Share Ownership Distribution, Non-renewable Resources Extraction Rate and Pollution Intensity

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Non-Renewable Resources Extraction Rate
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Declaration

No part of this thesis has been submitted elsewhere for any other degree or qualification in this or any other university. It is all my own work unless referenced to the contrary in the text.

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In memory of my grandparents

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Abstract

There is increasing concern for scarcity of natural resources and deterioration of the environment due to economic activity. Although theoretically the Hotelling rule not only provides an optimal extraction for the resource owner's profit maximization problem but also provides the optimal solution for society as a whole, the rule fails to fit the facts and only applies to the idealised world for which it was constructed. In particularly, when the resource firm realises it can affect its price depending on extraction, shareholders will disagree on the extraction rate. Thus, how to deal with the shareholders' interests and make decisions for resource firms is of central importance. Endogenizing firms' objectives through shareholder voting via majority rule is considered as the solution.

This thesis analyzes the behaviour of resources firms in shareholder voting equilibrium when the firms' decisions are taken through shareholder voting. Firstly, theoretical models are formulated for the extraction rate and pollution intensity of resources firms respectively. We show that the share ownership owned by the largest shareholder is an important determinant of extraction rate and pollution intensity. Moreover empirical studies using panel data are conducted to test the hypothesis. We find strong evidence supporting our theoretical implications. As for the extraction rate in resource firms, the results indicate a significant and negative relation between extraction rate and the share owned by the largest shareholder. However, a significantly positive relation is found using oil fields level data. As for the pollution emissions in firms, we find the firm where the largest shareholder holds a larger share will have lower pollution intensity.

Chapter 1

Introduction

1.1 Research Motives and Aims

Non-renewable resources include fossil fuel energy such as petroleum (crude oil), natural gas and coal and non-energy minerals such as metal and copper. These natural resources usually take millions of years to form naturally by geological processes so that they exist in the form of finite stocks. Once these reserves are extracted, they cannot be renewed. Eventually non-renewable resources will become too costly to harvest and human beings will need to find other resources to substitute. In terms of social benefits, an optimal extraction is considered to have the property that the stock goes to zero at exactly the same point in time that demand and extraction go to zero (Perman, et al., 2003). Moreover, the production and consumption of non-renewable fossil energy fuels contribute to global warming, for example, in petroleum refining. Therefore, our research is centered on non-renewable resources extraction and pollution emissions.

The problem of optimal non-renewable resources extraction is first demonstrated by Hotelling (1931). In its simplest form, the Hotelling rule states that the price of a non-renewable resource should rise at the real rate of interest, which is a necessary condition for an extraction programme to be efficient. However, the rule fails to fit the facts and only applies to the idealized world for which it was constructed. Moreover, when a firm realizes it can affect its price depending on extraction, the shareholders often disagree on the extraction rate the firm should take. The reason is that an individual with a share ownership different from the population average tends to manipulate prices to alter wages and profits. Therefore, how to deal with the shareholders' interests and make extraction decisions for non-renewable resources is of central importance under the incomplete market.

In line with Yalcin and Renström (2003), shareholder voting is a solution to reconciling the shareholders' interests through the mechanism of majority voting, and thereby preferences of the shareholders are consistent with the objective of the firm. Shareholders vote on candidates taken from the group of shareholders, and the majority-elected candidate will implement his or her preferred production decision (i.e. the candidate decision-maker is referred as *Median Voter*). Applying median-voter theorem, shareholder voting equilibrium is defined as the production decision which is taken by a candidate decision-maker since the candidate decision-maker cannot lose against any other candidate in a binary election. Shareholder voting equilibrium is considered as production decision via media voter.

Another related paper by Roemer (1993) assumes that all individuals have the same preferences but differ in share endowments and the voters' optimal level of the externality increases as voters' share ownership of the firm increases. He finds that the poorer the median voter is relative to the average, a shift towards share egalitarian ownership under a median voter assumption will result in greater environmental degradation: as the median voter comes to control more resources, her preferred level of pollution rises. On the other hand, when the level of environmental degradation is picked by those who pursue profit by sacrificing environmental quality, will have the positive impact on environmental quality because redistribution lead to a decrease in their income and thereby the desire of the wealthy for pollution is weakened.

Intrigued by the failure of Hotelling's (1931) rule and the papers by Yalcin and Renström (2003) and Roemer (1993), this thesis seeks to formulate theoretical models demonstrating the role of share ownership distribution or the largest shareholder in non-renewable resources extraction and pollution emissions, which has not been considered in existing literature. Meanwhile, we attempt to conduct empirical analysis examining whether the share of the largest shareholder is a determinant of extraction and pollution decisions.

1.2 Contributions and Datasets Issues

The theoretical models, together with the empirical evidence complement the extant studies on endogenous firm objectives by showing the effects of shares owned by the largest shareholder on firm decisions. Yalcin and Renström (2003) and Roemer (1993) deal only with the role of share ownership distribution in production / pollution decisions of firms through majority voting theoretically. We apply this mechanism to natural resources and environmental economics aiming to investigate if share ownership distribution matters for resources firms. At the same time, the theoretical models are developed.

The principal contribution of our study is that, contrary to previous literature, which focuses on the determinants of non-renewable resources extraction rate either only economic factors such as price and lagged production or only cost function with geological characteristics such as remaining reserves and pay thickness, there is one more critical factor to consider—share ownership distribution.

The second contribution of this thesis is in the theoretical respect: theory models are formulated for chapter 3 and chapter 5. Chapter 3 extends the work of Yalcin and Renström (2003) into resources firms and oil fields respectively. Chapter 5 constructs a model concerning the relationship between share ownership distribution and pollution of firms which reaches a conclusion counter to that of Roemer (1993).

The third contribution is methodological: updated estimation techniques compared to those in relevant literature are used. All our empirical studies are estimated with panel data techniques which allow particular attention to be paid to the firm/field heterogeneity and the dynamic features of the model. In chapter 3, System Generalized Method of Moments estimator (GMM) is used. It not only takes into account the endogeneity bias and dynamic effects but also mitigates the bias which a small sample may cause. In chapter 4, random effects model is applied to capture the unobservable characteristics of oil fields. In chapter 5, different from one related paper concerning firm pollution emissions by Berrone et al. (2010), who estimate their panel regressions applying Ordinary Least Squares (OLS), we use Feasible

Generalized Least Squares (FGLS) and Panel Corrected Standard Error (PCSE) which fit panel data and ensure the results are consistent and efficient.

The focus of our study is restricted to firms engaging in non-renewable resources production and exploration in chapter 3 and chapter 4. The foremost problem we encountered is about the reliability of data and the sufficiency of the sample. Initially we collected data from the annual reports of coal mining firms. But the problem was that different firms across different countries adopt different measurement in reserves and most could not provide complete information of reserves for each mine continuously. Therefore, we turn to oil firms.

In addition to the above contributions, another advantage of our study is the uniqueness of the datasets we use. As for chapter 3, due to the difficulty in access to oil reserves of firms, we take firm value as an appropriate proxy for it. Moreover, the share ownership data, production and price data are collected manually from annual reports of firms. As for chapter 4, unlike Pesaran (1990) and Favero (1992), who estimate the oil supply of UK Continental Shelf oil fields in aggregated output equation, we use the disaggregated data by oil fields. Moreover, all the datasets we use in the estimation are gathered manually. As for chapter 5, we improve on Berrone (2010) regarding the measurement of pollution emissions in two ways. First, we use the updated weighting factor, i.e. the value of Human Toxicity Potential (HTP) of Hertwich et al. (2006). Second, rather than using pollution emissions in pounds directly, we use pollution intensity through dividing pollution emissions by real sales.

1.3 The Structure of the Thesis

In this thesis, we would explore three research questions:

(1) How does share ownership distribution affect extraction rate of resource firms when firm decisions are taken through shareholder voting?

(2) How does share ownership distribution impact extraction rate of North Sea oil fields when resource firms have strategic interactions on the same plateau?

(3) How does share ownership distribution affect pollution intensity among firms in a duopoly model with shareholder voting?

The structure of the thesis is organized as follows. In chapter 2, we provide a literature review on fundamental concepts of non-renewable resources extraction and endogenous firm objectives via median voter. First, we present the initiation of the theoretical argument —Hotelling models and the relevant extensions for optimal extraction of non-renewable resources for competitive firms and a social planner followed by an overview of endogenizing the firm production decisions through shareholder voting. Lastly, we survey the paper of Roemer (1993) who demonstrated the role of share ownership distribution in pollution emissions.

Chapter 3 is devoted to studying the effect of the shares owned by largest shareholder on extraction rate of non-renewable resources across firms. Relevant empirical literature is reviewed. Then, a simple open-economy non-renewable resource model where individuals differ in share ownership of the resource firm is formulated and our hypothesis is developed. Lastly, we test if the share ownership of the largest shareholder determines the extraction rate of oil using 20 US oil firms over 1993-2007.

Chapter 4 is devoted to studying the effect of share ownership held by the largest shareholder on extraction rate in oil fields focusing on the literature about the production modeling of oil fields. We perform an econometric estimation and examine if the largest shareholder does matter for extraction rate based on 44 oil fields of the UK Continental Shelf over 1997-2001.

Chapter 5 is devoted to studying the effect of share ownership by the largest shareholder on pollution emissions. Existing empirical studies concerning the determinants of pollution are summarized. Next, we build a duopoly model which can capture strategic interaction among firms showing the possibility that firms where the larger shareholder holds a larger share will have lower pollution intensity in a shareholder voting equilibrium. Finally, by estimating FGLS and PCSE models, we test the hypothesis that the larger the share owned by the largest shareholder, the smaller the pollution intensity. The observations are focused on three industries: Primary Metal (SIC-code33), Metal Mining (SIC-code10) and Petroleum Refining and related Industries (SIC-code 29).

