in countries with more corruption (i.e., $\beta_{4i} > 0$) is tested, with results showing a positive and statistically significant effect in Russia, the US, Nigeria, and Australia. The goodness of fit is higher than when autocorrelation was not accounted for.
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Oil production in Australia</th>
<th>Oil production in Brazil</th>
<th>Oil production in Russia</th>
<th>Oil production in Nigeria</th>
<th>Oil production in China</th>
<th>Oil production in US</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT</td>
<td>786.1923***</td>
<td>165.3721</td>
<td>11006.4700***</td>
<td>3206.9930***</td>
<td>2917.1650***</td>
<td>9256.1080***</td>
</tr>
<tr>
<td></td>
<td>(44.9387)</td>
<td>(100.4197)</td>
<td>(515.2575)</td>
<td>(192.4319)</td>
<td>(39.9257)</td>
<td>(189.6482)</td>
</tr>
<tr>
<td>TREND</td>
<td>0.1706</td>
<td>7.1851 ***</td>
<td>34.5411 ***</td>
<td>4.2275 ***</td>
<td>4.1754 ***</td>
<td>-7.8328 ***</td>
</tr>
<tr>
<td></td>
<td>(0.1487)</td>
<td>(0.2463)</td>
<td>(0.5086)</td>
<td>(0.4049)</td>
<td>(0.1932)</td>
<td>(0.7042)</td>
</tr>
<tr>
<td>OILPRICE</td>
<td>7.8944*</td>
<td>-10.0784 ***</td>
<td>70.6837 ***</td>
<td>10.2471 ***</td>
<td>2.6446*</td>
<td>47.2518 ***</td>
</tr>
<tr>
<td></td>
<td>(4.1847)</td>
<td>(2.0998)</td>
<td>(10.5037)</td>
<td>(2.8310)</td>
<td>(1.4950)</td>
<td>(15.6808)</td>
</tr>
<tr>
<td>CORRUPT</td>
<td>-110.8197**</td>
<td>192.0586 ***</td>
<td>-1598.1370 ***</td>
<td>-294.1055 ***</td>
<td>-1.6747</td>
<td>-296.0343 **</td>
</tr>
<tr>
<td></td>
<td>(43.0872)</td>
<td>(31.5242)</td>
<td>(145.1900)</td>
<td>(45.4500)</td>
<td>(12.8562)</td>
<td>(124.2950)</td>
</tr>
<tr>
<td>CORRUPT*PRICE</td>
<td>2.0426**</td>
<td>-6.0335 ***</td>
<td>38.5193 ***</td>
<td>9.0859 ***</td>
<td>0.2753</td>
<td>11.7145 ***</td>
</tr>
<tr>
<td></td>
<td>(0.9416)</td>
<td>(0.9575)</td>
<td>(5.3659)</td>
<td>(1.7785)</td>
<td>(0.5810)</td>
<td>(4.0289)</td>
</tr>
<tr>
<td>LAGGED RESIDUAL</td>
<td>0.8714***</td>
<td>0.6889 ***</td>
<td>0.9355 ***</td>
<td>0.8006 ***</td>
<td>0.5642 ***</td>
<td>0.6206 ***</td>
</tr>
<tr>
<td></td>
<td>(0.0370)</td>
<td>(0.0663)</td>
<td>(0.0445)</td>
<td>(0.0730)</td>
<td>(0.0744)</td>
<td>(0.0865)</td>
</tr>
<tr>
<td>Ljung Box Q. Stat, lags(3)</td>
<td>0.3002</td>
<td>0.3601</td>
<td>0.4224</td>
<td>0.5865</td>
<td>0.2445</td>
<td>0.3462</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.8128</td>
<td>0.9607</td>
<td>0.9938</td>
<td>0.8152</td>
<td>0.9671</td>
<td>0.8637</td>
</tr>
<tr>
<td>Obs., n</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>178</td>
</tr>
</tbody>
</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors in parenthesis.
2.4.5 Price elasticities

In order to provide a clearer understanding of the responsiveness of oil production to price, and how this responsiveness behaves in the presence of corruption, we convert the results to elasticity form.

The price elasticity of supply is derived as $(\beta_{2i} + \beta_{4i} \overline{CORRUPT_i}) \frac{\overline{OILPRICE_i}}{Y_i}$ for each country $i$, and the change in price elasticity due to an increased level of corruption is $\beta_{4i} * \frac{\overline{OILPRICE_i}}{Y_i}$, both computed at data means. Results are presented in Table 2.6, which shows that at a corruption value of zero, a 1% increase in oil price would significantly increase the amount of oil produced (or supplied) by about 0.08% in China, 0.34% in Nigeria, and 0.22% in Russia and US.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Price elasticities at a corruption value of zero</th>
<th>Price elasticities at a corruption value of 1</th>
<th>Change in elasticities due to corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Price elasticities at a corruption value of zero</td>
<td>Price elasticities at a corruption value of 1</td>
<td>Change in elasticities due to corruption</td>
</tr>
<tr>
<td>Australia</td>
<td>1.7796 *** (0.0000)</td>
<td>2.2088*** (0.0000)</td>
<td>0.4293*** (0.0000)</td>
</tr>
<tr>
<td>Brazil</td>
<td>0.1438 (0.3161)</td>
<td>0.0795 (0.6951)</td>
<td>-0.0643 (0.2857)</td>
</tr>
<tr>
<td>China</td>
<td>0.0823*** (0.0025)</td>
<td>0.0984*** (0.0050)</td>
<td>0.0161*** (0.0480)</td>
</tr>
<tr>
<td>Nigeria</td>
<td>0.3351*** (0.0000)</td>
<td>0.4628*** (0.0000)</td>
<td>0.1277*** (0.0002)</td>
</tr>
<tr>
<td>Russia</td>
<td>0.2155*** (0.0000)</td>
<td>0.2883*** (0.0000)</td>
<td>0.0728*** (0.0000)</td>
</tr>
<tr>
<td>US</td>
<td>0.2211*** (0.0030)</td>
<td>0.2759*** (0.0032)</td>
<td>0.0548*** (0.0041)</td>
</tr>
<tr>
<td>Obs., n</td>
<td>178</td>
<td>178</td>
<td>178</td>
</tr>
</tbody>
</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Prob > F in parenthesis
At a corruption value of 1, a 1% increase in price would increase oil production by about 0.10% in China, 0.46% in Nigeria, 0.29% in Russia and 0.28% in the US. Each additional increase in corruption significantly increases these elasticity estimates by 0.02% in China, 0.13% in Nigeria, 0.07% in Russia and 0.06% in the US. Brazil has statistically insignificant elasticity values. In summary, corruption increases the elasticities of the responsiveness of oil production to price, as the model predicted.

2.4.6 Robustness checks

2.4.6.1 Including alternative oil production covariates

To examine the robustness of the results, other possible covariates of crude oil production such as GDPPC were included. Results, shown in Table 2.7, indicate that the sign, magnitude (except in Australia) and statistical significance of model parameters are similar with the original oil production model in Table 2.5. In Russia, for example, at a corruption value of zero, a dollar increase in price would increase production by 70.0181 TBD (as against 70.6837 TBD in Table 2.5), and each additional movement up the corruption scale adds 35.0013 TBD (against 38.5193 TBD in Table 2.5). Results for other countries are similar. Other covariates, such as electricity production from natural gas, were also examined. Results (not shown) show a similar sign, magnitude and statistical significance of the system parameters as in the national income estimation.
Table 2.7: Robustness check using an alternative oil production covariate (GDPPC)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Oil production in Australia</th>
<th>Oil production in Brazil</th>
<th>Oil production in Russia</th>
<th>Oil production in Nigeria</th>
<th>Oil production in China</th>
<th>Oil production in US</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT</td>
<td>1050.2400***</td>
<td>186.4750*</td>
<td>11293.6100***</td>
<td>3617.9320***</td>
<td>2936.0840***</td>
<td>10372.7400***</td>
</tr>
<tr>
<td></td>
<td>(48.6221)</td>
<td>(107.3913)</td>
<td>(556.3324)</td>
<td>(238.6301)</td>
<td>(38.4961)</td>
<td>(661.3621)</td>
</tr>
<tr>
<td>TREND</td>
<td>1.0410***</td>
<td>7.0953***</td>
<td>37.1094***</td>
<td>9.4685***</td>
<td>3.1933***</td>
<td>-2.7467</td>
</tr>
<tr>
<td></td>
<td>(0.1519)</td>
<td>(0.2758)</td>
<td>(0.6027)</td>
<td>(0.6230)</td>
<td>(0.2595)</td>
<td>(2.8842)</td>
</tr>
<tr>
<td>OILPRICE</td>
<td>22.4572***</td>
<td>-9.6680***</td>
<td>70.0181***</td>
<td>6.4970*</td>
<td>3.6658*</td>
<td>49.4929***</td>
</tr>
<tr>
<td></td>
<td>(4.1847)</td>
<td>(2.1935)</td>
<td>(11.2933)</td>
<td>(3.5374)</td>
<td>(1.4675)</td>
<td>(15.9306)</td>
</tr>
<tr>
<td></td>
<td>(43.5569)</td>
<td>(32.0678)</td>
<td>(156.9687)</td>
<td>(57.0173)</td>
<td>(12.6567)</td>
<td>(125.3555)</td>
</tr>
<tr>
<td>CORRUPT*PRICE</td>
<td>4.7454***</td>
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<td>35.0013***</td>
<td>4.0401*</td>
<td>1.2138*</td>
<td>12.0968***</td>
</tr>
<tr>
<td></td>
<td>(0.9359)</td>
<td>(0.9784)</td>
<td>(5.7388)</td>
<td>(2.3948)</td>
<td>(0.6281)</td>
<td>(4.0569)</td>
</tr>
<tr>
<td>GDPPC</td>
<td>-0.0101***</td>
<td>-0.0064</td>
<td>-0.1032***</td>
<td>-0.9531***</td>
<td>0.0970***</td>
<td>-0.0414*</td>
</tr>
<tr>
<td></td>
<td>(0.0008)</td>
<td>(0.0070)</td>
<td>(0.0090)</td>
<td>(0.1031)</td>
<td>(0.0282)</td>
<td>(0.0236)</td>
</tr>
<tr>
<td>LAGGED RESIDUAL</td>
<td>0.8466***</td>
<td>0.691***</td>
<td>0.8799***</td>
<td>0.6948***</td>
<td>0.5554***</td>
<td>0.6138***</td>
</tr>
<tr>
<td></td>
<td>(0.0446)</td>
<td>(0.0666)</td>
<td>(0.0582)</td>
<td>(0.0715)</td>
<td>(0.0723)</td>
<td>(0.0899)</td>
</tr>
<tr>
<td>Ljung Box Q. Stat, lags(3)</td>
<td>0.5327</td>
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<td>0.8680</td>
<td>0.6166</td>
<td>0.1577</td>
<td>0.3370</td>
</tr>
<tr>
<td>$R^2$</td>
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<td>0.9608</td>
<td>0.9928</td>
<td>0.8282</td>
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<td>0.8644</td>
</tr>
<tr>
<td>Obs., n</td>
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<td>178</td>
<td>178</td>
<td>178</td>
<td>178</td>
<td>178</td>
</tr>
</tbody>
</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors in parenthesis.
2.4.6.2 Using panel data with fixed effect estimation

In this section, we show estimation results using a panel data framework and fixed effects. Results are reported in Table 2.8, and are similar to the individual country estimates in Table 2.5. The responsiveness of oil production to price is positive. At zero corruption value oil price has a positive and significant effect on oil production (i.e., a dollar increase in price would increase production by about 25 TBD); and this price effect increases substantially with higher corruptibility values (for example, at a corruption value of 1, a dollar increase in price would increase production by about 34 TBD). The price elasticity of supply is computed as 0.2411 with no corruption and this elasticity estimate increases to 0.3240 at corruption value of 1. This means that oil production is increasing in price, and more so at higher values of corruption. This implies that results are robust to this alternative estimation procedure.