Finally, chapter 6 concludes the thesis with an overview of our theoretical proposition and empirical findings, then a discussion of the results and the policy implications is provided. Finally, some limitations and future research directions are presented.

All the data and empirical estimations generated by Stata can be found on a CD-Rom which is enclosed with this thesis.

Chapter 2

Literature Review of the Fundamental Concepts

2.1 Introduction

Concerning scarcity of natural resources and deterioration of the environment due to economic activity, resources economists have engaged in accumulating considerable knowledge. The problem of optimal non-renewable resource extraction is first demonstrated by Hotelling (1931). In its simplest form, the Hotelling rule states that the price of a non-renewable resource should rise at the real rate of the interest, which is a necessary condition for an extraction programme to be efficient.

However, most extant studies suggest that this economic theory of exhaustible resources does not adequately explain producer behaviour. To reconcile the theory with the reality, economists have expanded Hotelling's basic theoretical framework by introducing more realistic factors to fit the facts. Exploration activity has been modelled by allowing new additions of unlimited reserves (Pindyck, 1978; Pesaran, 1990). Imperfect competition among producers has been considered (Stiglitz, 1976; Salant, 1976; Perman et al., 2003). Moreover, asymmetric information has been incorporated in the basic Hotelling model (Gaudet et al., 1995; Osmundsen, 1998). Taxation effects have been modelled by introducing the distortions due to non-neutral tax policy (Slade, 1984; Perman et al., 2003; Krautkramer, 1990; Favero, 1992). Technical change is also explored by considering cost-lowering technological improvements (Slade, 1982; Cuddington and Moss, 2000; Managi et al., 2005).

Our research is concentrated on non-renewable resources extraction decisions of firms in incomplete markets since profit-maximization is no longer a well defined objective for firm due to lack of price normalization. Accordingly the shareholders often disagree about the objectives the firm should pursue. Majority vote of shareholders may be one solution to respect shareholders unanimity, which is free of the complications and is a more reasonable mechanism relevant to other mechanisms or approaches (Sadanand and Williamson, 1991; Geraats and Haller, 1998). Kelsey and Milne (1996) show the existence of a simultaneous equilibrium with competitive exchange in markets where consumers and producers are price-takers, but each firm's production decisions are determined by an internal collective criterion. Yalcin and Renström (2003) have demonstrated that shareholder voting equilibrium is the production decision which is taken by a candidate decision-maker (the electorate being shareholders) because the candidate decision-maker cannot lose against any other candidate in a binary election. Roemer (1993) analyzes how the level of pollution changes as the distribution of share ownership becomes more egalitarian.

As for non-renewable resources extraction in incomplete markets, prior studies demonstrate that how producers extract non-renewable natural resources in monopolistic firms differs from a social planner but without considering the role of shareholders voting in production decisions for a monopolistic firm. They simply analyze whether some producers adhere to the Hotelling rule and reach the conclusion that a monopoly-owned non-renewable resource tends to be exhausted at a slower rate than is socially optimal (e.g. Stiglitz, 1976; Pindyck, 1978; Perman *et al*, 2003). Moreover, little empirical study is found to explore the factors influencing the extraction decisions of the monopolistic producer, particularly for the effect of share ownership distribution when decisions are taken through by shareholder voting.

Our research fills the gap between two strands of literature. The first strand is about non-renewable resource optimal extraction in incomplete markets. The second strand is about the firm's objectives are endogenized through shareholder voting via media voter. Our emphasis on petroleum extraction complements the analysis by Yalcin and Renström (2003) and links it to the extraction problem of non-renewable resources. Meanwhile, it considers the fact that extraction and use of fossil fuels such as oil, gas, and coal leads to the excessive accumulation of carbon dioxide in the atmosphere. Motivated by Roemer (1993) who has shown the role of share ownership distribution in pollution decisions via the median voter rule, we also address its effect on pollution abatement decisions when firm objectives are endogenized through shareholder voting.

This chapter only includes the fundamental theory and concepts relevant to our study whereas related empirical literature will be provided in chapter 3, 4 and 5 respectively. The rest of this chapter begins by reviewing the theoretical model of optimal extraction of non-renewable resources by a social planner and a competitive firm whereby the Hotelling rule (1931) is derived and illustrated. More complicated extensions of the Hotelling model fitting the reality are surveyed in section 2.2.1 and applications of Hotelling theory relevant to extraction of petroleum are presented in section 2.2.2. In section 2.3, previous studies on endogenized firm objective through shareholder voting are reviewed. In section 2.4, studies related to pollution emissions at firm level are summarized.

2.2 Optimal Extraction of Non-renewable Resources

This part of the literature review considers how non-renewable resources are extracted for a social planner and for a firm in perfectly competitive markets separately. As for a social planner, social welfare is maximized given the constraints of fixed resource stock. As for a decision-maker in a competitive firm, the firm's profit is maximized which is subject to fixed initial stock for all firms collectively.

The socially optimal extraction programme involves the choice of resource extraction $R(t)$ over the interval t = 0 to t = T that satisfies the resource stock constraint, S_t and which maximizes social welfare, *W*[1]. Mathematically, we have

$$\text{Max} \quad W = \int_0^T U(R(t))e^{-\rho t}dt \tag{2.1}$$

$$\text{Subject to} \quad \dot{S}_t = -R_t \tag{2.2}$$

In order to obtain a formal solution to this optimization problem, R_t must be chosen so that the discounted marginal utility is equal at each point in time, that is

$$\frac{\partial U}{\partial R}e^{-\rho t} = \text{constant} \tag{2.3}$$

Moreover, the social utility from consuming a quantity R of the resource may be defined as $U(R) = \int_0^R P(R)dR$ in which *P*(*R)* denote the inverse demand function for the resource, indicating that the resource net price P is a function of the quantity extracted R, *P*(*R)* = Ke^{-aR}. By differentiating total utility with respect to R

1 For excellent discussion of the underlying welfare framework , see Stern (2007): page 49-59.

(the rate of resource extraction and use), we obtain $\frac{\partial U_t}{\partial R(t)} = P_t$ which states that the marginal social utility of resource use equals the royalty of the resource P_t. Hence, the requirement that the discounted marginal utility be constant is equivalent to the requirement that the discounted net price is constant as well. That is,

$$\frac{\partial U}{\partial R} e^{-\rho t} = P_t e^{-\rho t} = constant = P_0$$

Rearranging this condition, we obtain $P_t = P_0 e^{\rho t}$ which implies that the value of a unit of reserves in the ground is the same as its current value above the ground less the marginal costs of extracting it.

Then by differentiating $P_t = P_0 e^{\rho t}$, we obtain $\frac{\dot{P}_t}{P_t} = \rho$, the Hotelling rule. It states that the shadow price or royalty P_t of non-renewable resource should rise at a rate which is equal to the social utility discount rate ρ when the social value of the resource is to be maximized. That is to say, according to Hotelling's rule, the value of a unit of reserves in the ground (also called in situ resource price) is the same as its current value above the ground less the marginal costs of extracting it. Moreover, this is a necessary condition for an extraction program to be efficient and does not fully characterize the solution to the optimization problem.

In contrast to a social planner, a price-taker makes extraction decision by maximizing its firm's discounted profit instead of a utilitarian social welfare subjected to the total initial reserves $\bar{S}$ for all firms collectively, which is displayed as:

$$\text{Max} \quad W = \int_0^T P \cdot R_{j,t} e^{-it} dt \tag{2.4}$$

$$\text{subject to} \quad \int_0^T (\sum_{j=1}^{m} R_{j,t}) dt = \bar{S} \tag{2.5}$$

The profit-maximizing extraction rate $R_{j,t}$ is obtained when its discounted marginal profit is the same at any time, namely $\frac{\partial PR_{j,t}}{\partial R_{j,t}} e^{-it} = P_t e^{-it} = constant$. The result implies that market net price of the resource must grow over time at the market interest rate, namely $\frac{\dot{P}_t}{P_t} = i$, once again it is the Hotelling efficiency rule which is identical to the outcome of the social optimal solution as shown above. Therefore, the extraction path in competitive market economies is socially optimal when the market interest rate is equal to social discount rate and extraction cost is zero.

Summing up, the Hotelling rule is an efficient condition that must be satisfied by any optimal extraction programme regardless of utilitarian social welfare and competitive market economies. According to Hotelling (1931), there are five main factors determining a non-renewable natural resource price: the marginal cost of extraction, the back stop price of the next best substitute, demand and the resource reserves and the discount rate.

However, when these variants are unknown, we are not able to determine the price path of the natural resource and an optimal extraction rate. In particular, if the demand is non-isoelastic, for example, when private and social discount rates[2] are different, market extraction paths may be biased compared with optimal path. Moreover, as Mankiw and Reis (2007) specified, information stickiness is present in all markets when setting prices, wages, and consumption and especially for smaller shareholders who are inattentive, sporadically updating their information sets. It is shown that monetary policy and aggregate demand shocks account for most of the variance of inflation, output, and hours.

2.2.1 Extensions of the Hotelling model

The Hotelling rule (1931) is based on very restrictive assumptions such as perfect information and costless extraction. Economists attempt to improve its empirical validity by adding more realistic assumptions such as exploration activity (Pindyck, 1978; Pesaran, 1990), imperfect competition (Stiglitz, 1976; Salant, 1976; Perman et al., 2003), asymmetric information (Gaudet et al., 1995; Osmundsen, 1998), resource taxation (Perman et al., 2003; Krautkramer, 1990; Favero, 1992), and technical

[2] In terms of discount rate, see excellent discussion in Stern (2007), page 58-59.

change (Slade, 1982; Cuddington and Moss, 2000; Managi et al., 2005). These prior studies are briefly reviewed as follows.

2.2.1.1 Exploration

Pindyck (1978) demonstrates that optimal exploratory activity and production are simultaneously determined in the context of a continuous-time model under certainty. He considers that potential resource reserves are unlimited. A conclusion is reached that the price paths will be U-shaped. Because when the initial reserves endowment is small, at first production will increase as reserves are developed, and later it will decline as both exploratory activity and the discovery rate fall.

By building on the theoretical contributions of Pindyck (1978), Pesaran (1990) has developed a multi-period discrete-time econometric model for the analysis of exploration and extraction decisions of a price-taking firm operating under uncertainty. He proposed the production equation under the Rational Expectation Hypothesis (REH for short) and Adaptive Expectations Hypothesis (AEH for short) respectively:

$$q_t = (1-\phi)q_{t-1} + \alpha_0 z_{t-1} + \alpha_1 z_{t-1}(p_t - \beta p_{t+1}) + \alpha_2 z_{t-1} q_{t+1} + \alpha_3 z_{t-1} h_{t+1} + u_t \quad \text{(REH) (2.6)}$$

$$q_t = (1-\phi)q_{t-1} + \alpha_0 z_{t-1} + \alpha_1 (1-\beta) z_{t-1} \tilde{p}(\theta) + \alpha_2 z_{t-1} q_{t+1} + \alpha_3 z_{t-1} h_{t+1} + v_t \quad \text{(AEH) (2.7)}$$

where $Z_t = \frac{R_t}{R_t + \gamma}$, $h_t = \frac{q_t}{R_{t-1}} - \frac{1}{2}(\frac{q_t}{R_{t-1}})^2$, and R_t denotes quarterly proven reserves computed from yearly reserves, β is discount factor, p_t represents real price of oil computed as 1.0107*average quarterly spot prices of Brent Crude or Arabian Light Crude /average quarterly index of export prices of industrial countries. In addition, adaptive expectations of the real oil prices are constructed recursively according to $\tilde{p}_t(\theta) = \theta \tilde{p}_{t-1}(\theta) + (1-\theta) p_{t-1}$.

Furthermore, Pesaran (1990) has applied the framework to an empirical analysis of oil exploration and extraction on the United Kingdom Continental Shelf (UKCS).

Both equations are estimated by OLS showing that production is positively correlated with the lagged production or price. Moreover, under the assumption of zero discount rate, they found strong positive price effects on oil supplies only in the case of supply equation with adaptively formed price expectations.

2.2.1.2 Imperfect competition

The presence of imperfect competition evidently influences the optimal extraction of firms. Although Hotelling analyzes the cases of perfect competition and monopoly, his work contain no game-theoretic considerations[3]. In this section, relevant models of the non-renewable resources extraction in incomplete markets, including monopoly, oligopoly, and a cartel-versus-fringe, are reviewed.

There has been much literature concerning the rate of exploration of a non-renewable resource in a monopolistic market. Stiglitz (1976) demonstrated that, under a special case of a stationary isoelasticity demand, with zero extraction costs, monopolistic and competitive price paths will coincide. In other cases, a monopolist tends to extract less than a producer in a competitive market. This means that the monopolist will take a longer time than the competitive market to exhaust the same initial resource stock suggesting that the monopolist is a more conservation minded than a competitive market would be. The same conclusion is reached by Perman et al. (2003). The influence of monopoly in price paths is captured by empirical studies. For example, Ellis and Halvorsen (2002) investigate the gap between price and marginal cost. Through estimating the model for the largest firm in the nickel industry, they find that market power accounts for the large share of the gap.

Motivated by the post-1973 oil market and the presence of OPEC as a dominant player, Salant (1976) treats the oil market as consisting of a dominant firm (i.e. cartel) and a fringe of price-taking firms. The open loop Nash-Cournot equilibrium is solved by defining that the competitive fringe takes as given price paths by the dominant player and then choose an extraction rate, while the dominant player

[3] As Hotelling (1931) suggested, a more realistic market structure for non-renewable resource is some form of oligopolistic competition rather than a monopoly.

chooses a price path given the aggregate extraction path of competitive fringe. During the decision process, the dominant player and the competitive fringes do not consider the effect of their strategies on each other.

An open-loop Nash equilibrium among several oligopolistists is characterized by Loury (1986) who considers that these firms have the same marginal cost but different initial reserves. Loury shows that aggregate output falls over time, in particular those firms with smaller reserves deplete faster than firms with large reserves. Lewis and Schmalensee (1980) consider firms that differ in extraction costs. They demonstrate that in an open-loop Nash equilibrium the lowest cost deposit may not be exhausted first, which is contrary to what is dictated by a social planner. The same result is given by Benchekroun et al. (2009, 2010) who assume that there are two groups both consisting of identical firms, and firms can differ across groups in deposit size and marginal cost. They also find that an increase in the aggregate stock of the fringe with higher extraction cost may undermine social welfare.

Focusing on open-loop equilibrium in an extractive duopoly, Gaudet and Long (1994) analyze the effect of a marginal transfer from one firm to another and show that a transfer that gives rise to more unequal stock distribution will lead to the industry's higher output and profit. This result is a dynamic counterpart of results obtained in the static Cournot oligopoly model of Bergstrom and Varian (1985) who consider that an increase in the marginal cost of one firm will lead to an equal decrease in the marginal cost of its rival.

Some other studies adopt the cartel-versus-fringe approach in which the cartel is considered as a Stackelberg leader (Gilbert, 1978; Newbery, 1981; Ulph, 1982; Groot, Withagen and de Zeeuw, 1992). In contrast to Salant's model, the cartel determines its extraction path first, and the fringe reacts to that. The cartel takes the fringe's reaction into account in choosing the extraction path. However, a problem with the open-loop Stackelberg equilibrium is not time-consistent. The leader will have an incentive to renege on its announced plan and will manipulate the fringe's reaction when there is no binding contract. To avoid the problem of time inconsistency, Groot, Withagen and de Zeeuw (2003) propose a model of cartel and fringe under the feedback assumption. When the number of fringe firms tends to be infinitely large, the value function for each fringe is linear in its own stock but independent of other firms' stock. They not only find that the open-loop Stakelberg solution is time-consistent but also find it coincides with the feedback solution path.

2.2.1.3 Asymmetric information

For non-renewable natural resources exploitation, government as the owner of the resource (called the principal) will delegate the extraction of the resource to a firm or firms (called the agent). If both the government and the delegated firm can perfectly observe the resource price and the extraction costs, the observed extraction path will satisfy the Hotelling rule of non-renewable resources optimal extraction. Then the royalty schedule must induce the mining firm to deplete the mine in a way that marginal net benefits increase at the rate of interest (Gaudet et al., 1995). In practice, however, the firm knows more than the owner such as extraction costs and deposit size. The literature introduces the asymmetry of information into the Hotelling model for non-renewable resources extraction aiming to arrive at a more general characterization of the optimal royalty.

Gaudet et al. (1995) consider the effects of asymmetric information on extraction costs and analyze optimal non-renewable resource royalty contracts (payment and extraction path). They show that the asymmetry of the information constraints the government's effort to recuperate the resource rent via a royalty payment imposed on the firms exploiting the resource. In comparison with full information extraction, when the resource stock is required to be exhausted in two periods by optimal contracts, information asymmetry decreases the production in the first period for all types of firms except the most efficient. Moreover, even the output of the lowest cost firm is distorted when exhaustion in two periods is not warranted.

Osmundsen (1998) develop a model of optimal regulation in exploiting non-renewable natural resources when government faces the problem of asymmetric information about reserves. It is shown that optimal contracts in a two-period distort both the extent and the pace of extraction. When the choice of terminal period is endogenized, it is optimal to distort the number of extraction periods in response to the asymmetry of information.

Turning attention to our study in terms of petroleum extraction, the effects of asymmetry of information is a concern as it is likely to be more severe than other non-renewable resources. According to Osmundsen (1995, 1998), two explanations for this are: (1) large resource rents may induce firms to exaggerate true costs, and (2) particularly for the vertically integrated multinational petroleum firms, they have more opportunities to camouflage their true costs.

2.2.1.4 Resource taxation

Extractive industries are subject to many forms of taxation and government regulations such as severance taxes, royalties, subsidies and price controls. Those taxes can be levied at any stage of production (e.g. exploration, refining or fabrication). A neutral tax system can be omitted from an economic and econometric model. A system can be considered *neutral* if it does not affect the decisions of economic agents. When a non-neutrality tax system is omitted, its instability might cause the break-down of a backward looking econometric model (Lucas, 1976).

Many people have studied the effects of taxations on extraction profile under perfect competition. Slade (1984) developed a model for assessing the effects of taxation on resource extraction for a vertically integrated extractive firm incorporating various sorts of taxes and subsidies at different stages of production. After estimation of a U.S. copper-mining firm which has only one mine, the solutions are compared with those solutions in tax-free situations with respect to the magnitude and time pattern of distortions. He shows that taxation affects the extraction path and cumulative ore[4] extraction as well as cumulative metal production. Only the first effect can be observed. However, in practice, the latter two effects dominate. Moreover, taxies and subsidies can change ultimate ore extraction and metal processing intensities in opposite ways depending on the stages of production at which the tax is imposed.

[4] The term 'Ore' represents one mineral in the ground.