<table>
<thead>
<tr>
<th>Table 2.8: Fixed effect regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
</tr>
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<td>CONSTANT</td>
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<tr>
<td>TREND</td>
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<tr>
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</tr>
<tr>
<td>PRICE</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>CORRUPT</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>CORRUPT*PRICE</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>GDPPC</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>LAGGED</td>
</tr>
<tr>
<td>RESIDUAL</td>
</tr>
<tr>
<td>$R^2$</td>
</tr>
<tr>
<td>Obs., n</td>
</tr>
</tbody>
</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors in parenthesis
2.5 Summary, conclusion and limitations

2.5.1 Summary and conclusion

This chapter investigates the role of corruption in crude oil production and environmental damage caused by the oil industry. Using a theoretical model, a comparison between the second-best case with and without corruption shows that the parameter space over which the high cost efficiency multinational oil company (H-type) would get the contract in the presence of corruption is considerably enlarged, and the parameter space for which no one gets the contract is reduced dramatically.

The theoretical findings of the chapter are two-fold. The first is that corruption misaligns the official’s incentives and creates economic inefficiencies. The second is that in the presence of corruption, the official places a lower weight on environmental damage than what the government actually prescribes.

Using a monthly data from February 1994 to December 2008, this chapter presents empirical results which support the hypothesis that oil corruption increases the responsiveness of oil production to price. The result is robust to heteroscedasticity, autocorrelation in the residuals, and alternative model specifications. It is found that price has a substantial effect on crude oil production but that this effect is amplified by corruption, especially in Russia, the US and Nigeria. These results support a key prediction of the theoretical model.

2.5.2 Limitations and future research

This chapter also has a number of limitations.

1. It is possible that the official could award the contract to more than one party at the same time (e.g., two or more H-types, or one H-type and one L-type, and so on). In this case,
the dynamics of the game may change and lead to different outcomes than what was obtained in this chapter. In such cases, we are likely to get different results in terms of how the official makes his decisions. Further studies could explore these alternatives to see how the official’s decision-making process is driven in a dynamic setting.

2. The game played in this study is static and does not allow for a repeated dynamic framework. For example, it is possible that the decision to award the oil contract today will depend on the bribe the official will receive after (and not before) the contract is awarded. This leads to a repeated game with different choice of who wins the contract and how much is produced compared to the one-shot game. This approach is left for future research.

3. It is well known that cross sectional data is more appropriate for estimating a static model. However, due to data limitations, times series data were used here. Future studies might consider estimating the model with cross sectional data.

4. The empirical model is restrictive in the sense that not all the implications of the theoretical model are tested. In future research it will be interesting to explore other implications of the theoretical model empirically. For example, it will be important to test whether the weight on environmental damage is smaller due to corruption.

5. Data used in this chapter covers only six countries: Nigeria, the US, Russia, Brazil, Australia and China. In future studies, one might expand the data set to additional countries (e.g., Saudi Arabia, Iran, Iraq, Kuwait, Canada, etc.).
REFERENCES


3.1 Introduction

Crude oil prices have experienced a sharp decline in recent years. In early 2014 oil was priced around $105 per barrel but by Jan 2015 the price had fallen to $45 per barrel (See Figure 3.1).

![WTI and Brent Crude Oil](image)

*Figure 3.1: Crude oil price movement from Jan. 2014 to Jan. 2015*

More recently, oil prices have failed to recover significantly and have remained in the $40-$50 per barrel range throughout most of 2016. This persistent oil price decrease has been attributed to several factors including the strength of the US dollar, the Iranian nuclear deal, global
oversupply concerns (particularly due to oil fracking in the US), huge oil reserves (Menton, 2014) and lower global demand. According to Bowler (2015), the effect of this decline is devastating to many oil exporting nations, leading to significant reductions in revenue. Because global oil prices influence national oil prices (Gienko, 2009), this recent oil price decline transmits across national boundaries. In other words, increases and decreases in oil prices transmit across spatially distinct national boundaries, though perhaps imperfectly and with delays.

A large body of research exists on spatial price transmission (SPT) and regional market integration. For example, Dillon and Barrett (2013) examined the transmission of global oil and maize prices to local prices in east Africa, and found that global oil prices have a strong and significant effect on maize prices via fuel transport costs. They also found that crude oil price shocks generally transmit much faster than maize prices. Bremmer and Kesselring (2016) studied the relationship between US gas prices and crude oil prices during the Great Recession and found that gas prices increase more rapidly when crude oil prices increase than they decrease when crude oil prices fall. In another recent study, Sajjadur (2016) investigated the responses of gasoline prices to crude oil price shocks and found an asymmetric price response, and that oil price volatility is an integral part of these asymmetries.

SPT studies have focused on a wide range of other markets and prices using a variety of methods (e.g., Bailey and Brorsen, 1989; Goodwin and Schroeder, 1991; Batterham and Macaulay, 1994; Balke and Fomby, 1997; Goodwin and Holt, 1999; Goodwin and Harper, 2000; Fackler and Goodwin, 2001; Goodwin and Piggott, 2001; Radchenko, 2005; Negassa and Myers, 2007; Adilov and Samavati, 2009; Myers and Jayne, 2012; Atil, 2014; Ghoshray, 2014; Liu and

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13 For other price transmission studies, see Perron (1989), Borenstein et al. (1997), Balke et al. (1998), Bachmeier and Griffin (2003), Serra et al. (2011) and Frondel et al. (2016).
Ma, 2014; Karagiannis et al., 2015; Kristoufek and Lunackova, 2015; Pal and Mitra, 2015; Qin et al., 2016). However, none of these studies has examined the explicit role corruption may play in influencing SPT, especially when there is potential for non-competitive behavior in the underlying markets. This study aims to fill this knowledge gap.

This paper investigates the link between crude oil diversion (corruption) and SPT by modeling the degree to which price shocks transmit across spatially distinct oil markets when there is potential for non-competitive and corrupt behavior that may influence trade volumes and price determination. Nigeria is used as a case study. Results show that crude oil diversion, where corrupt practices lead to oil being diverted from formal marketing channels, plays a major role in influencing price transmission performance. The study also uses an econometric model to provide quantitative estimates of the effects of oil diversion in Nigeria on SPT across markets. The finding that oil diversion is important in explaining SPT improves our understanding of the effects and costs of corrupt business practices in the oil industry.

This paper develops a conceptual model that predicts: (1) an increase (decrease) in world oil price will increase (decrease) the equilibrium level of Nigerian prices, and (2) for a given change in world price this increase (decrease) is higher with than without corruption. Results from the empirical application are consistent with these predictions, and suggest that oil corruption is important in explaining spatial price movements. The results also suggest that corruption negatively influences trade volumes. Empirical results show that, because of highly elastic world demand, Nigeria has limited ability to influence the prices it receives by varying output. Nevertheless, the extent of corrupt oil diversion still affects prices and relative price relationships.
The remainder of this chapter proceeds as follows. Sections 3.2 and 3.3 provide background on the Nigerian oil industry and discuss various contractual arrangements for oil production and marketing in Nigeria. Section 3.4 argues that these contractual arrangements may facilitate non-competitive behavior, and discusses the potential role of non-competitive behavior in SPT. In section 3.5, a model for studying SPT and evaluating the role of corruption in influencing price transmission performance is developed, and comparative static results on the effects of oil corruption are derived. Section 3.6 derives an econometric estimation strategy for the corruption effect. Data description and summary are presented in section 3.7 while results are reported in section 3.8. The main conclusions are provided in section 3.9.

3.2 Background on corruption in the Nigerian oil industry

Transparency International (2015) predicts that two decades from now about 90% of the world’s oil and gas production will come from developing countries. Many of these countries are underdeveloped and are among the poorest countries in the world. According to Kolstad and Wiig (2008), resource-rich developing countries often display poor economic performance due to problems associated with corruption, such as illicit business deals and undisclosed business track records (AlixPartners, 2015). In Africa, the countries with the highest oil and gas reserves and production (Nigeria and Angola) are also among the most corrupt nations in the world (Kolstad and Soreide, 2009).

The literature is replete with studies addressing oil corruption in the Nigerian oil and gas industry. For example, Osoba (1996) and Ades and Di Tella (1999) observe that crude oil sales were a major avenue for corrupt practices in Nigeria, and further noted that income from Nigeria’s oil business “created extraordinary opportunities for corruption.” Moreover, since
Nigeria’s independence in 1960, the Economic and Financial Crimes Commission (EFCC)\(^\text{14}\) noted that several oil deals amounting to about $380 billion have either been wasted or stolen by government officials (Kolstad and Soreide, 2009; This Day, 2012; Brock, 2014). Katsouris and Sayne (2013) also noted that on average 100,000 barrels per day went missing in 2013 in Nigeria due to corruption.

Several possible solutions to corruption have been proposed. Transparency International outlines two such solutions: providing more accurate financial reporting which would help hold government officials accountable, and publishing audited reports that meet international standards. The Global Economic Symposium (GES, 2015) also noted that by establishing a rigorous integrity system, such as whistleblower protection, a holistic and formidable force against corruption could be achieved. Lopez-Claros (2014) further suggested six major strategies for combating the corruption menace: (1) paying civil servants well; (2) creating transparency and openness in government spending; (3) cutting red tape; (4) replacing regressive and distorted subsidies; (5) establishing international conventions; and (6) deploying smart technology.

While many of these solutions can mitigate corruption they may also remain ineffective, especially in Nigeria, without a clear understanding of the mechanisms through which corruption can influence trade volumes and price determination in the crude oil market. A good understanding of the Nigerian oil industry, and how corruption affects it, is pertinent for developing an effective strategy to address these issues.

\(^{14}\) The EFCC is an anti-corruption commission established by President Olusegun Obasanjo (the first democratically elected Nigerian President, 1999-2007) and has received international accolades for its fight against corruption, including money laundering and Advanced Free Fraud, popularly known as “419”. For example, 31 of the 36 state governors in Nigeria were under investigation for corruption by the EFCC in September 2006 (BBC, 2006).
3.3 Contractual arrangements in the Nigerian oil industry

The Nigerian National Petroleum Corporation (NNPC) is the Nigerian governmental agency that controls Nigerian oil and contracts with multinational petroleum exploration and production companies (MPEPCs) to produce and market Nigerian oil. Production and marketing is coordinated through Joint Operating Arrangements (JOAs) and Production Sharing Contracts (PSCs) between the NNPC and the MPEPCs.

JOAs regulate partnerships between the NNPC and the MPEPCs and are the dominant contractual arrangement, accounting for approximately 90% of total Nigerian oil and gas production. The JOAs also determine the distribution of costs and profit between the NNPC and the MPEPCs. According to Ameh (2007), the MPEPCs first submit an annual budget which must be approved by the joint venture. Thereafter, they present a monthly cash call statement stipulating a share of funds required for oil and gas production by the respective members in the venture. Income from this agreement is shared proportionally to the equity stake in the venture, while the MPEPCs pay tax and royalty obligations as well as other operating and technical costs.

This profit-sharing approach (equity stake) in the JOAs between the NNPC and the MPEPCs applies to: (a) Shell Petroleum Development Company of Nigeria Limited (SPDC), which is a British/Dutch joint venture comprised of NNPC (55%), Shell (30%), TotalFinaElf (10%) and Agip (5%), and produces about 50% of Nigeria’s total crude; (b) Chevron Nigeria Limited (CNL), which is an American joint venture comprised of NNPC (60%) and Exxon-Mobil (40%); (c) Mobil Producing Nigeria Unlimited (MPNU), which is an American joint venture comprised of the NNPC (60%) and Exxon-Mobil (40%); (d) Nigerian Agip Oil Company Limited (NAOC), an Italian joint venture which comprises the NNPC (60%) and Elf...
(now Total) (40%); (e) NNPC Texaco--Chevron, a joint venture that is owned by NNPC (60%) and operated by Texaco (20%) with Chevron having a 20% stake; and (f) other local independent oil firms such as Eternal Oil and Gas PLC, Beco Petroleum Products PLC, Zenon Oil Limited and Conoil, accounting for about 5% of crude oil output in Nigeria (Muhammad, 2015).

With funding and technical challenges, along with declining NNPC revenue from the JOAs, PSCs are now gaining more prominence and acceptance. The PSCs are regulated contractual provisions that are controlled by the Deep Offshore and Inland Basin Production Sharing Contract Act of 2004 (Onyeaso, 2015). There is now “a deliberate effort to shift the contractual structure from JOAs to the PSCs” in Nigeria (Ameh, 2007).