Moreover, Krautkramer (1990) develops a model for examining the effects of taxation on resource depletion when ore quality varies within deposits and ore quality selection is constrained. He concludes that tax policy is less conserving of the resource when ore quality is heterogeneous within deposits. In particular a constant severance tax can induce faster depletion, reduce the life of the mine and increase the production of metal when extraction is feasible.

Another related paper is by Perman et al. (2003) who analyze the effect of revenue tax or subsidy on resource royalties. They show that imposition of revenue tax (revenue subsidy) is equivalent to an increase (decrease) in extraction cost. Therefore, consistent with Slade (1984), taxies and subsidies can change ultimate ore extraction in opposite directions. In contrast to revenue tax, revenue subsidy may lead to lower initial gross price and shorten the time to exhaust the stock.

Particularly for fossil fuels taxation, Ulph and Ulph (1994) analyze the optimal time path of a carbon tax and show that some factors cause the carbon tax to rise whereas others cause it to fall. They also demonstrate the numerical results suggesting that a carbon tax is supposed to be upward initially and then downward. In contrast, Sinclair (1994) argues that declining oil taxation is advantageous if falling time-trend carbon taxation can lessen future global warming.

Very few econometric models, except Favero (1992), have been done on estimating the effects of taxation on non-renewable resources extraction and exploration. Favero (1992) has expanded Pesaran (1990) econometric model of petroleum exploration and extraction policies for ‘price taking’ suppliers in the UKCS. Favero (1992) estimates the oil supply function by taking the UKCS taxation system into account. He concludes the post-tax shadow price of oil in the ground becomes negative suggesting that the model overstates the impact of taxation on profit. This feature is attributed by the inability of the model to capture recent modifications in taxation aimed at helping development. He supports suggestions by Pesaran (1990) that the result needs a further disaggregation of the investment and production decision into exploration development and extraction decisions may be worth considering. Inspired by Favero (1992), we investigate the extraction decision of the

UKCS by disaggregating the extraction of the UKCS into the extraction of oil fields in chapter 4.

2.2.1.5 Technological change

The empirical failure of Hotelling has been credited in part to technical changes. On the one hand, new techniques and processes may obtain synthetic substitutes for non-renewable resources. On the other, improvement in technology may facilitate more efficient exploration and production, thereby potentially offsetting the depletion effect on resource prices.

Slade (1982) examines the effect of technological change on the exhaustible-resource industry particularly on market prices. The author argues that marginal extraction costs fall over time as technology improves thereby market prices can fall early on when scarcity rents are small. However, as reserves depletes, prices eventually rise and the price paths is U-shaped.

Cuddington and Moss (1998) investigate the determinants of the average exploration cost for additional petroleum reserves in the U.S. over 1967-1990. Technological change played a major role in allaying what would lead to a sharp rise in the average cost of finding additional reserves of natural gas. The impact of technological change on finding costs for U.S. crude oil reserves has been more modest in comparison with natural gas. A similar conclusion is reached by Managi et al. (2005) who test the impact of technological change on offshore oil and gas exploration-discovery and of drilling cost in the Gulf of Mexico from 1947 to 1998, both at field level and at regional level. They use the number and significance of technological innovations as a proxy for technological change. The results show that technological change plays a very significant role in increasing reserves and lowering cost over the past 50 years.

Many studies have shown the Hotelling rule has difficulty in explaining the actual initial price level (Miller and Upton, 1985; Gately, 1984). Nevertheless, a notable exception is found in the work of Lin and Wagner (2007). Using data on the oil market from 1970 to 2004, Lin and Wagner incorporate stock effects and the technological progress in the theoretical Hotelling model and show that the oil price is consistent with the Hotelling model. Therefore, technological change matters for reconciling the Hotelling theory with reality.

2.2.2 Application to petroleum extraction

The Hotelling model has received considerable development and application in petroleum exploration and extraction (Pearce and Turner, 1990; Tietenberg, 2000). We concentrate on the petroleum supply studies aiming to address the determinants of petroleum production decisions in prior studies.

Mabro et al. (1986) construct a static linear model dealing with oil output in terms of seasonal dummies, a time, a time trend, and the nominal price of Brent Crude. Using monthly data covering the periods from January 1980 to February 1985, they find that seasonal variations have significant impact on U.K. oil production but fail to find the evidence of price sensitivity of oil output.

Unlike Mabro et al. (1986), Pesaran (1990) accounts for price and cost expectations (in rational expectations hypothesis and adaptive expectations hypothesis respectively) and dynamic effects of lagged production. An econometrical model is developed based on the work of Pindyck (1978) regarding optimal exploration and extraction for oil price-taking firms in which their objective is to maximize the expected profits. In the model, he shows that price changes in oil supplies depending crucially on the formation of price expectations. Moreover, non-OPEC oil production not only depends on price but also depends on expected future output-reserve ratios. The latter dependence arises due to the assumption of joint determination of extraction and exploration decisions.

After estimating this model with UKCS data over the periods 1978-1986, Pesaran (1990) finds strong positive price effects on oil supplies only in the hypothesis of the supply equation with adaptive price expectations. However, using Norwegian data over 1989-2008, the model in Pesaran (1990) is evaluated by Persson (2011) who finds poor results and concludes that it is not valid to use in Norwegian production.

Another related study is by Nygreen et al. (1998) who evaluate a model of Norwegian petroleum production and transportation which had been used by the Norwegian Petroleum Directorate and major Norwegian oil producers for more than fifteen years. As for the model, the optimal solutions are derived from maximization of total net present value of future cash flows or minimization of deviations from an initial target including both economic and engineering constraints (i.e. pipeline and production capacity). The authors reach the conclusion that this model has influenced historical oil production and planning. Nevertheless, most important production decisions are made in line with political factors.

Summing up, extant models provide possible thinking ways of petroleum production decisions. Production decisions in practice are not always made simply according to the models of optimal production. According to Nygreen et al. (1998), accompanying political effects might make the models more reliable and applicable.

2.3 Endogenizing the Production Decisions

In complete markets, it is reasonable for a firm to maximize profit when the price is normalized and there is unanimity among shareholders. However, in incomplete markets, in addition to price normalization problem, shareholders often disagree on the effect of changes in firm production plans. Therefore, profit-maximization is no longer a well-defined objective for the firm in incomplete markets. In this section, the literature focuses on the source of shareholders disagreements and the solution to aggregate the shareholders interests as well as related theory by Yalcin and Renström (2003).

2.3.1 The source of failure of shareholders unanimity

If markets are incomplete, profit-maximization is no longer a well-defined objective for the firm, and shareholders disagreement may occur in equilibrium. This source of the disagreement seems natural and realistic. Investors have differing subjective assessment of investments in the absence of markets (DeMarzo, 1993). On the other hand, there may be conflicts of interest between managers and shareholders of the firm (a so-called principal-agent problem) as well as among shareholders themselves. But even if the principal-agent problem is absent, if managers are eager to fulfill the wishes of the shareholders, the problem remains that the shareholders themselves may disagree over what objectives the firm should pursue (Geraats and Haller, 1998). Moreover, Yalcin and Renström (2003) suggest that shareholders often tend to disagree about the objectives the firm should pursue, and none of them may favour profit maximization. Early work concerning objectives of firms with incomplete markets has explored the consequence of specific decision criteria. For instance, Geanakoplos et al. (1987) have established that even the most promising decentralised decision producer leads to generic inefficient allocations in stock market economies.

The failure of shareholder unanimity is a major concern in the literature summarized by Haller (1988). Haller (1986) points out that shareholder disagreement results from the fact that the firm has got market power and, that its production decision affects equilibrium prices. If investors differ in preferences, they prefer different relative prices. If they differ in endowments, then the firm's decisions will affect the value of these endowments and will have a redistributive effect. Moreover, DeMarzo (1993) also investigates the source of this shareholder disagreement and in particular characterizes the relationship between the preferences of the shareholders and its production objectives.

Finally, under imperfect competition, the problem concerning the suitability and appropriateness of profit or net market value maximization has been disputed for a long time. As Yalcin and Renström (2003) specified, as for suitability, the lack of fairly general equilibrium existence results was a concern. Standard techniques turned out to have little impact in many instances, while nonexistence was established in some other instances. As for appropriateness, the objective of profit or net market value maximization is questionable if firms exercise market power. For instance, Geraats and Haller (1998) analyze various cases to show that (actual or asymptotic) shareholder unanimity and (actual or asymptotic) net-market-value maximization are, by and large, unrelated phenomena. This finding contrasts with the results under replication where asymptotic shareholder unanimity and asymptotic net-market-value maximization go hand-in-hand.

The issue of oligopolistic or monopolistic market power and the genuine source of shareholder disagreement may be convoluted with another important issue known as the "*numeraire* problem": how to account properly for profits. Yalcin and Renström (2003) point out that in certain models, even the definition of profits is dubious because of the price normalization or *numeraire*, problem. Nevertheless, when firms exercise market power and maximize nominal profits, price normalization has real effects, as first addressed by Gabszewicz and Vial (1972). Different real outcomes would then be obtained under different price normalization rules (see Haller (1986); Grodal (1996); in addition, see Bohm (1994); Dierker and Grodal (1996) among others, for attempts to address or resolve this issue. According to Yalcin and Thomas (2003), a further issue is that when a firm has market power, net market value maximization may not be supported by shareholders who often disagree on the objectives the firm should undertake. Thus, the need to reconcile or aggregate shareholder interests arises. Shareholder voting may be the solution.

2.3.2 The mechanisms of reconciling shareholders disagreements

There are two ways in which the literature has resolved this problem. One is to restrict either the feasible set of potential modifications of production plans or the nature of the utility functions to reconcile the disagreements among shareholders; the other is to devise alternative mechanisms for the firm's decision-making such as maximization of the expected utility of profit (Sandmo, 1971; Leland, 1972) and maximization of a weighted sum of the shareholders' utilities (Diamond, 1967).

As for the first approach, the conditions necessary for unanimity of shareholders are too restrictive and not realistic. For instance, the restricting of individual's preference (Baron, 1979) and the competitive assumptions about how potential changes in firm plans will be evaluated (Grossman and Stiglitz, 1980). As for the alternative mechanism approach, prior papers encounter one difficulty that truthful revelation by shareholders of their preferences is required. Moreover, the mechanisms are usually very abstract decision-making rules which place large computational and informational demands on the shareholders.

In contrast, majority rule is free of these complications and is a more reasonable mechanism (Sadanand and Williamson, 1991). As Gerrates and Haller (1998) suggest, if the median-voter argument applies, the core elements are very easily determined as the most preferred alternatives of the median voter. Kelsey and Milne (1996) show the existence of a simultaneous equilibrium with competitive exchange in markets where consumers and producers are price-takers, but each firm's production decisions are determined by an internal collective criterion. When the firm's production decisions are taken through shareholder voting, the consistency between preferences of the shareholders and the objective of firm is ensured thereby the firm objective is endogenized (Yalcin and Renström, 2003).

2.3.2.1 Median voter theory

When a decision is reached by voting or is arrived at by a group all of whose members are not in complete accord, the median-voter theorem for voting in committees will be adopted, which is proposed by Black (1948) and applied to electoral competition and extension to representative democracy by Downs (1957). The median voter theorem, is a famous voting model positing that in a majority election, if voter policy preferences can be represented as a points along a single dimension, if all voters vote deterministically for the politician that commits to a policy position closest to their own preference, and if there are only two politicians, then if the politicians want to maximize their number of votes they should both commit to the policy position preferred by the median voter.

To appreciate the logic of the median voter model, consider a setting where three individuals —Anne, Bob and Charlie—are to choose a restaurant for lunch. Anne prefers a restaurant where lunch can be had for $5.00, Bob favours a bit better fare at a restaurant serving $10.00 lunches, and Charlie wants a gourmet restaurant where lunch will cost around $20.00. Bob can be said to be the *median voter* because exactly the same number of individuals prefer a more expensive restaurant than Bob as prefer a less expensive restaurant than Bob, here one each. For convenience assume that, given any two options, each member of the lunch group prefers restaurants with prices closer to their preferred restaurant to ones that are farther from it. Now consider some majority decisions over alternative restaurants:

OPTIONS	PATTERN OF VOTES			RESULT
$10 vs. $20	A: 10	B: 10	C: 20	10
$5 vs. $20	A: 5	B: 5	C: 20	5
$5 vs. $16	A: 5	B: 5	C: 16	5
$10 vs. $5	A: 5	B: 10	C: 10	10

Example is from Congleton (2002)

Note that Bob always votes in favour of the outcome that wins the election. Note also Bob's preferred $10 restaurant will defeat any other. As specified above, the median voter's ideal point is always a Condorcet winner. Consequently, once the median voter's preferred outcome is reached, it cannot be defeated by another in pair-wise majority voting.

Congleton (2002) further identifies two versions of the median voter theorem: a weak form which says that the median voter "casts his or her vote for the policy that is adopted," and a strong form, which states that the median voter "always gets her most preferred policy." Moreover, Dasgupta and Maskin (2008) have shown that simple majority rule satisfies five standard and attractive axioms —the Pareto property, anonymity, neutrality, independence of irrelevant alternatives, and (generic) decisiveness —over a larger class of preference domains than (essentially) any other voting rule.

However, there is a well-known theoretical problem with majority rule that appears to reduce the applicability of the median voter model. A median voter does not always exist. For example, suppose there are three voters —Anne, Bob and Cathy –who must choose among three policy alternatives—I, II, and III. Suppose that Anne prefers option III to II to I, while Bob prefers I to III to II and Cathy prefers II to I to III. Note that the pattern of votes will be, III > II and II > I, but I > III. Majority rule can lead to inconsistent rankings of policy alternatives, and to unstable policy choices. Black (1948) pointed out that single peaked preferences are sufficient to guarantee the existence of a median voter in one dimensional issue spaces. But in two-dimensional cases, a median voter exists only in cases where voter tastes are very symmetrically distributed (Plott, 1969).

2.3.2.2 The existence and the nature of shareholder voting equilibrium

Geraats and Haller (1998) have made several simplifying assumptions to validate the median-voter approach: absence of conflicting interests of management and shareholders; focus on a single firm to isolate the most pertinent issues of shareholder voting; a one-dimensional production decision; a specific quadratic cost function to avoid corner solutions; and a mean-variance setting. They provide the two key prerequisites for the median-voter argument: (1) a one-dimensional space of alternatives; (2) single-peakedness of individual preferences.

Rather than voting directly on the firm's production decisions, Yalcin and Renstrom (2003) assume that shareholders vote on candidates taken from the group of shareholders, and the majority-elected candidate will implement his or her preferred production decision (i.e. the candidate decision-maker is referred to as the *Median Voter*). Applying the median-voter theorem, shareholder voting equilibrium is defined as the production decision which is taken by a candidate decision-maker since the candidate decision-maker cannot lose against any other candidate in a binary election.

The existence of voting equilibrium is by no means guaranteed when multidimensional (production or other) decisions are taken (Plott, 1967). Whereas Sadanand and Williamson (1991) established the existence of equilibrium with shareholders voting in production economy with incomplete markets based on the mechanism of majority rule. Allocation of the shares of the firms and the initial good are determined by trading in the market. Production decisions are made collectively by the shareholders using the version of majority rule. DeMarzo (1993) incorporates a model of corporate control into a general equilibrium framework for production economies with incomplete markets. Firms' objectives are viewed as being subject to shareholders' control via some decision mechanism. As long as the decision mechanism is responsive to unanimous preference by shareholders, shareholder control is consistent with but stronger than the value maximization.

In a general equilibrium model with certain externalities between production and consumption, Kelsey and Milne (1996) show the existence of a simultaneous equilibrium with competitive exchange in markets where consumers and producers are price-takers, but each firm's production decisions are determined by an internal collective criterion. Again with multidimensional production decisions, a recurrent theme in a small literature using the simultaneity model is that ceteris paribus a firm maximizes the welfare of one of its final shareholders in equilibrium provided equilibrium exists (see Gevers, 1974; Benninga and Muller, 1979; DeMarzo, 1993).

Moreover, DeMarzo (1993) shows that in some instances where a voting equilibrium exists, the firm's production plan is optimal for the largest shareholder of the firm (for other forms of shareholder participation, see Forsythe and Suchanek (1984) and Haller (1991)). In addition, Geraats and Haller (1998) analyze the outcome of a single majority voting among shareholders of a single firm with one-dimensional production decisions. The asset market is effective by assumption and the safe asset is chosen to be the numeraire. As a result of their assumption on a stock market economy, a shareholder voting equilibrium (i.e., a median voter outcome in before-trade voting) exists and is essentially unique.

2.3.3 The effects of share ownership distribution

Yalcin and Renström (2003) analyze the behaviour of a monopolistic firm in general equilibrium and demonstrate that inequality of share ownership distribution leads to underproduction or overproduction relative to the efficient level when production decisions are taken through shareholder voting via median voter.

As stated in the paper by Yalcin and Renström (2003), shareholders are asked to express preferences over *l2* (labour for the monopoly sector) to recognize the general equilibrium price consequences. The consumer *h*'s indirect utility can be obtained:

$$V^h(l_2) = \phi(\psi^h(l_2))^{1+a+b}(l_2)^{\alpha\beta}(L-l_2)^{\alpha+b} \tag{2.8}$$

where

$$\psi^h(l_2) = \frac{\theta_1{}^h(1-\alpha) + \theta_2{}^h(a-(\alpha+b)\frac{l_2}{L-l_2}) + (\alpha+b)\frac{L^h}{L-l_2}}{1+a+b} \tag{2.9}$$

$$\psi^{h'}(l_2) = \left(\frac{L^h}{L} - \theta_2^h\right)\frac{\alpha+b}{1+a+b}\frac{L}{(L-l_2)^2} \tag{2.10}$$

From the derivative of $\psi^h(l_2)$ with respect to *l2*, the net effect of the consumer's endowment of shares θ_2^h relative to her endowment of potential work time is explicitly implied. A change in consumer *h*'s share ψ^h is increasing/constant/decreasing in sector 2(monopoly firms) activity if her share θ_2^h in the monopoly firm is less/equal/greater than the population average.

The production decision is defined as a shareholder voting equilibrium by Yalcin and Renström (2003). Shareholders vote on candidates and the majority-elected candidate will make the production decisions. Under the assumption that all consumers have the same time endowment, production in the monopoly firm is higher/equal/lower output than the Competitive Economic Equilibrium (CEE) if the median voter owns a proportion of shares in the monopoly firm that is lower/equal/higher than the inverse of the population size. In particular, if consumers are identical in their labour endowments and public ownership, then the CEE results.

Another related paper exploring the distribution of share ownership is by Renström and Roszbach (1998). They analyze wage setting by a monopoly union, when union members own shares in the firm. Union members vote on the wage rate and the firm is a price-taker. They conclude that the more right-skewed the distribution of share ownership among union members the higher is the demanded wage rate and the higher is unemployment.