In PSCs, the costs of exploration and production are borne completely by the MPEPCs. That is, if oil discovery and exploration costs $e$ are successful, resulting in a commercial find, then oil revenue $R$ is obtained by taking gross sales $Y$ and deducting the cost of commercial extraction $c$ and the payment of royalty $r$, giving $R = Y - c - r$. Thereafter, the oil company pays income tax $T$ to the Nigerian government (Ameh, 2007; Aturu, 2009; Onyeaso, 2015). Then the NNPC gets $SR + T$ and the oil company gets $(1 - S)R - T - e$, with $S$ representing the profit-sharing formula. Currently, about 90% of oil and gas production comes from JOAs and about 10% from PSCs. The differences in contractual arrangements are represented below in Figure 3.2.
Figure 3.2: Framework of crude oil production and share in the joint operating arrangements and production sharing contracts

**Oil Contractual Arrangements in Nigeria**

10% of oil and gas

Production Sharing Contracts

90% of oil and gas

Joint Operating Arrangements

If oil is found:

Oil Discovery and Exploration with cost, \( e \)

Revenue oil, \( R = Y - c - r \)

NNPC gets, \( SR + T \)

Oil Company gets, \( (1 - S)R - T - e \)

If oil is not found:

Income shared proportionally with the government’s stake in parenthesis

- SPDC (55%)
- Chevron Nigeria Limited (60%)
- MPNU (60%)
- NAOC (60%)
- NNPC Texaco (60%)
- Other local independent oil firms
3.4 Non-competitive behavior in the Nigerian oil market

A market can be considered perfectly competitive if (a) all buyers and sellers in the market are price-takers; (b) the product is homogeneous; (c) there are many buyers and sellers; (d) transaction costs are zero; and (e) there is perfect information, implying that the price being charged in the market is common knowledge (Sexton, 2013). However, there are reasonable arguments supporting the contention that the international oil market is non-competitive. On the supply side, for example, sellers are not necessarily price takers—some oil-producing nations form a cartel as members of the Organization of Petroleum Exporting Countries (OPEC), to which Nigeria belongs, and as such can restrict oil output in order to increase oil prices above the competitive level (Zycher, 2008). In addition, the NNPC clearly dominates domestic production and pricing in Nigeria and there is imperfect information regarding oil prices and quantities traded. This means that it may be more appropriate to model the Nigerian oil trade to allow for a non-competitive market structure. On the other hand, Nigeria’s ability to exploit market power on international markets is likely limited by the fact that it only markets a small fraction of world production and therefore faces a very price elastic demand. The recent emergence of shale oil production in North America has also clearly increased competition on world oil markets.

Changes in oil production by the OPEC nations (which produce about 40% of total world crude) is an important factor affecting international oil prices (EIA, 2015). In fact, oil consuming nations usually enter into bargaining agreements with producers, and therefore price-taking on the buying side may not be an appropriate assumption either. Another point to note is that crude oil is not homogenous as it differs in Sulphur content and other characteristics which can make
substitution of oil from different sources more difficult. Therefore, the model in the next section investigates the degree to which price shocks could be transmitted across space and time in the presence of corruption, and also accounts for possible non-competitive behavior in the oil industry.

3.5 Price transmission models

3.5.1 Non-competitive price transmission without corruption

Because of the dominant role of the NNPC in all of the JOAs and PSCs, we assume the NNPC controls Nigerian oil output and acts as a monopolist in deciding how much Nigerian oil to produce and market. Nevertheless, there are many alternative sources for oil besides Nigeria so buyers can readily substitute oil with similar characteristics from other producers if Nigerian prices are set too high. This suggests that, while the NNPC can influence the price Nigeria receives for oil, it is constrained by the elasticity of demand for Nigerian oil which is likely to be quite elastic due to the existence of close substitutes from other suppliers. We represent this oil demand function facing Nigeria from the rest of the world as:

\[ q = D(p, x, y) \]

where \( q \) is quantity of Nigerian oil demanded, \( p \) is price of Nigerian oil, \( x \) is a vector of other world oil prices, and \( y \) is a vector of world oil demand shifters.

The NNPC is assumed to act as a monopolist with profit:

\[ \pi = pq - C(q, w) \]

where \( C \) is a convex cost function, \( w \) is a vector of other variables (e.g., factor prices) which influence costs, and the NNPC can influence \( p \) through its choice of \( q \) given the demand function.
(1), with the extent of the influence depending on the price elasticity of demand. The profit-
maximizing choice of \( q \) is characterized by the standard necessary condition for a monopolist’s
output choice:

\[
(3) \quad p \left( \frac{1+\xi}{\xi} \right) - C'(q, w) = 0
\]

where \( \xi \) is the price elasticity of demand for Nigerian oil on the world market and \( C'(q, w) \)
indicates differentiation with respect to \( q \) (marginal cost of production). Equation (3) is the
standard monopoly requirement that marginal revenue equals marginal production cost.

Together, the demand function (1) and marginal condition (3) determine equilibrium
price and quantity of Nigerian oil as a function of demand shifters \( y \), factor prices \( w \), and other
world oil prices \( x \). In particular, the resulting equilibrium equation for price takes the form:

\[
(4) \quad p = P(w, x, y)
\]

which shows how world oil prices \( x \) transmit to equilibrium Nigerian prices \( p \) in the presence of
non-competitive behavior displayed by the NNPC. We could use equations (1) and (3) to
undertake a comparative static analysis of the nature of this price transmission from world to
Nigerian oil prices. However, we postpone such a comparative static analysis until we have
incorporated the role of corruption.

3.5.2 Non-competitive price transmission with corruption

Now consider the same non-competitive NNPC that is also subject to corruption and oil
diversion in the Nigerian oil industry. Assume \( q \) now represents official output and that a
proportion of this, \( s \), is captured and diverted from the official supply chain as a result of corrupt
practices. NNPC only pays production costs on the official output because the diverted oil is not
accounted for in official production figures. However, oil diversion itself is costly since it
requires bribes, establishment of an unofficial supply chain, and is subject to some probability of exposure and penalty. We assume, for simplicity, that the diverted oil is sold at the official price $p$ for Nigerian crude. However, purchases of diverted oil are not part of the official supply chain and so the demand function (1) still only depends on official output $q$. Under these assumptions, the NNPC’s profit function can be written:

\[
\pi = pq(1 + s) - C(q, w) - K(s, z)
\]

where $K$ is a convex diversion cost function which depends on the share of official output diverted $s$ and a vector of variables $z$ representing the effectiveness of the rule of law, voice and accountability, and other costs of diversion. Notice that diversion costs depend on the share of diverted oil not just the amount of oil diverted. This is to account for the fact that the probability of exposure and penalty for diverting a given quantity of oil should decrease as the total official quantity produced increases. Profit maximization is subject to the same demand function (1) which explains official demand for Nigerian oil.

The NNPC now chooses official output $q$ and the diversion share $s$. The resulting necessary conditions, along with the associated demand function, which we restate here for convenience, leads to the following Nigerian oil market equilibrium conditions under corruption:

\[
\begin{align*}
(6a) \quad p(1 + s)\left(\frac{1+\xi}{\xi}\right) - C'(q, w) &= 0 \\
(6b) \quad pq &= K'(s, z) \\
(6c) \quad q &= D(p, x, y)
\end{align*}
\]
where $K'(s, z)$ denotes differentiation with respect to $s$ (marginal cost of increasing the diversion share) and the second-order conditions are satisfied by the convexity of $C$ in $q$ and $K$ in $s$. The equilibrium price equation associated with this system will take the form:

\begin{equation}
(7)\quad p = P(w, x, y, z)
\end{equation}

which explains both how changes in world oil prices $x$ get transmitted to Nigerian price $p$, and how changes in the corruption environment $z$ influence Nigerian oil price $p$.

\subsection*{3.5.3 Comparative statics with corruption}

In this section, we investigate two important comparative static questions. First, how does the presence of corruption influence the equilibrium level of Nigerian oil price and official production levels (holding other factors constant)? Second, how does the presence of corruption influence the nature of price transmission from world oil price to Nigerian oil price? These issues are important to understanding the role of corruption in the Nigerian oil industry.

To answer the first question, let $(p^*, q^*)$ denote equilibrium price and quantity in the absence of oil diversion (i.e. they jointly solve equations (1) and (3)). Now evaluate the necessary condition for quantity under oil diversion (6a) at $(p^*, q^*)$. In this case, the derivative of the profit function with respect to official production with diversion is given by:

\begin{equation}
(8)\quad \frac{\partial \pi}{\partial q} = p^* \left( \frac{1+\xi}{\xi} \right) - C'(q^*, w) + p^* s \left( \frac{1+\xi}{\xi} \right).
\end{equation}

By definition, the first two terms sum to zero at $(p^*, q^*)$ so at this point the derivative is given by:

\begin{equation}
(9)\quad \frac{\partial \pi}{\partial q} = p^* s \left( \frac{1+\xi}{\xi} \right) \leq 0
\end{equation}
depending on whether the demand for Nigerian oil on the world market is inelastic or elastic. However, world demand for Nigerian oil is likely to be price elastic and it is well known that a monopolist will never produce at a point where demand is inelastic anyway. Therefore at \((p^*, q^*)\) the derivative in (9) will be positive. Then, since the profit function is concave, the positive slope at \((p^*, q^*)\) shows that the optimal quantity with diversion, \(q^0\), must be higher than \(q^*\) as long as the diversion share is positive. Because of the negative demand elasticity, this then implies that the price under diversion must be lower, \(p^0 < p^*\), or of course if demand were perfectly elastic then price would not change. These results show that corruption and oil diversion increase the amount produced and, assuming demand is not perfectly elastic, decrease the resulting price. This result is represented graphically in Figure 3.3, which shows the equilibrium price and quantity in the absence \((p^*, q^*)\) and presence \((p^0, q^0)\) of oil diversion.

![Diagram](image-url)

**Equilibrium price and quantity without oil diversion, \((p^*, q^*)\)**

**Equilibrium price and quantity with oil diversion, \((p^0, q^0)\)**

**Crude oil demand for Nigerian oil**

\(p \leq p^0 < p^*\)
To evaluate the second question, we compute the comparative static effect of a change in world oil price on the equilibrium Nigerian price under corruption, holding other exogenous variables constant. We call this effect (derivative) the price transmission effect and note that it will depend on the amount of oil diverted. We then investigate how the presence of corruption influences the sign and magnitude of this price transmission relationship.

The system in (6) contains three equations with three endogenous variables $q$, $s$ and $p$. By taking the total derivative of (6) and assuming only one $x_i$ changes (for example, the Brent Crude (BC) oil price, holding other exogenous variables constant), the system yields:

10a) \[(1 + s) \left( \frac{1+\xi}{\xi} \right) dp - C''(q,w) dq + p \left( \frac{1+\xi}{\xi} \right) ds = 0\]

10b) \[q dp + pdq - K''(s,z) ds = 0\]

10c) \[-D'(p) dp + dq = D'(x_i) dx_i\]

where $C''(q,w)$ and $K''(s,z)$ denote the second derivative of $C$ with respect to $q$ and $K$ with respect to $s$, respectively, and $D'(p)$ and $D'(x_i)$ denote differentiation of $D(p,x,y)$ with respect to $p$ and $x_i$, respectively. We solve this system to find the price, quantity, and diversion effects as:

11a) \[
\begin{bmatrix}
\frac{\partial p}{\partial x_i} \\
\frac{\partial s}{\partial x_i} \\
\frac{\partial q}{\partial x_i}
\end{bmatrix} = \begin{bmatrix}
(1 + s) \left( \frac{1+\xi}{\xi} \right) & p \left( \frac{1+\xi}{\xi} \right) & -C''(q,w) \\
q & -K''(s,z) & p \\
-D'(p) & 0 & 1
\end{bmatrix}^{-1} \begin{bmatrix}
0 \\
0 \\
D'(x_i)
\end{bmatrix}.
\]

Evaluating the inverse and rearranging gives:
(11b) \[
\begin{align*}
\frac{\partial p}{\partial x_i} &= \frac{1}{\Delta} \left[ \left( \left( 1 + s \right) \left( \frac{1+\xi}{\xi} \right) p + C''(q, w)q \right) D'(x_i) \right. \\
\frac{\partial s}{\partial x_i} &= \frac{1}{\Delta} \left[ -\left( \left( 1 + s \right) \left( \frac{1+\xi}{\xi} \right) p + C''(q, w)q \right) D'(x_i) \right. \\
\frac{\partial q}{\partial x_i} &= \frac{1}{\Delta} \left[ -\left( \left( 1 + s \right) \left( \frac{1+\xi}{\xi} \right) p + C''(q, w)q \right) D'(x_i) \right]
\end{align*}
\]

where \( \Delta = \left[ C''(q, w)K''(s, z) - p^2 \left( \frac{1+\xi}{\xi} \right) \right] D'(p) - \left( \frac{1+\xi}{\xi} \right) \left[ pq + (1 + s)K''(s, z) \right] \) is the relevant determinant. Notice that the second-order conditions for a maximum\(^{15}\) require that

\( C''(q, w)K''(s, z) > p^2 \left( \frac{1+\xi}{\xi} \right) \). Since demand for oil is price elastic, then \( \Delta < 0 \) because quantity demanded and the Nigerian price are negatively related (i.e., \( D'(p) < 0 \)). In addition, as the world price of oil \( x_i \) increases, it is expected that countries will buy more Nigerian oil, ceteris paribus, so we have \( D'(x_i) > 0 \). Therefore, in the presence of oil diversion, an increase in world oil price \( x_i \) will lead to an increase in: (1) the equilibrium level of Nigerian oil price; (2) the amount of oil diverted; and (3) the level of Nigerian output\(^{16}\). Of course, even without diversion, an increase in world oil prices should increase Nigerian output and price. So it is important to investigate how the magnitude of these effects changes under corruption.