On the other hand, Roemer (1993) has shown the role of share distribution in pollutant emission level, modeling a situation in which a firm's production causes a negative externality. All individuals have the same preferences but differ in share endowments. The firm's production decisions are taken through shareholder voting. He shows that the more right-skewed the distribution of share ownership is, i.e., the poorer the median voter is relative to the average, the more production and the more of the externality the firm produces. Furthermore, in the political-economic models where the voters determine the level of the public bad but shareholdings are determined endogenously on a stock market, the optimal level of the public bad is indeed increasing in the share of the firm an agent holds at equilibrium, and a redistribution of wealth which engenders a more equal distribution of shares of firms at equilibrium lowers the equilibrium level of the public bad (Roemer, 1992a, 1992b).

2.3.4 Trading in shares and the redistribution effect

Most of the literature analyzes a situation where share ownership is exogenous and there is no trade in shares. However, individuals may purchase additional shares (deviating from the initial distribution) to acquire voting rights and affect the decisions in their desired direction. Moreover, by purchasing/selling shares, the individuals also affect the equilibrium prices of shares.

Geraats and Haller (1998) divide the shareholders into two classes: naive and sophisticated shareholders. As for naive investors, they take the initial shareholdings as unalterable. They vote on the current production decision as if this decision was inconsequential for the future stock market allocation. Sophisticated investors, by definition, are assumed to have resolved this problem. They anticipate correctly the impact of the current production decision on their ultimate welfare, a case of perfect foresight or "rational expectations." They find that no sophisticated shareholder supports the production plan that maximizes the net market value of the firm. An investor's preferred production plan depends on his initial or final shareholdings and risk aversion. Distributional assumptions regarding initial shareholdings and risk aversion parameters prove crucial for the median voter outcome.

Furthermore, before-trade shareholder voting leads to asymptotic net-market-value maximization when the median investor is naive and the median share size goes to zero so that the wealth from shareholdings outweighs future risk exposure. In the case of after-trade voting, investors do not have the opportunity to adjust their share holdings after the voting so that they incorporate the cost of production home by the final shareholders. As a consequence, naive investors prefer asymptotic market-value maximization whereas sophisticated investors may obtain strategic shareholdings to influence the voting outcome (Geraats and Haller, 1998).

However, Yalcin and Renström (2003) have further explored that non-strategic investors do not recognize their influence on the decision of the monopoly firm when trading shares, and then any initial distribution of shares can constitute a shareholder voting equilibrium. On the other hand, if investors recognize that when purchasing/selling shares of the monopoly firm they change the identity of the decisive individual, shareholders always have the incentive to trade their shares until the competitive equilibrium is reached. Instead of short-selling constraints, if individuals realize their influence on the voting outcome when trading, and if individuals are allowed to sell short their shares, then trade occurs until the distribution of shares is such that the voting outcome supports the CEE. This result is close to the Coase Theorem, in the sense that the economy trades itself to efficiency. If individuals are not allowed to sell short their shares then the equilibrium is such that all shareholders agree on the production decision, but it typically involves underproduction relative to the CEE. They conclude that it is not market power itself that causes underproduction, but the inability to perfectly trade the rights (shares) in the economy.

2.4 Pollution emissions

The exploitation of non-renewable resources has been linked to pollution problems. The most prominent link is the extraction and use of fossil fuels such as oil, gas, and coal and the excessive accumulation of carbon dioxide in the atmosphere (Long, 2011). For example, petroleum refining generates negative externality which contributes to global warming.

Most models of pollution choices assume that firms maximize profits. However, the typical justification for profit maximization is the Fisher Separation Theorem (see Milne, 1981), which specifies that all shareholders will agree on maximizing the firm value only when there are no externalities and the firm is a price-taker and financial markets are complete. Furthermore, profits are not well-defined because of the price normalization problem (Yalcin and Renstrom, 2003; Kelsey and Milne, 2006).

Hence, in the presence of market distortions, shareholders tend to disagree on the objectives the firm should undertake. To respect shareholders' unanimity, majority vote of shareholders is proposed for the solution[5]. The next section surveys the theory of Roemer (1993) who explores how the level of pollution changes as the distribution of share ownership becomes more egalitarian.

2.4.1 Definitions and Basic specification of Roemer's model

A firm in which a small number of people influence its decisions must choose the level of various externalities such as the amount of pollutants the firm will emit. While these pollutants enter negatively into everyone's utility function, they also enter positively into the profit function of the firm as less pollution control equipment means greater profits.

[5] According to Coase (1937), only when property rights are well defined and enforceable, when all economic agents have full information, when transaction cost is low, there is no need for third party's intervention to correct externalities, because economic agents can bargain to achieve a Pareto optimal resource allocation. However, in practice these conditions are rarely satisfied. Therefore, the shareholding by an affected third party is considered as a solution to deal with the externality problems.

Economic equilibrium at externality level x is defined by Roemer (1993) as a pair of non-negative functions: wage function $\overline{w}(\cdot,x)$ and total income function $\bar{y}(\cdot,x)$. Therefore $\bar{y}(s,x)=\overline{w}(s,x)+\varphi(s)\Pi(x)$ where $\overline{w}(s,x)$ and $\bar{y}(s,x)$ are the wage and total income respectively of an agent with skill level s. $\varphi(s)$ is the percentage of share ownership the agent holds in terms of skills. The firm's profits is denoted $\Pi(x)$. Then the consumer's indirect utility for the externality is defined as: $v(x,s)\equiv u(\bar{y}(s,x),x)$. Meanwhile, Roemer (1993) assumed that the marginal utility with respect to skill at equilibrium is increasing in the level of the externality, namely $\frac{d}{dx}[u_1(\bar{y}(s,x),x)\cdot(w_1(s,x)+\varphi'(s)\Pi(x))]>0$ for all non-negative $x\in[0,\bar{x}]$ and all s.

On the one hand, Roemer (1993) proposed that $v(x,s)$ is concave in x and $x(s)$ is single-valued and optimal skill level s^* exists and $x(s)>0$ if $s>s^*$. $x(s)$ is a strictly increasing function on $[s^*,1]$. In addition, he also showed the desired level of the externality increases with one's share of profits for this case the marginal utility of income is constant when preferences is quasi-linear ($u(y,x)=y-q(x)$ and q is convex); in the meantime, the share distribution increases in s ($\varphi'(s)>0$) and the marginal production is increasing in externality.

2.4.2 The effect of share ownership on pollutants level

The egalitarian distribution of shares is defined by the share function $\varphi^e(s)=\frac{\theta(s)}{f(s)}\equiv 1$ where $\theta(s)$ denotes the percentage of share ownership for individuals in the firm and $f(s)$ indicates the fraction of the individual skill level in population. To eliminate the inegalitarian distribution circumstances, a representation of a process by which the distribution can become more egalitarian at time t in [0,1] the distribution of share ownership is given by:

$$\varphi(s,t)=t\varphi^e(s)+(1-t)\varphi(s) \tag{2.11}$$

Then the utility for a voter of types owns fraction θ of the firm at equilibrium give by:

$$v^s(x,\theta) = u(w(s,x) + \theta\Pi(x), x) \qquad (2.12)$$

where his ideal level of the externality, call it $x^s(\theta)$, is obtained by setting $\frac{d}{dx}v^s(x,\theta) = 0$.

Therefore, Roemer (1993) has shown that the voters' optimal level of the externality increases as his share ownership θ of firm increases $\frac{dx^s}{d\theta} > 0$ (2.13) even when the marginal utility of income decreases rapidly with income.

Finally, three main political scenarios under which the level of externality is chosen by the electorate are envisaged. Under median voter politics, under the conditions of proposition 2.12 or 2.13, since preferences are single-peaked and the optimal level of the public bad for a voter is increasing in s, the unique Condorcet winner is the level of the externality that is for s^m, the median of the distribution of skill measured as the probability *F*. When the share of corporate stock held by the median voter is less than a per capita share (i.e. $\varphi(s^m) < 1$), according to process (2.11), the median voter's share therefore rises as the distribution becomes more egalitarian over time. By proposition (2.13), the median voter's optimal level of the externality rises.

Under interest group politics, either under a dictatorship or through lobbying by the wealthy, or the firm inordinately impacts on political decision on the level of externality, or a political party representing the interest of the wealthy wins a democratic election, Roemer (1993) pointed out that the interest group will choose higher levels of externality than with median voter politics. However, by more egalitarian redistribution in (2.11), shares are redistributed and the large shareholders become less large; accordingly economic democracy leads to a decrease in the level of externality.

Under *Determination of externality by shareholders*, all shareholders vote on the level of externality in the share-democratic firm, and the unique Condorcet winner is the level of externality preferred by the median shareholder. If the median shareholder owns a larger-than-per-capita share for the locality, then economic democratization will lower his/her share and, by proposition (2.13), the level of externality chosen will decrease.

2.5 Conclusions

On basis of the Hotelling rule for non-renewable resources optimal extraction, extant literature has introduced many realistic factors to reconcile the theory with the reality. A strand of studies, in particular, extends the Hotelling model in petroleum extraction modeling. Nevertheless, oil firms or oil fields fail to make optimal production decisions according to the theoretical models. In incomplete markets, shareholder voting is considered as a solution to eliminating shareholders' disagreements on production plans and pollution control, thereby firm objectives are endogenized. Given this initiation, it would be of crucial research value to provide a thorough understanding of the relationship between share ownership distribution and production as well as pollution emissions when firm decisions are taken through shareholder voting. Besides, the relevant empirical literature is provided in a separate chapter. In chapter 3, the tests of the Hotelling rule are surveyed. In chapter 4, oil production modeling and the main determinants of extraction of oil fields are reviewed. In chapter 5, related studies for pollution emissions of firms are presented. Especially for chapter 3 and chapter 5, representative empirical studies are summarized in tables.