### 3.5.4 Comparative statics without corruption

We now consider the SPT effect without corruption in order to make a comparison with the corruption case. Without corruption, the optimal production figure \( q \) must satisfy condition (3). By taking the total derivative of (1) and (3) and assuming only \( x_i \) changes, we obtain the following system of equations:

---

\(^{15}\) At optimal values of official quantity and diversion, \((q, s)\), the following provides the sufficient conditions for a maximum: \( -C'(q, w) < 0 \), \( -K'(s, z) < 0 \) and \( C''(q, w)K''(s, z) - p^2 \left( \frac{1+\xi}{\xi} \right) > 0 \).

\(^{16}\) These positive price transmission relationships occur because demand for Nigerian oil is price elastic.
\[(12a) \left( \frac{1+\xi}{\xi} \right) dp - C''(q, w) dq = 0 \]

\[(12b) -D'(p) dp + dq = D'(x_i) dx_i,\]

which can be represented as

\[(12c) \begin{bmatrix} \frac{\partial p^n}{\partial x_i} \\ \frac{\partial q^n}{\partial x_i} \end{bmatrix} = \begin{bmatrix} \left( \frac{1+\xi}{\xi} \right) & -D''(q, w) \\ -D'(p) & 1 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ D'(x_i) \end{bmatrix} = \frac{1}{j} \begin{bmatrix} C''(q, w) D'(x_i) \\ \left( \frac{1+\xi}{\xi} \right) D'(x_i) \end{bmatrix} \]

where the superscript \( n \) indicate no-diversion, and the determinant \( J = \left( \frac{1+\xi}{\xi} \right) - C''(q, w)D'(p) > 0 \) since \( |\xi| \geq 1 \). These comparative static results show that, assuming no oil diversion, an increase in world oil price will increase both the equilibrium level of Nigerian prices and the optimal output and, therefore, the signs of these effects are the same as with corruption. Villar and Joutz (2006) noticed a similar price transmission relationship in the US, and were able to show a positive contemporaneous impact of West Texas Intermediate (WTI) crude oil price on natural gas prices.

### 3.5.5 Comparing price transmission effects

Oil prices are expected to have different transmission effects with and without corruption. To show how the presence of corruption influences the magnitude of this effect, compare the effects in both cases. To begin, notice that if the price elasticity of demand for Nigerian oil is unitary, \( \xi = -1 \), then

\[(13) \frac{\partial p}{\partial x_i} = \frac{\partial p^n}{\partial x_i} = -\frac{D'(x_i)}{D'(p)} > 0 \]
which shows that the magnitude of the (positive) SPT effect would be the same with or without corruption. And if \( \xi \in (-\infty, -1) \), then the effect with corruption is greater than without corruption, \( \frac{\partial p}{\partial x_i} > \frac{\partial p^n}{\partial x_i} > 0 \). To show this result, recall that

\[
(14a) \quad \frac{\partial p}{\partial x_i} = \frac{-\left( C''(q,w)K''(s,z) - p^2 \mathcal{L} \left( \frac{1+\xi}{\xi} \right) \right) D_i}{\left( C''(q,w)K''(s,z) - p^2 \mathcal{L} \left( \frac{1+\xi}{\xi} \right) \right) D_i(p) - \left( \frac{1+\xi}{\xi} \right) \mathcal{L} \left( \frac{1+\xi}{\xi} \right) \left[ pq + (1+s)K''(s,z) \right]} = \frac{\partial p^n}{\partial x_i}.
\]

Multiply through by the inverse of \( \frac{\partial p^n}{\partial x_i} \) to obtain:

\[
(14b) \quad \frac{-\left( C''(q,w)K''(s,z) - p^2 \mathcal{L} \left( \frac{1+\xi}{\xi} \right) \right) D_i}{\left( C''(q,w)K''(s,z) - p^2 \mathcal{L} \left( \frac{1+\xi}{\xi} \right) \right) D_i(p) - \left( \frac{1+\xi}{\xi} \right) \mathcal{L} \left( \frac{1+\xi}{\xi} \right) \left[ pq + (1+s)K''(s,z) \right]} \leq 1 \quad \text{or} \quad \frac{c''(q,w)D_i}{c''(q,w)D_i(p) - \left( \frac{1+\xi}{\xi} \right) \mathcal{L} \left( \frac{1+\xi}{\xi} \right) \left[ pq + (1+s)K''(s,z) \right]} \leq 1.
\]

So the question reduces to whether

\[
(14d) \quad C''(q, w)K''(s, z) - p^2 \left( \frac{1+\xi}{\xi} \right) \leq C''(q, w)(pq + (1 + s)K''(s, z)) \quad \text{or} \quad \frac{c''(q, w)D_i}{c''(q, w)D_i(p) - \left( \frac{1+\xi}{\xi} \right) \mathcal{L} \left( \frac{1+\xi}{\xi} \right) \left[ pq + (1+s)K''(s,z) \right]} \leq 1.
\]

\[
(14e) \quad -p^2 \left( \frac{1+\xi}{\xi} \right) \leq C''(q, w)(pq + sK''(s, z)).
\]

Since the left-hand side of the inequality (14e) is negative and the right-hand side is positive, it must be the case that (14b) is greater than unity or that \( \frac{\partial p}{\partial x_i} > \frac{\partial p^n}{\partial x_i} > 0 \). Therefore, it can be concluded that while the signs remain unchanged, the magnitude of the SPT effect in the presence of corruption is greater than without corruption. The quantitative estimate of these price transmission effects, with and without corruption, will be investigated in more detail in the empirical application.
3.6 Empirical application

For empirical implementation we need to specify functional forms for relevant equations, collect data, and implement an appropriate estimation strategy. If we use time series data for estimation, we may also need to account for the possibility of dynamic adjustment in the data. Finally, we need to overcome the limitation that the share of oil diversion is not directly observable. To account for the latter problem, we solve (6b) for s to get an expression for the diversion share that depends on official revenue $pq$ and the diversion cost variables $z$:

$$s = S(pq, z).$$  

(15)

Substituting (15) into (6a), and (for convenience) re-stating the demand function (1), leads to the following two equation system which eliminates direct dependence on the diversion share $s$:

(16a)  $p \left(1 + S(pq, z) \right) - C'(q, w) = 0$

(16b)  $q = D(p, x, y)$.

Functional forms also need to be chosen for the oil demand $D(p_t, x_t, y_t)$, production cost $C(q_t, w_t)$ and the diversion share $S(p_t q_t, z_t)$, where $t$ subscripts are now included because we propose estimation with aggregate time series data. We assume a simple constant elasticity demand function of the form:

(17a)  $\ln(q_t) = \alpha + \xi \ln(p_t) + \beta \ln(x_t) + \phi \ln(y_t)$

where $x_t$ is Brent Crude (BC) oil price, and $y_t$ is a vector of per capita income (GDP per capita) in US, Brazil and India, the major oil importing countries; and $\alpha, \xi, \beta$ and $\phi$ are parameters to be estimated. We also assume production cost takes the following generalized Leontief form:
\[(17b) \quad C(q_t, w_t) = q_t^\gamma [\delta_1 w_{1t} + 2\delta_{12} (w_{1t} w_{2t})^{0.5} + \delta_2 w_{2t}] \]

where the two factor prices \(w_{1t}\) and \(w_{2t}\) are the interest rate (cost of capital) and labor force participation rate (a proxy for wage rate (price of labor))\(^{17}\), and \(\gamma\) and the \(\delta\) are parameters to be estimated. The model can be extended to more than two factor prices. The returns to scale parameter \(\gamma\) indicates the degree to which the cost of producing oil will increase as production increases. If \(0 < \gamma < 1\) there is increasing returns to scale; if \(\gamma > 1\) there is decreasing returns to scale; and if \(\gamma = 1\) then we have constant returns to scale.

For the diversion share equation, we assume a simple linear in logs form:

\[(17c) \quad S(p_t q_t, z_t) = \theta_0 + \theta_1 \ln(z_{1t}) + \theta_2 \ln(z_{2t}) + \theta_3 \ln(p_t q_t) \]

where \(z_{1t}\) and \(z_{2t}\) are factors influencing diversion costs (which could also be generalized to include more factors). In this case, the parameters \(\theta_1\), \(\theta_2\) and \(\theta_3\) are the expected unit change in the oil diversion share for a 1% change in rule of law \(z_1\), voice and accountability \(z_2\) and oil revenue \(pq\), respectively.

Substituting the functional forms (17) into the corruption model (16) and adding random error terms for estimation leads to the nonlinear simultaneous econometric model:

\[(18a) \quad p_t \left( \frac{1+\xi}{\xi} \right) \left( 1 + \theta_0 + \theta_1 \ln(z_{1t}) + \theta_2 \ln(z_{2t}) + \theta_3 \ln(p_t q_t) \right) \]

\[ -\gamma q_t^{\gamma-1} (\delta_1 w_{1t} + 2\delta_{12} (w_{1t} w_{2t})^{0.5} + \delta_2 w_{2t}) - \varphi = u_t \]

\[ (18b) \quad \ln(q_t) - a - \xi \ln(p_t) - \beta \ln(x_t) - \phi \ln(y_t) = v_t \]

\(^{17}\) Labor force participation rate is used as a proxy for wage rate since the wages of workers in the Nigerian oil industry are unavailable.
where \( u_t \) and \( v_t \) are random errors and \( \varphi \) and \( \alpha \) are constants. The model is estimated using a generalized method of moment (GMM) estimator, and the null hypothesis of no oil diversion (no corruption effect) is evaluated by testing \( H_0: \theta_0 = \theta_1 = \theta_2 = \theta_3 = 0 \).

The GMM estimator has advantages when there are endogenous explanatory variables, which is the case here. For example, Poghosyan and Hesse (2009) investigated the relationship between crude oil price shocks and bank profitability using data from 11 Middle East and North African oil-exporting countries. They used a GMM procedure to account for persistence in bank profits and to account for endogeneity using lags of the endogenous explanatory variable as instruments. They found that oil prices indirectly influence bank profitability through other macro channels. Kablan (2010) also used GMM estimation to examine different factors determining banking system efficiency in sub-Saharan Africa. He observed that the GMM estimator is robust to simultaneity bias, inverse causality, and omitted variables using the lagged first differences of the system endogenous variables as instruments. For other studies using lags of endogenous explanatory variables as instruments in a GMM framework, see the pioneering work by Hansen (1982), Arellano and Bond (1991), Sorensen (2007), Cotet and Tsui (2009) and Bruckner et al. (2011).

Maximum likelihood (ML) estimation could also have been used to account for endogeneity but it requires strong distributional assumptions on the errors. Jagannathan et al. (2002) noted that the use of ML estimation requires the assumption that the errors are “serially uncorrelated and conditionally homoscedastic” and that a violation of this assumption would bias the system estimates. However, GMM provides consistent parameter estimates even when there is serial correlation and conditional heteroscedasticity in the errors, and is more robust to violations of normality (Jagannathan et al., 2002). Another advantage of GMM is that it only
requires specification of the moment conditions from first-order conditions, and does not make any further distributional assumptions on the data. For these reasons, the GMM estimator is used to generate system parameter estimates in our empirical work.