Chapter 3

Share Ownership Distribution and Natural Resources Extraction Rate

3.1 Introduction

The problem of making production decisions in an exchange economy was first addressed in the Arrow-Debreu (1954) model, which assumed complete markets and the existence as well as the optimality of equilibrium. The precondition for firm decision-making is value maximization. It is reasonable as a result of shareholders' unanimity and normalized market price. But in incomplete markets, the main difference is that shareholders will generally disagree on the effect of changes in firm production plans. Accordingly, profit-maximization is no longer a well defined objective for the firm due to the price normalization problem, and shareholders' disagreement may occur in equilibrium as individuals differ in share ownership of the resource firm.

In particular, in terms of non-renewable resources, they are viewed as existing in the form of fixed stocks of reserves, which once extracted cannot be renewed. Moreover, it is known that the production and consumption of non-renewable fossil energy fuels are the primary cause of many of the world's most serious environmental problems. Although theoretically the Hotelling rule provides an optimal solution for the resource owner and social planner, the rule fails to fit the facts and only applies to the idealised world for which it was constructed. When the resource firm realises it can affect its price by changing extraction, shareholders will disagree on the extraction rate. The reason is that an individual with a share ownership different from the population average wishes to manipulate prices and alter wages versus profits. Thus, how to deal with the shareholders' interests and make extraction decisions for non-renewable resources is of central importance under the incomplete market.

Shareholder voting is a resolution to reconcile shareholders' disagreement or aggregate investors' interests through the mechanism of majority voting, and thereby preferences of the shareholders are consistent with the objective of the firm (DeMarzo, 1993; Yalcin and Renström, 2003). More importantly, the distribution of share ownership plays an important role in firm's behaviour when decisions are taken through shareholder voting. The reason is that when a firm has market power it can alter prices through the redistribution among shareholders according to the shareholders' endowments. Shareholders with different endowments would support different production plans. The distribution of endowments would affect the identity of the median voter of the firm and thereby affect the firm's behaviour.

Yalcin and Renström (2003) have carried out one of the few studies analyzing the effect of share ownership distribution on production decisions, demonstrating that depending on the underlying distribution, rational voting may imply overproduction as well as underproduction, relative to the efficient level. Any initial distribution of shares is equilibrium, if individuals do not recognize their influence on voting when trading shares. However, when they do, and there are no short-selling constraints, the only equilibrium is the efficient one. When short-selling constraints are introduced, it is more likely to result in underproduction in the monopoly firm.

In the realm of natural resources economics, no previous study examines the effect of share ownership distribution on extraction of natural resources either theoretically or empirically. In theoretical part, we formulate a simple open-economy non-renewable resource extraction model in which individuals differ in share ownership of the resource firm. The resource extraction decision is assumed to be taken by a decisive individual (i.e. median voter in voting distribution). Given voting rights distribution is naturally left-skewed, the median voter share increases as the share ownership of the largest shareholder increases when keeping the same distribution. We take the share of the largest shareholder as a proxy for the share of the median in the voting distribution. Our hypothesis is that if substitution elasticity is low, the extraction rate is smaller if the largest shareholder holds a larger share.

In the empirical part, we use a panel of 20 U.S. oil firms over the period 1993-2007 to estimate the extraction equation as a function of lagged extraction rate, share ownership held by the largest shareholder, firm size and debt ratio. The empirical analysis is performed with different econometric techniques including System GMM and Within Group IV. Our results is consistent with the theoretical hypothesis that the larger the share ownership owned by the largest shareholder, the lower the extraction rate of non-renewable resources.

Overall, this chapter makes three contributions to the extant literature. First, this chapter links two strands of literature: production decision being endogenized through shareholder voting and optimal extraction model for non-renewable resources. To the best of our knowledge, no other study explores the effect of share ownership distribution on the extraction rate of natural resources.

Second, this chapter is innovative in terms of the system GMM methodology we use in the context of share ownership concentration. Considering the lagged dependent variable and two control variables are likely to be jointly endogenous where they are simultaneously determined with the dependent variable or subject to two-way causality, system GMM is used to mitigate these problems. Moreover, system GMM estimator allows a small sample in the presence of an autoregressive component and has lower bias and higher efficiency than OLS, Fixed Effects and First-differenced GMM.

Third, when measuring extraction rate, we use the ratio of the value of production over the firm value. This proxy may provide another novel and feasible alternative for extraction rate of firms since previous researchers encounter difficulty in collecting reserve data of non-renewable resources either at country or firm level (e.g. Young, 1992; Pickering, 2008).

The rest of the paper proceeds as follows. Section 3.2, reviewing the related empirical studies in two strands: one is a test of the Hotelling rule, the other is about the relationship between shareholder ownership distribution and production decisions. Section 3.3 formulates the theoretical economics model. Section 3.4 describes the data and methodology. Section 3.5 provides empirical results and discussions. The sensitivity analysis is given in section 3.6 and the chapter concludes in section 3.7.

3.2 Literature review - Empirical part

3.2.1 Testing of the Hotelling rule

Barnett and Morse (1963) collect time-series data on the price of a resource and explore whether the proportionate growth rate of the price is constant. The results indicate that resource prices including iron, copper, silver and timber fell over time, which is a disconcerting result for proponents of the standard theory. Subsequent researchers have shown a variety of results for different resources or different time periods. For example, Gaudet (2007) investigates U.S. price data for the period 1870-2004 for copper, lead, zinc, coal and petroleum, 1880-2004 for tin, 1900-2004 for aluminium and nickel and 1920-2004 for natural gas and plot the rate of change of price of each of those seven non-renewable minerals and three non-renewable fossil fuels. He finds high volatility in the rate of change of those prices. But more significantly this volatility appears centred at zero. In fact, in none of the ten cases is the mean rate of change of price significantly different from zero. It is very hard to detect any trend in the actual price levels of those resources. All in all, there is no clear picture of whether resource prices typically rise or fall over time.

Many studies have pursued the net price approach since both net price and utility discount rate ρ are unobservable. The proxy is constructed for net price by subtracting marginal costs from the gross market price. Slade (1982) made one of the earliest studies of this type. She concluded that some resources have U-shaped quadratic price paths, having fallen in the past but latterly rising. Other studies of this type are Stollery (1983), who generally supported the Hotelling hypothesis, and Halvorsen and Smith (1991), who were unable to support it. In addition, other approaches have also been used to test the Hotelling rule and fuller details can be found in the survey paper by Berck (1995).

Given above empirical study, the failure of Hotelling rule to fitting the facts is mainly attributed to two aspects. On one hand, Hotelling rule is constructed only apply to the idealized world with zero shocks. On the other hand, under the imperfect competition, there are various factors or shocks driving the price drift such as political policy, taxation, economic crisis, demand elasticity and so on. As for the application of Hotelling rule, hence it is no longer relied in our study. Our particular focus is given to the extraction decisions of resource firms in the incomplete market when taking into account the preferences of the individual who have a share different from the population average.

3.2.2 Share ownership distribution and firm performance

As explained above, instead of testing the Hotelling rule, our study aims to examine the effect of share ownership distribution on the non-renewable resources optimal extraction through linking two strands of extant literature: the Hotelling model for non-renewable resources optimal extraction and the role of share ownership distribution in firm production/ pollution decisions. The theoretical literature is surveyed in chapter 2 and the empirical studies are summarized as follows.

There is a huge amount of empirical literature investigating the effects of ownership structure on firm performance based on agency theory, which analyzes the relationship between principals/ owners and agents/managers. Most empirical studies have estimated the relationship between ownership concentration and performance in the form:

$$\pi_{it} = \alpha + \beta_1 OwnershipVariables_{it} + \delta X_{it} + \varepsilon_{it}$$

Where X is a vector of control variables include nation and industry effects, which both influence ownership structure and performance (Pedersen and Thomsen, 1997, 1999). The empirical evidence mainly focuses on two aspects: firstly, ownership concentration and performance; and secondly, insider ownership and performance. The latter study is beyond our research and is ignored here. These relevant empirical results are summarized below and tabled in Appendix B.

Early studies, beginning with Berle and Means (1932), tend to find a positive association between ownership concentration and accounting profitability (Cubbin and Leech, 1983). Using ownership structure data for large Japanese corporations, Morck et al. (2000) reach the same conclusion that Japanese firms' average q ratios rise monotonically with both ownership by management and corporate block holders. The positive relation between firm value and corporate block holdings is consistent with the hypothesis of Shleifer and Vishny (1986) that large block holders are a way of overcoming the free-rider problems in shareholder monitoring associated with dispersed ownership. Gedojlovic and Shapiro (2002) have offered a positive relationship between ownership structure and financial performance of Japanese corporations with panel data.

In contrast, working with a variety of measurements for owner concentration, including largest shareholder's share ownership, top five, top ten and top twenty as well as Herfindahl index, Leech and Leahy (1991) show ownership concentration for 470 U.K.-listed firms has negative coefficients in market value divided by ordinary share capital, trading profit margin and growth rate of net assets. Using U.K. financial services sector data comprised of 111 firms over 1992-1994, Mudambi and Nicosia (1998) find that the Herfindahl index measured as ownership concentration has a negative impact on actual rate of return at 5 percent significance level. Lehmann and Weigand (2000) examine the more network- or bank-oriented German system. In panel regressions for 361 German corporations over 1991-1996, they find that ownership concentration affects profitability significantly and negatively.

In addition to results with linear relationship, some related studies (Gedajlovic and Shapiro, 1998; Thomsen and Pedersen, 2000; Miguel et al., 2004) found a non-linear relationship concerning ownership effects. Gedajlovic and Shapiro (1998) empirically examine the ownership concentration-performance relationship using 1030 medium to large firms with 11 industrial sectors (including oil) across Canada, France, Germany, the U.K. and U.S. from 1986 to 1991. Strong ownership effects are found in the U.S., weaker effects in Germany, traces of effects in the U.K., and no effects at all in Canada or France. For the U.S., direct non-linear ownership effects are found (the ownership coefficient is negative and significant; the squared ownership is positive and significant). In particular, in the U.S., concentrated ownership does not exert a positive marginal effect on profitability unless the firm is either highly concentrated, or highly diversified.