The GMM procedure is implemented by specifying the model equations in (18), applying a weighting matrix that determines how each moment condition is weighted, and selecting a list of instruments. In our application, the major instrument set includes lags of the model exogenous and endogenous variables \((z_{1t-1}, z_{2t-1}, w_{1t-1}, w_{2t-1}, x_{t-1}, y_{t-1}, p_{t-1}, \ln q_{t-1})\).

### 3.7 Data

We use monthly data from January 2006 to December 2013. Data are sourced from the Euromoney Institutional Investor Company, US Energy Information Administration (EIA), Reporters Without Borders Press Freedom Index (RWB), Central Bank of Nigeria (CBN), World Bank (WB) and the World Economic Forum Global Competitiveness Survey (WEF). Table 3.1 presents the variable definitions and units of data used to estimate (18). These include Nigerian crude oil production (official oil output), Nigerian Bonny Light oil price, Brent Crude (BC) oil price, Nigerian interest rate, Nigerian labor force participation rate, rule of law in Nigeria, voice and accountability in Nigeria\(^{18}\), GDP per capita in US, Brazil and India, and time trend. Summary statistics for each variable are presented in Table 3.2.

The labor force participation rate in Nigeria is about 55.6% on average while the rule of law is about 38.9%, on average, showing some potential for corruption. The Nigerian Bonny Light and Brent oil prices have similar means of 90.66 and 88.37 dollars per barrel, respectively.

---

\(^{18}\) Rule of law is defined as the “perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts…” (Rule of Law. (n.d.)), while voice and accountability describes “the ability of citizens to hold leaders, governments and public organizations to account” (DFID, 2009).
Table 3.1: Variable definition

<table>
<thead>
<tr>
<th>Variables</th>
<th>Definitions and Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q )</td>
<td>Nigerian crude oil production in million barrels</td>
</tr>
<tr>
<td>( p )</td>
<td>Nigerian oil price (Nigerian Bonny Light) in dollars per barrel</td>
</tr>
<tr>
<td>( p_{brent} )</td>
<td>Brent crude (BC) oil price in dollars per barrel</td>
</tr>
<tr>
<td>( w_1 )</td>
<td>Interest rate, which is the Nigerian monetary policy rate (%)</td>
</tr>
<tr>
<td>( w_2 )</td>
<td>Labor force participation rate, total (% of total population ages 15-64)</td>
</tr>
<tr>
<td>( z_1 )</td>
<td>Rule of law (From 0 (low) to 1 (high))</td>
</tr>
<tr>
<td>( z_2 )</td>
<td>Voice and accountability (From 0 (low) to 1 (high))</td>
</tr>
<tr>
<td>( y_1 )</td>
<td>Income (GDP) per capita in US in current US dollars</td>
</tr>
<tr>
<td>( y_2 )</td>
<td>Income (GDP) per capita in India in current US dollars</td>
</tr>
<tr>
<td>( y_3 )</td>
<td>Income (GDP) per capita in Brazil in current US dollars</td>
</tr>
<tr>
<td>( t )</td>
<td>Time trend that captures wage and other factor price trend effects</td>
</tr>
</tbody>
</table>

Table 3.2: Summary statistics of key variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs.</th>
<th>Mean</th>
<th>Std. Dev</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>( q )</td>
<td>96</td>
<td>2.3819</td>
<td>0.1545</td>
<td>2.051</td>
<td>2.64</td>
</tr>
<tr>
<td>( p )</td>
<td>96</td>
<td>90.659</td>
<td>23.902</td>
<td>44.950</td>
<td>138.740</td>
</tr>
<tr>
<td>( p_{brent} )</td>
<td>96</td>
<td>88.373</td>
<td>23.550</td>
<td>39.950</td>
<td>132.72</td>
</tr>
<tr>
<td>( w_1 )</td>
<td>96</td>
<td>9.234</td>
<td>2.451</td>
<td>5.699</td>
<td>13.297</td>
</tr>
<tr>
<td>( w_2 )</td>
<td>96</td>
<td>55.613</td>
<td>0.388</td>
<td>55</td>
<td>56.20</td>
</tr>
<tr>
<td>( z_1 )</td>
<td>96</td>
<td>0.389</td>
<td>0.042</td>
<td>0.330</td>
<td>0.460</td>
</tr>
<tr>
<td>( z_2 )</td>
<td>96</td>
<td>0.604</td>
<td>0.054</td>
<td>0.51</td>
<td>0.7</td>
</tr>
<tr>
<td>( y_1 )</td>
<td>96</td>
<td>49061.71</td>
<td>2092.066</td>
<td>46437.07</td>
<td>52980.04</td>
</tr>
<tr>
<td>( y_2 )</td>
<td>96</td>
<td>4204.441</td>
<td>699.9686</td>
<td>3172.707</td>
<td>5301.794</td>
</tr>
<tr>
<td>( y_3 )</td>
<td>96</td>
<td>13761.87</td>
<td>1393.282</td>
<td>11501.98</td>
<td>15787.74</td>
</tr>
</tbody>
</table>
Figure 3.4 presents the Nigerian Bonny Light and Brent oil prices. In 2009, oil prices dropped to about 40 dollars per barrel due to global recession and global oversupply concerns. However, prices then rose again to above 110 dollars per barrel in 2011. Also notice a general co-movement between these prices in which the Nigerian Bonny Light is almost always higher than the Brent oil price. As shown in Figure 3.5, there is a generally positive relationship between Nigerian oil prices and Nigerian oil output.
Figure 3.5: Nigerian oil price and production levels
3.8 Econometric results

In reporting the results, particular attention is given to the effect of oil diversion due to corruption on the SPT elasticity and the speed of price transmission. Specifically, model estimation results are used to:

1. Test for the existence of a corruption (oil diversion) effect on Nigerian oil prices and production;
2. Provide quantitative estimates of the effect of corruption on Nigerian oil prices and production (if a statistically significant effect is found);
3. Provide quantitative estimates of price transmission elasticities between world and Nigerian oil prices both with and without corruption to estimate the effect of corruption on price transmission (if the corruption effect is statistically significant).
4. Provide quantitative estimates of the speed of price transmission between world and Nigerian oil prices, both with and without corruption, in order to estimate the effect of corruption on the speed of price transmission (if the corruption effect is statistically significant).

3.8.1 Effects of corruption under competitive behavior

Before reporting the results we discuss the expected signs of the parameters. The parameter $\xi$, which is the price elasticity of demand for Nigerian oil, is expected to be negative ($\xi < 0$) while the marginal cost parameters are expected to be positive ($\delta > 0$). Also, as noted in the comparative statics section, the Brent price elasticity parameter is expected to be positive ($\beta > 0$). The income elasticity of demand $\phi$ could be positive, negative or zero, depending on national oil demand characteristics by oil purchasing nations. However, we would generally expect higher incomes to lead to increases in demand ($\phi > 0$).
In addition, note that the diversion share equation is

\[ S(p_t q_t, z_t) = \theta_0 + \theta_1 \ln(z_{1t}) + \theta_2 \ln(z_{2t}) + \theta_3 \ln(p_t q_t). \]

Hence, if the rule of law in the country is strong, the amount of oil that will be diverted from formal marketing channels should decrease, implying that \( \theta_1 < 0 \). Also, \( \theta_2 \) shows the change in diversion share for a 1% change in the country’s voice and accountability. This is also expected to be negative (\( \theta_2 < 0 \)) since countries with well-developed political rights and press freedom are more likely to speak out in the event of corruption. The parameter \( \theta_3 \) determines how crude oil diversion behaves for a 1% change in revenue. Since the Nigerian oil price (and by extension, revenue) usually co-moves with world oil prices, and since increases in world oil price also increase the amount of diversion (as the comparative statics section indicates), then it is expected that \( \theta_3 > 0 \). However, given that an increase in revenue may also lead to stricter measures to curtail oil diversion it could be that \( \theta_3 < 0 \). Consequently, the expected sign of \( \theta_3 \) is indeterminate.

Econometric results for the case when competitive behavior is imposed, \( (\xi) = 1 \) in 18(a), are presented in Table 3.3. “Demand-only” results are from estimating the demand equation by itself instead of as part of the system. “Demand-supply” results are for the two-equation system allowing for a corruption effect. The own price elasticity of demand and Brent price elasticity are significant at 1% in both demand-only and demand-supply estimations. Results indicate that a 1% increase in the Nigerian oil price would lead to about 5.88% and 4.37% drop in oil demand in the demand-only and demand-supply specifications, respectively; while a 1% increase in the Brent price increases oil demand by 5.77% and 4.35%, respectively. The income elasticities of demand of major oil importing nations are statistically insignificant.
Table 3.3: Oil supply and demand under corruption assuming perfect competition

<table>
<thead>
<tr>
<th>Model Parameters</th>
<th>Parameters</th>
<th>Demand-only</th>
<th>Demand-supply with corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant: Oil demand</td>
<td>$\alpha$</td>
<td>1.1872</td>
<td>8.4092</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(16.041)</td>
<td>(10.7265)</td>
</tr>
<tr>
<td>Price elasticity of demand</td>
<td>$\xi$</td>
<td>-5.8762***</td>
<td>-4.3696***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.0545)</td>
<td>(1.1216)</td>
</tr>
<tr>
<td>Brent price elasticity</td>
<td>$\beta$</td>
<td>5.7652***</td>
<td>4.3530***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.9322)</td>
<td>(1.0842)</td>
</tr>
<tr>
<td><strong>GDP per capita of major oil importers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>$\phi_1$</td>
<td>-0.3257</td>
<td>-0.3809</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.8379)</td>
<td>(0.6384)</td>
</tr>
<tr>
<td>India</td>
<td>$\phi_2$</td>
<td>-1.0407</td>
<td>-0.2177</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.3594)</td>
<td>(0.8516)</td>
</tr>
<tr>
<td>Brazil</td>
<td>$\phi_3$</td>
<td>2.0393</td>
<td>0.5761</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.2586)</td>
<td>(1.4090)</td>
</tr>
<tr>
<td>Constant: Oil supply</td>
<td>$\varphi$</td>
<td>120.3437***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(21.4008)</td>
<td></td>
</tr>
<tr>
<td>Returns to scale</td>
<td>$\gamma$</td>
<td>0.5901***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0584)</td>
<td></td>
</tr>
<tr>
<td><strong>Cost variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest rate</td>
<td>$\delta_1$</td>
<td>-1.7862***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.5553)</td>
<td></td>
</tr>
<tr>
<td>Interest rate * Labor force participation</td>
<td>$\delta_{12}$</td>
<td>0.6907***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.2217)</td>
<td></td>
</tr>
<tr>
<td>Labor force participation</td>
<td>$\delta_2$</td>
<td>1.3125***</td>
<td></td>
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<td></td>
<td></td>
<td>(0.1849)</td>
<td></td>
</tr>
<tr>
<td><strong>Corruption effect</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice and Accountability</td>
<td>$\theta_1$</td>
<td>-0.0116***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0034)</td>
<td></td>
</tr>
<tr>
<td>Rule of law</td>
<td>$\theta_2$</td>
<td>-0.0122***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0021)</td>
<td></td>
</tr>
<tr>
<td>Oil revenue</td>
<td>$\theta_3$</td>
<td>-0.0689***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0012)</td>
<td></td>
</tr>
<tr>
<td><strong>Test:</strong> $\delta_1 = \delta_{12} = \delta_2 = 0$</td>
<td>$\chi^2(3)$</td>
<td>246.81</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prob $\chi^2$</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td><strong>Test:</strong> $\theta_1 = \theta_2 = \theta_3 = 0$</td>
<td>$\chi^2(3)$</td>
<td>4591.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prob $\chi^2$</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>Obs., n</td>
<td>95</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors are presented in parenthesis. Results are corrected for heteroscedasticity and are estimated using a GMM procedure.
In the demand-supply specification, the cost variables are both individually and jointly statistically significant at 1% with a p-value 0.0000. The oil diversion variables (voice and accountability, rule of law and revenue) show a negative and statistically significant effect. The null hypothesis of no corruption (oil diversion) effect is rejected (p-value = 0.0000) at the 1% level using a Wald test. This implies that allowing for an oil diversion effect significantly improves the fit of the model. Therefore, corruption in the crude oil market appears to be important in explaining price levels, production, and spatial price differences for Nigerian oil.

### 3.8.2 Effects of corruption under non-competitive behavior

Under non-competitive behavior we allow for \((\frac{\xi}{1+\xi}) \neq 1\) in 18(a). This more general specification of the model was estimated and results for the demand-only and demand-supply with corruption specifications are reported in Table 3.4. Results show similar parameter estimates and significance of the price elasticity of demand, Brent price elasticity, and income elasticity as was the case in Table 3.3 which imposes competitive behavior. The only real difference is in the magnitude of the marginal cost parameters. Furthermore, notice that the estimated corruption parameters are the same in Tables 3.3 and 3.4. This implies that, because of highly elastic demand for Nigerian oil, non-competitive behavior is having little effect on the Nigerian oil market. However, corruption has a statistically significant effect irrespective of whether we allow non-competitive behavior or impose competitive behavior.
Table 3.4: Oil supply and demand under corruption allowing for non-competitive behavior

<table>
<thead>
<tr>
<th>Model Parameters</th>
<th>Parameters</th>
<th>Demand-only</th>
<th>Demand-supply with corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant: Oil demand</td>
<td>(a)</td>
<td>1.1872</td>
<td>8.4092</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(16.041)</td>
<td>(10.7306)</td>
</tr>
<tr>
<td>Price elasticity of demand</td>
<td>(\xi)</td>
<td>-5.8762***</td>
<td>-4.3696***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.0545)</td>
<td>(1.1221)</td>
</tr>
<tr>
<td>Brent price elasticity</td>
<td>(\beta)</td>
<td>5.7652***</td>
<td>4.3520***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.9322)</td>
<td>(1.0846)</td>
</tr>
<tr>
<td><strong>GDP per capita of major oil importers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>(\phi_1)</td>
<td>-0.3257</td>
<td>-0.3809</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.8379)</td>
<td>(0.6384)</td>
</tr>
<tr>
<td>India</td>
<td>(\phi_2)</td>
<td>-1.0407</td>
<td>-0.2177</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.3594)</td>
<td>(0.8521)</td>
</tr>
<tr>
<td>Brazil</td>
<td>(\phi_3)</td>
<td>2.0393</td>
<td>0.5761</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.2586)</td>
<td>(1.4099)</td>
</tr>
<tr>
<td>Constant: Oil supply</td>
<td>(\varphi)</td>
<td>120.3471***</td>
<td></td>
</tr>
<tr>
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<td></td>
<td>(21.4635)</td>
<td></td>
</tr>
<tr>
<td>Returns to scale</td>
<td>(\gamma)</td>
<td>0.5901***</td>
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<td>(0.0585)</td>
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</tr>
<tr>
<td><strong>Cost variables</strong></td>
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</tr>
<tr>
<td>Interest rate</td>
<td>(\delta_1)</td>
<td>-1.3774***</td>
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<td></td>
<td></td>
<td>(0.4280)</td>
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</tr>
<tr>
<td>Interest rate *Labor force participation</td>
<td>(\delta_{12})</td>
<td>0.5326***</td>
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<tr>
<td></td>
<td></td>
<td>(0.1709)</td>
<td></td>
</tr>
<tr>
<td>Labor force participation</td>
<td>(\delta_2)</td>
<td>1.0121***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.1429)</td>
<td></td>
</tr>
<tr>
<td><strong>Corruption effect</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice and Accountability</td>
<td>(\theta_1)</td>
<td>-0.0116***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0034)</td>
<td></td>
</tr>
<tr>
<td>Rule of law</td>
<td>(\theta_2)</td>
<td>-0.0122***</td>
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<tr>
<td></td>
<td></td>
<td>(0.0021)</td>
<td></td>
</tr>
<tr>
<td>Oil revenue</td>
<td>(\theta_3)</td>
<td>-0.0689***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0012)</td>
<td></td>
</tr>
</tbody>
</table>

\(Test: \delta_1 = \delta_{12} = \delta_2 = 0\)
\(\chi^2(3)\) 246.55
Prob > \(\chi^2\) 0.0000

\(Test: \theta_1 = \theta_2 = \theta_3 = 0\)
\(\chi^2(3)\) 4587.29
Prob > \(\chi^2\) 0.0000

Obs., n 95 95

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors are presented in parenthesis. Results are corrected for heteroscedasticity and are estimated using a GMM procedure.
3.8.3 Spatial price transmission and supply elasticities

Formulas for the SPT and supply elasticities (i.e., the effect of world price on the quantity of Nigerian oil production) under corruption are calculated from model (18). Then we apply these formulas using mean values of variables and the estimated parameters to provide quantitative estimates of the effect of corruption on price transmission performance and Nigerian oil production.

To obtain the SPT and supply elasticities under corruption totally differentiate (18) with respect to \( p, q \) and \( x \), holding other exogenous variables constant to give:

\[
(19a) \quad \left( \frac{1+\xi}{\xi} \right) [1 + \theta_0 + \theta_1 \ln(z_{1t}) + \theta_2 \ln(z_{2t}) + \theta_3 \ln(p_t q_t) + \theta_3]dp \\
-\gamma(\gamma - 1)q_t^{\gamma - 2}(\delta_1 w_{1t} + 2\delta_{12}(w_{1t}w_{2t})^{0.5} + \delta_2 w_{2t})dq = 0
\]

\[
(19b) \quad -\frac{\xi}{p_t} dp + \frac{1}{q_t} dq = \frac{\beta}{x_t} dx.
\]

which can be solved and represented in matrix form as:

\[
(20) \quad \begin{bmatrix}
\frac{\partial p}{\partial x} \\
\frac{\partial q}{\partial x}
\end{bmatrix} = \begin{bmatrix}
M_1 & -M_2 \\
-M_3 & M_4
\end{bmatrix}^{-1} \begin{bmatrix}
0 \\
0
\end{bmatrix} = \frac{1}{R_1} \begin{bmatrix}
M_4 & M_2 \\
M_3 & M_1
\end{bmatrix} \begin{bmatrix}
0 \\
0
\end{bmatrix} = \frac{1}{R_1} \begin{bmatrix}
M_2 M_5 \\
M_1 M_5
\end{bmatrix}
\]

where \( M_1 = \left( \frac{1+\xi}{\xi} \right) [1 + \theta_0 + \theta_1 \ln(z_{1t}) + \theta_2 \ln(z_{2t}) + \theta_3 \ln(p_t q_t) + \theta_3], M_2 = \gamma(\gamma - 1)q_t^{\gamma - 2}(\delta_1 w_{1t} + 2\delta_{12}(w_{1t}w_{2t})^{0.5} + \delta_2 w_{2t}), M_3 = \frac{\xi}{p_t}, M_4 = \frac{1}{q_t}, M_5 = \frac{\beta}{x_t} \) and the determinant is \( R_1 = M_1 M_4 - M_3 M_2 \). Therefore, the following expressions give the SPT and supply elasticities with corruption:

\[
(21a) \quad \frac{\partial \ln p}{\partial \ln x} = \frac{\partial p}{\partial x} \frac{x}{p} = \frac{M_2 M_5}{R_1} \frac{x}{p} \quad \text{and} \quad (21b) \quad \frac{\partial \ln q}{\partial \ln x} = \frac{\partial q}{\partial x} \frac{x}{q} = \frac{M_2 M_5}{R_1} \frac{x}{q}.
\]
Without corruption the SPT and supply elasticities can be evaluated by setting $\theta_0 = \theta_1 = \theta_2 = \theta_3 = 0$ and proceeding as before to get:

\[(22a) \left(\frac{1+\xi}{\xi}\right) dp - \gamma(\gamma - 1)q_t^{\gamma - 2}(\delta_1 w_{1t} + 2\delta_{12}(w_{1t}w_{2t})^{0.5} + \delta_2 w_{2t})dq = 0\]

\[(22b) -\frac{\xi}{p_t} dp + \frac{1}{q_t} dq = \frac{\beta}{x_t} dx\]

which can be represented as:

\[(23) \begin{bmatrix} \frac{\partial p^n}{\partial x} \\ \frac{\partial q^n}{\partial x} \end{bmatrix} = \begin{bmatrix} N_1 & -N_2 \\ -N_3 & N_4 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ N_5 \end{bmatrix} = \frac{1}{R_2} \begin{bmatrix} N_4 & N_2 \\ N_3 & N_1 \end{bmatrix} \begin{bmatrix} 0 \\ N_5 \end{bmatrix} = \frac{1}{R_2} \begin{bmatrix} N_2 N_5 \\ N_1 N_5 \end{bmatrix}\]

where $N_1 = \left(\frac{1+\xi}{\xi}\right)$, $N_2 = \gamma(\gamma - 1)q_t^{\gamma - 2}(\delta_1 w_{1t} + 2\delta_{12}(w_{1t}w_{2t})^{0.5} + \delta_2 w_{2t})$, $N_3 = \frac{\xi}{p_t}$, $N_4 = \frac{1}{q_t}$, $N_5 = \frac{\beta}{x_t}$ and $R_2 = N_1 N_4 - N_3 N_2$ is the determinant\(^{19}\). Therefore, the SPT and supply elasticities without corruption are given as

\[(24a) \frac{\partial ln p^n}{\partial ln x} = \frac{\partial p^n}{\partial x} \frac{x}{p} = \frac{N_2 N_5}{R_2} \frac{x}{p} \quad \text{and} \quad (24b) \frac{\partial ln q^n}{\partial ln x} = \frac{\partial q^n}{\partial x} \frac{x}{q} = \frac{N_1 N_5}{R_2} \frac{x}{q}.\]

Results, which are evaluated at data means and estimated parameter values, are reported in Table 3.5. The SPT elasticity shows that in the absence of corruption a 1% increase in world oil price would increase the Nigerian price by 0.4885% but with corruption the elasticity increases to 1.9384%. Standard error estimates computed from the estimated GMM covariance matrix suggest the difference is statistically significant. The SPT elasticity with corruption is quite high and greater than one, indicating that the corruption effect on price transmission is

\(^{19}\) Notice that since $\gamma(\gamma - 1)q_t^{\gamma - 2}(\delta_1 w_{1t} + 2\delta_{12}(w_{1t}w_{2t})^{0.5} + \delta_2 w_{2t}) = C''(q,w)\frac{\xi}{p_t} = D'(p)$, and $\frac{\beta}{x_t} = D'(x_t)$ the SPT and quantity (supply) effects are exactly the same as was obtained in the comparative statics section in equation (12), and that the SPT effect with or without corruption also gives the same (positive) effect as was the case in equation (13) if price elasticity of demand is unitary.
large. This result is consistent with earlier comparative static results which found that SPT with corruption should be higher than without corruption. The implication of this finding is that the world oil price has a significant effect on Nigerian oil price and that this effect is amplified by corruption.

**Table 3.5: Spatial price transmission (SPT) and supply elasticities with and without corruption**

<table>
<thead>
<tr>
<th></th>
<th>Oil demand-supply</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SPT elasticities</td>
<td>Supply elasticities</td>
</tr>
<tr>
<td>Without corruption</td>
<td>0.4885***</td>
<td>2.1758***</td>
</tr>
<tr>
<td></td>
<td>(0.1227)</td>
<td>(0.5463)</td>
</tr>
<tr>
<td>With corruption</td>
<td>1.9384***</td>
<td>-4.1240***</td>
</tr>
<tr>
<td></td>
<td>(0.2153)</td>
<td>(1.0278)</td>
</tr>
</tbody>
</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Standard errors in parenthesis.

For the supply elasticities, results show that a 1% increase in world price would increase production by 2.1758% without corruption but decrease it by 4.1240% with corruption. The sign of the supply elasticity with corruption is not consistent with a priori expectations as we would anticipate a positive effect both with and without corruption. However, one possible explanation is that the presence of corruption incentivizes higher oil diversion, which leads to a reduction in the documented (official) quantity of oil supplied, especially in the presence of increasing returns to scale. Devereux et al. (1996) found a similar result that in a non-competitive market with increasing returns to scale there may be a negative supply response to price increases.

**3.8.4 Dynamics and speed of adjustment**

The presence of adjustment costs that cause slow adjustment to changing economic incentives and/or habit persistence or costs of changing the source of oil purchases could introduce dynamics into the model. One approach to dealing with this possibility is to imbed lags of the dependent variables into (18):
(25a) \[ p_t = a_1 + \left[ \left( \frac{\xi}{1+\xi} \right) + \frac{\left( \delta_1 w_{1t} + 2\delta_{12} (w_{1t}w_{2t})^{0.5} + \delta_2 w_{2t} \right)}{\left( 1+\theta_0 + \theta_1 \ln(x_{1t}) + \theta_2 \ln(x_{2t}) + \theta_3 \ln(p_t q_t) \right)} \right] + \mu_{11} \ln(p_{t-1}) \]

\[ + \mu_{12} \ln(q_{t-1}) + u_t \]

(25b) \[ \ln(q_t) = a_2 + \xi \ln(p_t) + \beta \ln(x_t) + \phi \ln(y_t) + \mu_{21} \ln(q_{t-1}) + \mu_{22} \ln(p_{t-1}) + v_t \]

where \( \mu = (\mu_{11}, \mu_{12}, \mu_{21}, \mu_{22}) \) is a vector of speed of adjustment\(^{20}\) parameters in the oil supply and demand equations. This specification allows incorporation of dynamics and speed of price transmission into the system. We use the GMM estimator to get consistent parameter estimates, using two-period lags of oil production and price and one period lags of exogenous variables as instruments.\(^{21}\)

Results from estimating (25) are presented in Table 3.6 and show that oil prices are no longer statistically significant once model dynamics are incorporated. However, the cost function parameters and the effect of corruption remain statistically significant at the 1% level. It is not clear why the model shows less statistically significant price effects after allowing for dynamics but it is important that we still find crude oil corruption negatively influences trade volumes and drives the Nigerian oil market.

The estimated speed of adjustment parameters are statistically insignificant in the demand-supply specification, except for the parameter on lagged log price in the supply equation which is marginally significant at 10%. However, the adjustment parameters are jointly significant at the 1% with a p-value = 0.0005, indicating the presence of dynamic adjustment effects.

---

\(^{20}\) For more detailed treatment of the speed of adjustment model, see Blinder (1986), Hall and Rossana (1991) and Arioglu and Tuan (2014).

\(^{21}\) This study uses lagged dependent and explanatory variables as instruments as proposed by Reed (2004), Poghosyan and Hesse (2009), and Kablan (2010). However, there could be problems associated with this approach as pointed out by Bellemare et al. (2015). While the possibility of such problems is acknowledged, alternative instruments were not available in the present application.
Table 3.6: Results allowing for dynamics

<table>
<thead>
<tr>
<th>Model variables</th>
<th>Parameters</th>
<th>Demand-only</th>
<th>Demand-supply with corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant: Oil demand</td>
<td>( a )</td>
<td>8.3340</td>
<td>6.1216</td>
</tr>
<tr>
<td>Price elasticity of demand</td>
<td>( \xi )</td>
<td>-1.2997</td>
<td>-5.3932</td>
</tr>
<tr>
<td>Brent price elasticity</td>
<td>( \beta )</td>
<td>0.9259</td>
<td>4.9407</td>
</tr>
<tr>
<td>GDP per capita of major oil importers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>( \phi_1 )</td>
<td>-0.4229</td>
<td>-0.3288</td>
</tr>
<tr>
<td>India</td>
<td>( \phi_2 )</td>
<td>0.4841</td>
<td>-0.3254</td>
</tr>
<tr>
<td>Brazil</td>
<td>( \phi_3 )</td>
<td>-0.6494</td>
<td>0.7649</td>
</tr>
<tr>
<td>Lagged log of output in oil demand specification</td>
<td>( \mu_{21} )</td>
<td>0.7921***</td>
<td>0.1385</td>
</tr>
<tr>
<td>Lagged log of price in oil demand specification</td>
<td>( \mu_{22} )</td>
<td>0.3804*</td>
<td>0.3826</td>
</tr>
<tr>
<td>Constant: Oil supply</td>
<td>( \varphi )</td>
<td>156.8966**</td>
<td>(77.8347)</td>
</tr>
<tr>
<td>Returns to scale</td>
<td>( \gamma )</td>
<td>0.7285***</td>
<td>(0.0757)</td>
</tr>
<tr>
<td>Cost variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest rate</td>
<td>( \delta_1 )</td>
<td>-2.5925***</td>
<td></td>
</tr>
<tr>
<td>Interest rate *Labor force participation</td>
<td>( \delta_{12} )</td>
<td>1.0168***</td>
<td></td>
</tr>
<tr>
<td>Labor force participation</td>
<td>( \delta_2 )</td>
<td>1.4339**</td>
<td></td>
</tr>
<tr>
<td>Corruption effect</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice and accountability</td>
<td>( \theta_1 )</td>
<td>-0.0136***</td>
<td></td>
</tr>
<tr>
<td>Rule of law</td>
<td>( \theta_2 )</td>
<td>-0.0144***</td>
<td></td>
</tr>
<tr>
<td>Oil revenue</td>
<td>( \theta_3 )</td>
<td>-0.0677***</td>
<td></td>
</tr>
<tr>
<td>Lagged log of output in oil supply specification</td>
<td>( \mu_{12} )</td>
<td>-0.0096</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.6 (cont’d)

<table>
<thead>
<tr>
<th>Model variables</th>
<th>Parameters</th>
<th>Demand-only</th>
<th>Demand-supply with corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagged log of price in oil</td>
<td>$\mu_{11}$</td>
<td>$-0.0085^*$</td>
<td>(0.0046)</td>
</tr>
<tr>
<td>supply specification</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test: $\delta_1 = \delta_{12} = \delta_2 = 0$</td>
<td>$\chi^2(3)$</td>
<td>13.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prob $&gt; \chi^2$</td>
<td>0.0042</td>
<td></td>
</tr>
<tr>
<td>Test: $\theta_1 = \theta_2 = \theta_3 = 0$</td>
<td>$\chi^2(3)$</td>
<td>1881.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prob $&gt; \chi^2$</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>Test: $\mu_{11} = \mu_{12} = \mu_{21} = \mu_{22} = 0$</td>
<td>$\chi^2(3)$</td>
<td>19.81</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prob $&gt; \chi^2$</td>
<td>0.0005</td>
<td></td>
</tr>
<tr>
<td>Obs., n</td>
<td>95</td>
<td>94</td>
<td></td>
</tr>
</tbody>
</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors are presented in parenthesis. Results are corrected for heteroskedasticity and are estimated using a GMM procedure.

3.8.5 Robustness checks

This section presents robustness checks using alternative sets of instruments, an alternative diversion cost function specification, and time trend as a proxy for the wage rate.

3.8.5.1 Robustness check using alternative sets of instruments

Equation (25) was re-estimated using lagged first difference endogenous variables $(\Delta p_{t-1}, \Delta \ln q_{t-1})$, and lags of the exogenous variables as instruments to investigate whether results are robust to first differencing of the lagged endogenous variables. Results are presented in Table 3.7.

Results show no major differences when compared with the dynamic oil supply and demand estimation in Table 3.6 using levels of endogenous variables as instruments. For example, the price elasticity, Brent price elasticity and the income elasticity remain insignificant while the magnitude, signs and significance of the cost and corruption parameters are the same in both estimations. This indicates that results are not sensitive to these alternative instruments.
Table 3.7: Robustness check using lagged first difference of model endogenous variables in a dynamic model

<table>
<thead>
<tr>
<th>Model variables</th>
<th>Parameters</th>
<th>Demand-only</th>
<th>Demand-supply with corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant: Oil demand</td>
<td>$\alpha$</td>
<td>8.3340</td>
<td>4.5840</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(5.3557)</td>
<td>(4.1476)</td>
</tr>
<tr>
<td>Price elasticity of demand</td>
<td>$\xi$</td>
<td>-1.2997</td>
<td>-1.2333</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.3219)</td>
<td>(0.8098)</td>
</tr>
<tr>
<td>Brent price elasticity</td>
<td>$\beta$</td>
<td>0.9259</td>
<td>1.2033</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.1499)</td>
<td>(0.7491)</td>
</tr>
<tr>
<td><strong>GDP per capita of major oil importers</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>$\phi_1$</td>
<td>-0.4229</td>
<td>-0.2034</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.3514)</td>
<td>(0.2787)</td>
</tr>
<tr>
<td>India</td>
<td>$\phi_2$</td>
<td>0.4841</td>
<td>0.1347</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.4120)</td>
<td>(0.3455)</td>
</tr>
<tr>
<td>Brazil</td>
<td>$\phi_3$</td>
<td>-0.6494</td>
<td>-0.1448</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.6627)</td>
<td>(0.5658)</td>
</tr>
<tr>
<td>Lagged log of output in oil demand specification</td>
<td>$\mu_{21}$</td>
<td>0.7921***</td>
<td>0.7307***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.1915)</td>
<td>(0.1050)</td>
</tr>
<tr>
<td>Lagged log of price in oil demand specification</td>
<td>$\mu_{22}$</td>
<td>0.3804*</td>
<td>0.0290</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.2210)</td>
<td>(0.0740)</td>
</tr>
<tr>
<td>Constant: Oil supply</td>
<td>$\varphi$</td>
<td>137.0275***</td>
<td>(40.2798)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.0931)</td>
</tr>
<tr>
<td>Returns to scale</td>
<td>$\gamma$</td>
<td>0.6703***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cost variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest rate</td>
<td>$\delta_1$</td>
<td>-2.4536***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.5165)</td>
<td></td>
</tr>
<tr>
<td>Interest rate *Labor force participation</td>
<td>$\delta_{12}$</td>
<td>0.9596***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.2043)</td>
<td></td>
</tr>
<tr>
<td>Labor force participation</td>
<td>$\delta_2$</td>
<td>1.3092***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.3285)</td>
<td></td>
</tr>
<tr>
<td><strong>Corruption effect</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice and accountability</td>
<td>$\theta_1$</td>
<td>-0.0122***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0035)</td>
<td></td>
</tr>
<tr>
<td>Rule of law</td>
<td>$\theta_2$</td>
<td>-0.0131***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0024)</td>
<td></td>
</tr>
<tr>
<td>Oil revenue</td>
<td>$\theta_3$</td>
<td>-0.0687***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0020)</td>
<td></td>
</tr>
<tr>
<td>Lagged log of output in oil supply specification</td>
<td>$\mu_{12}$</td>
<td>-0.0047***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0149)</td>
<td></td>
</tr>
<tr>
<td>Lagged price in oil supply specification</td>
<td>$\mu_{11}$</td>
<td>-0.0086**</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0039)</td>
<td></td>
</tr>
</tbody>
</table>
### Table 3.7 (cont’d)

<table>
<thead>
<tr>
<th>Model variables</th>
<th>Parameters</th>
<th>Demand-only</th>
<th>Demand-supply with corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test:</strong> (\delta_1 = \delta_{12} = \delta_2 = 0)</td>
<td>(\chi^2(3))</td>
<td>33.98</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prob &gt; (\chi^2)</td>
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<td></td>
</tr>
<tr>
<td><strong>Test:</strong> (\theta_1 = \theta_2 = \theta_3 = 0)</td>
<td>(\chi^2(3))</td>
<td>2809.83</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prob &gt; (\chi^2)</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>Obs., n</td>
<td>94</td>
<td>94</td>
<td></td>
</tr>
</tbody>
</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors are presented in parenthesis. Results are corrected for heteroskedasticity and are estimated using a GMM procedure.

### 3.8.5.2 Robustness check using alternative diversion cost function specification

The diversion cost function \(K\) depends on the share of official output diverted from formal marketing channels \(s\) and other variables such as rule of law \(z_1\) and political voice and accountability \(z_2\). However, there is a possibility that \(K\) might also depend on the quantity diverted. To incorporate this possibility, the model is re-estimated using quantity diverted \((sq)\) instead of the diversion share \((s)\) in the diversion cost function.

Results, shown in Table 3.8, indicate that the parameters of the marginal cost function \((\delta\) and \(\gamma)\), oil diversion function \(\theta\), price elasticity of demand \(\xi\), Brent price elasticity \(\beta\), and income elasticity of demand \(\phi\) consistently follow similar significance, sign and magnitudes to the original cost specification. Furthermore, all corruption parameters are jointly statistically significant. Therefore, main results are not sensitive to the alternative diversion cost.
Table 3.8: Robustness check using alternative cost function specification

<table>
<thead>
<tr>
<th>Model Parameters</th>
<th>Parameters</th>
<th>Demand-only</th>
<th>Demand-supply with corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant: Oil demand</td>
<td>$a$</td>
<td>1.1874</td>
<td>9.1148</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(16.032)</td>
<td>(10.8177)</td>
</tr>
<tr>
<td>Price elasticity of demand</td>
<td>$\xi$</td>
<td>-5.8762***</td>
<td>-4.3427***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.0522)</td>
<td>(1.1169)</td>
</tr>
<tr>
<td>Brent price elasticity</td>
<td>$\beta$</td>
<td>5.7651***</td>
<td>4.3433***</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.9301)</td>
<td>(1.0817)</td>
</tr>
<tr>
<td>GDP per capita of major oil importers</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US</td>
<td>$\phi_1$</td>
<td>-0.3257</td>
<td>-0.3419</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.8386)</td>
<td>(0.6389)</td>
</tr>
<tr>
<td>India</td>
<td>$\phi_2$</td>
<td>-1.0407</td>
<td>-0.1459</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.3576)</td>
<td>(0.8580)</td>
</tr>
<tr>
<td>Brazil</td>
<td>$\phi_3$</td>
<td>2.0393</td>
<td>0.3864</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.2554)</td>
<td>(1.4183)</td>
</tr>
<tr>
<td>Constant: Oil supply</td>
<td>$\varphi$</td>
<td></td>
<td>-69.5802***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(9.2052)</td>
</tr>
<tr>
<td>Return to scale</td>
<td>$\gamma$</td>
<td></td>
<td>2.0448***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.0163)</td>
</tr>
<tr>
<td>Cost variables</td>
<td>$\delta_1$</td>
<td></td>
<td>-0.3065***</td>
</tr>
<tr>
<td>Interest rate</td>
<td></td>
<td></td>
<td>(0.0882)</td>
</tr>
<tr>
<td>Interest rate *Labor force participation</td>
<td>$\delta_{12}$</td>
<td>0.1302***</td>
<td>(0.0372)</td>
</tr>
<tr>
<td>Labor force participation</td>
<td>$\delta_2$</td>
<td></td>
<td>0.3438***</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>(0.0537)</td>
</tr>
<tr>
<td>Corruption effect</td>
<td>$\theta_1$</td>
<td></td>
<td>-0.0050</td>
</tr>
<tr>
<td>Voice and Accountability</td>
<td></td>
<td></td>
<td>(0.0057)</td>
</tr>
<tr>
<td>Rule of law</td>
<td>$\theta_2$</td>
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<td>-0.0122***</td>
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<td></td>
<td></td>
<td>(0.0023)</td>
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<tr>
<td>Oil revenue</td>
<td>$\theta_3$</td>
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<td>-0.1597***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.0024)</td>
</tr>
<tr>
<td>Test: $\delta_1 = \delta_{12} = \delta_2 = 0$</td>
<td>$\chi^2(3)$</td>
<td>150.74</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Prob $&gt; \chi^2$ = 0.0000</td>
</tr>
<tr>
<td>Test: $\theta_1 = \theta_2 = \theta_3 = 0$</td>
<td>$\chi^2(3)$</td>
<td>7892.90</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Prob $&gt; \chi^2$ = 0.0000</td>
</tr>
<tr>
<td>Obs., n</td>
<td></td>
<td>95</td>
<td>95</td>
</tr>
</tbody>
</table>

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors are presented in parenthesis. Results are corrected for heteroskedasticity and are estimated using a GMM procedure.
3.8.5.3 Robustness check using time trend as a proxy for wage rate

There is some concern that labor force participation rate is a poor proxy for wage rate. A time trend may be a better proxy for wage increases and may also account for other cost factors that trend over time. To incorporate this possibility, the model is re-estimated to see if results are robust to inclusion of a time trend instead of the labor force participation rate.

Results are reported in Table 3.9 and indicate that price elasticity of demand, Brent price elasticity and income elasticity have similar magnitude, sign and statistical significance as was the case in Table 3.4. However, the cost function parameters are insignificant, and interest rate and its interaction with labor force now have a different sign. Furthermore, though the corruption parameters have similar signs and are jointly significant at 5% with a p-value = 0.0278, political voice and rule of law are individually statistically insignificant. Therefore, results are generally sensitive to the inclusion of a time trend.

### Table 3.9: Robustness check using time trend as a proxy for wage rate

<table>
<thead>
<tr>
<th>Model variables</th>
<th>Parameters</th>
<th>Demand-only</th>
<th>Demand-supply with corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant: Oil demand</td>
<td>$a$</td>
<td>1.1874 (16.032)</td>
<td>7.8084 (10.5200)</td>
</tr>
<tr>
<td>Price elasticity of demand</td>
<td>$\xi$</td>
<td>-5.8762*** (2.0522)</td>
<td>-4.4137*** (1.1490)</td>
</tr>
<tr>
<td>Brent price elasticity</td>
<td>$\beta$</td>
<td>5.7651*** (1.9301)</td>
<td>4.3867*** (1.1116)</td>
</tr>
<tr>
<td>GDP per capita of major oil importers</td>
<td>$\phi_1$</td>
<td>-0.3257 (0.8386)</td>
<td>-0.3772 (0.6304)</td>
</tr>
<tr>
<td></td>
<td>$\phi_2$</td>
<td>-1.0407 (1.3576)</td>
<td>-0.2714 (0.8375)</td>
</tr>
<tr>
<td></td>
<td>$\phi_3$</td>
<td>2.0393 (2.2554)</td>
<td>0.6864 (1.3912)</td>
</tr>
</tbody>
</table>
### Table 3.9 (cont’d)

<table>
<thead>
<tr>
<th>Model variables</th>
<th>Parameters</th>
<th>Demand-only</th>
<th>Demand-supply with corruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant: Oil supply</td>
<td>$\varphi$</td>
<td>246.7378</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(290.8553)</td>
<td></td>
</tr>
<tr>
<td>Return to scale</td>
<td>$\gamma$</td>
<td>3.0585</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3.8625)</td>
<td></td>
</tr>
<tr>
<td><strong>Cost variables</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interest rate</td>
<td>$\delta_1$</td>
<td>0.2110</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.1310)</td>
<td></td>
</tr>
<tr>
<td>Interest rate *Trend</td>
<td>$\delta_{12}$</td>
<td>-0.2139</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(2.2496)</td>
<td></td>
</tr>
<tr>
<td>Trend</td>
<td>$\delta_2$</td>
<td>0.4124</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4.0599)</td>
<td></td>
</tr>
<tr>
<td><strong>Corruption effect</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voice and Accountability</td>
<td>$\theta_1$</td>
<td>-0.0699</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.1053)</td>
<td></td>
</tr>
<tr>
<td>Rule of law</td>
<td>$\theta_2$</td>
<td>-0.0468</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.1156)</td>
<td></td>
</tr>
<tr>
<td>Oil revenue</td>
<td>$\theta_3$</td>
<td>-0.1028**</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.0410)</td>
<td></td>
</tr>
</tbody>
</table>

Test: $\delta_1 = \delta_{12} = \delta_2 = 0$

\[ \chi^2(3) \]

Prob $> \chi^2$

0.10

Test: $\theta_1 = \theta_2 = \theta_3 = 0$

\[ \chi^2(3) \]

Prob $> \chi^2$

9.12

Obs., n          | 95          | 94          |

***Significant at 1%, **Significant at 5%, *Significant at 10%. Robust standard errors are presented in parenthesis. Results are corrected for heteroscedasticity and are estimated using a GMM procedure.

The overall conclusion from the sensitivity analysis is that results are robust to alternative sets of instruments and an alternative diversion cost function specification but are sensitive to time trend effects.

### 3.9 Summary and conclusion

Previous studies have focused on SPT and market integration. However, these studies have ignored a potentially important aspect of oil production and consumption—the role oil corruption plays in influencing price transmission performance. This paper extends these studies by
modeling SPT effects in the presence of non-competitive market structure and corruption, using Nigeria as a case study.

A comparative static analysis using a theoretical model investigated how the presence of corruption influences Nigerian oil production and prices, and examined whether and how the presence of corruption influences price transmission performance from world to Nigerian oil prices. Theoretical results show that corruption increases the official amount produced and reduces crude oil prices. Results also indicate a positive price transmission effect (that is, an increase in world oil price strictly increases the equilibrium level of Nigerian oil prices), and that this increase is higher with than without corruption.

An empirical application finds support for the theoretical model. Empirical results show that oil corruption is important in explaining spatial price differences. The major empirical findings include:

1. As the Nigerian oil price increases by 1%, other things equal, crude oil demand for Nigerian oil would decrease 5.88% and 4.37% in demand-only and demand-supply estimations, respectively. A 1% increase in Brent price respectively increases oil demand by 5.77% and 4.35% in the demand-only and demand-supply estimations;
2. Oil corruption has an important effect in explaining spatial price differences, and increases production and reduces prices in Nigeria;
3. Changes in national income levels of oil consuming countries are not significant determinants of Nigerian oil demand;
4. Allowing for non-competitive behavior has little effect on estimates of Nigerian oil market outcomes and the role of corruption;
5. Allowing for dynamics in oil supply and demand, corruption still has a negative effect on price and a positive effect on supply;

6. The SPT elasticity between world and Nigerian oil prices is higher with corruption than without corruption, implying that the presence of corruption increases the responsiveness of Nigerian prices to world prices.

Since the presence of corruption increases the responsiveness of Nigerian prices to world prices, the Nigerian oil market, which is an important aspect of the Nigerian economy, will be even more dependent on external factors, such as world oversupply, lower global demand, and other market determinants, because of the corruption effect. This implies that the effect of world price changes on the Nigerian economy, of which over 90% of total export revenue comes from petroleum (OPEC, 2016), will be large; even more so because of the presence of corruption and oil diversion.
REFERENCES
REFERENCES


Data sources


This dissertation developed, estimated, and analyzed models that account for the effect of corruption and oil diversion on contract choice, prices, production, and price transmission. The goals were to examine whether corruption leads to economic inefficiency, whether corruption significantly influences oil output and prices, and whether corruption increases or decreases SPT effects.

Chapter 2 discussed the distortions caused by a corrupt contract allocation procedure in the presence of environmental damage caused by oil production. The model investigated:

1. Who gets the contract and the optimal output choice when the official is incorrupt and makes both production and firm decisions;
2. Who gets the contract and the optimal output choice when the incorrupt official only makes the contract allocation choice but allows the oil companies to make production decisions; and
3. Who gets the contract and the optimal output choice when the official is corrupt.

It was found that under (1), the high cost efficient oil company with a higher output choice would win the contract since it gives the government a higher payoff. Under (2), the official would compare the government payoff of different oil companies and an environmental damage trade-off is required to determine who gets the contract. This is because if the high cost efficient company wins the contract the government gets a higher profit but with higher environmental damage, and if the low cost efficient company wins the contract the government gets a lower profit but with a lower environmental damage. Therefore, the choice of who wins
the contract depends on how much weight the government places on environmental damage. In (3), the official would make a take-it-or-leave-it bribe offer to these companies and makes a similar comparison as in (2) but now places a lower weight on environmental damage than what the government prefers. In this case, the choice of who wins the contract would depend on a corruption-adjusted prioritization on environmental damage.

It was found that when corruption exists it misaligns the official’s incentives and creates economic inefficiencies by making the official select the company providing a higher bribe but with a lower government payoff. This means higher corruption causes decisions to be based more on profit and less on environmental damage than without corruption.

Econometric estimation showed that oil production is more responsive to prices when corruption is influencing the official’s contract choice. It was found that price has a substantial effect on production but that this effect is higher when corruption is influencing official decisions. Therefore, because oil production is more responsive to price in countries with more corruption, it implies that oil allocation decisions made by the official is based on monetary benefit more than social welfare.

In Chapter 3, we developed, estimated, and analyzed a model that captures the role of corruption in SPT. Results showed that corruption and oil diversion increase the amount of crude oil produced and decrease the Nigerian oil price. The comparative statics section also showed that an increase (decrease) in world price will lead to an increase (decrease) in Nigerian oil prices, and that this increase (decrease) is higher with than without corruption. Empirical estimates supported these conclusions, showing that the world oil price has a significant effect on Nigerian prices, but that this transmission effect is amplified by corruption.