In contrast, using 435 of the largest European companies and controlling for industry, capital structure and nation effects, Thomsen and Pederson (2000) find evidence of a bell-shaped effect with a maximum at an ownership share of 83 percent. A positive effect of ownership concentration on shareholder value (market-to-book value of equity) and profitability (asset returns) is shown, but the effect levels off for high ownership shares. Moreover, Miguel et al. (2004) also support the quadratic relationship between firm value and ownership concentration using new evidence from Spain. They have offered results that firm value increases with ownership concentration at low levels, and decreases with ownership concentration at high levels.

To sum up, a huge amount of literature comprises empirical studies concerning the relationship between firm performance and share ownership distribution. The difference between the present study and prior studies is in that we analyze the effect of share ownership distribution on extraction when firm decisions are taken through shareholder voting via the median voter. Next, an open-economy non-renewable resources model is formulated.

3.3 The Economics Model

3.3.1. Introduction

We formulate a simple open-economy non-renewable resource model where individuals differ in share ownership of the resource firm. Final goods producers are price takers, while the resource firm realizes it can affect its price, depending on extraction. Shareholders will disagree on the extraction rate. The reason is that an individual with a share different from the population average wish to manipulate prices to alter wages versus profits. This is the same effect as in Yalcin and Renström (2003) and we take as our shareholder voting equilibrium the extraction rate that cannot lose against an alternative extraction rate in a binary election (i.e. the extraction rate preferred by the median in the voting distribution). Contrary to Stiglitz (1976) the resource extraction path will not coincide with the first-best, unless the decisive shareholder holds a share exactly equal to one over the population size. The open-economy assumption simplifies the analysis (when r is exogenous). If we had used a closed-economy model, like Sinclair (1994), the resource firm would also have affected the return to savings, and shareholders would also have to take into account the redistribution between individuals of different savings, which complicates the analysis without altering the main incentives present when taking the resource-extraction decision.

3.3.2. The model setup

3.3.2.1 Final goods production

There is a large number of competitive (i.e. price taking) firms using capital, labour, and a non-renewable resource, producing under the same technology. They can borrow and lend on the international capital market, at the interest rate *r*. Final goods price is normalised to unity, and the prices of labour and the resource are denoted *w* and *p*, respectively. Firms' decisions can be represented as a representative firm, employing the aggregate quantities, solving:

$$\max_{K(t),A(t),L(t),X(t)} = F\big(K(t),\phi(L,X(t))\big)+r(t)(A(t)-K(t))-r(t)A(t)-w(t)L(t)-p(t)X(t) \quad (3.1)$$

where $K(t)$ is capital in production, $A(t)$ is domestically supplied capital, $L(t)$ is total labour (assumed to be constant), $X(t)$ is the use of the non-renewable resource. For simplicity the production technology is weakly separable, and F is homogenous of degree one in K and ϕ, and ϕ is homogenous of degree one in L and X. We are agnostic to whether the non-renewable resource is essential in production (i.e. whether $\phi(L,0)=0$). We can allow the case $\phi(L,0)>0$ for $L>0$, i.e. there is enough substitutability between the resource and labour (e.g. energy produced by manual work). An example of such a technology is CES with substitution elasticity different from one.

Denoting partial derivatives by subscripts, the first-order conditions give:

$$F_K\left(K(t),\phi(L,X(t))\right)=r(t) \tag{3.2}$$

$$F_\phi\left(K(t),\phi(L,X(t))\right)\phi_L\left(L,X(t)\right)=w(t) \tag{3.3}$$

$$F_\phi\left(K(t),\phi(L,X(t))\right)\phi_X\left(L,X(t)\right)=p(t) \tag{3.4}$$

The homogeneity of degree one assumptions (i.e. constant returns to scale) implies zero profits in the final goods sector and, since $r(t)$ is exogenous, F_K and F_ϕ are invariant with respect to K, L and X. In turn this implies that w and p are only functions of X (from decision making point of view).

3.3.2.2 Resource extraction

The non-renewable resource, S, is depleted according to

$$\dot{S}(t)=-X(t) \tag{3.5}$$

Given zero extraction costs (a simplifying assumption), the profits at each instant of time is:

$$\pi = p(t)X(t)=F_\phi\left(K(t),\phi(L,X(t))\right)\phi_X\left(L,X(t)\right)X(t)=\pi(X(t)) \tag{3.6}$$

where the second equality follows from (3.4), and the last equality denotes the fact that profits are only a function of X (from a decision making point of view).

3.3.2.3 Individuals' budgets

Individuals differ in share ownership of the resource firm, $\theta\in[\underline{\theta},\overline{\theta}]$, (assumed to be constant over time, for simplicity, and its density denoted $f(\theta)$) and possibly in initial capital, $a(0,\theta)$. Consumption at date t of an individual with share θ is denoted $c(t,\theta)$. The law of motion for individual capital is:

$$\dot{a}(t,\theta) = r(t)a(t,\theta) + w(t) + \theta\pi - c(t,\theta) \tag{3.7}$$

3.3.2.4 Preferences

The life-time utility of an individual with share θ is:

$$U(\theta) = \int_0^\infty e^{-\rho t} u\big(c(t,\theta)\big) dt \tag{3.8}$$

where ρ is the discount rate.

3.3.2.5 Consumption-savings equilibrium

Maximising (3.8) subject to (3.7) gives the consumption-Euler equation:

$$\dot{c}(t,\theta) = \frac{u_c\big(c(t,\theta)\big)}{-u_{cc}\big(c(t,\theta)\big)}\big[r(t) - \rho\big] \tag{3.9}$$

Denote the density function of the distribution shares as $f(\theta)$, then equation (3.9), (3.7) together with

$$A(t) = \int_{\theta_0}^{\bar{\theta}} a(t,\theta) f(\theta) d\theta \tag{3.10}$$

gives the equilibrium for any paths of $r(t)$ and $X(t)$ (the latter being the decision of the shareholders in the resource firm).

3.3.2.6. Preferences over extraction rates

For each shareholder we find the preferences over the extraction rates for the entire future (i.e. a time path of most preferred extraction rates). An individual then maximises (3.8), subject to (3.3)-(3.7).

Then the current-value Hamiltonian to the problem is:

$$H = u\big(c(t,\theta)\big) + q(t,\theta)\big[r(t)a(t,\theta) + w(X(t)) + \theta\pi(X(t)) - c(t,\theta)\big] - \lambda(t,\theta)X(t) \quad (3.11)$$

The first-order conditions are:

$$\frac{\partial H}{\partial c} = u_c\big(c(t,\theta)\big) - q(t,\theta) = 0 \quad (3.12)$$

$$\frac{\partial H}{\partial a} = q(t,\theta)r(t) = \rho q(t,\theta) - \dot{q}(t,\theta) \quad (3.13)$$

$$\frac{\partial H}{\partial X} = q(t,\theta)\big(w_X + \theta\pi_X\big) - \lambda(t,\theta) = 0 \quad (3.14)$$

$$\frac{\partial H}{\partial S} = 0 = \rho\lambda(t,\theta) - \dot{\lambda}(t,\theta) \quad (3.15)$$

Equations (3.12) and (3.13) give the consumption Euler equation (3.9), as before.

Next, notice that

$$w + \theta\pi = F_\phi(\phi_L + \theta\phi_X X) = F_\phi(\phi_L + \phi_X X/L + (\theta L - 1)\phi_X X/L) = F_\phi(\phi/L + (\theta L - 1)\phi_X X/L)$$

where the first equality follows from (3.3) and (3.4), and the last from homogeneity of degree one of ϕ. Then we obtain

$$\frac{\partial(w+\theta\pi)}{\partial X} = F_\varphi\big(\varphi_X/L + (\theta L - 1)(\varphi_X/L + \varphi_{XX}X/L\big) = F_\varphi\varphi_X\big(1 + (\theta L - 1)(1-\varepsilon\big)/L \quad (3.16)$$

where

$$\varepsilon \equiv -\frac{\phi_{XX}}{\phi_X} X \qquad (3.17)$$

Now (3.14) can be written as

$$F_\phi \phi_X q(t,\theta)\left[(\theta - 1/L)(1-\varepsilon) + 1/L\right] = \lambda(t,\theta) \qquad (3.18)$$

Log differentiating (3.18) with respect to time gives (Appendix A)

$$\frac{\dot{X}}{X} = -\frac{r(t)/\varepsilon}{1 + \frac{\varepsilon_X X}{\varepsilon} \frac{\theta - 1/L}{(\theta - 1/L)(1-\varepsilon) + 1/L}} \equiv -v(\theta, X; r) \qquad (3.19)$$

where

$$\tilde{\varepsilon} \equiv \frac{\varepsilon_X}{\varepsilon} X \qquad (3.20)$$

Notice that $\tilde{\varepsilon}$ is the log change of the elasticity of $\phi(L,X)$ with respect to X. For a function with unitary substitution elasticity, ε is constant and thus $\tilde{\varepsilon}$ is zero. For a CES function $\tilde{\varepsilon}$ is positive (negative) if the substitution elasticity is smaller (greater) than unity.

Equation (3.19) gives the optimal rate of decline in extraction over time, the larger v is the larger is the decline, and expectedly the larger is the rate of extraction x/S.

Proposition 1

At each level of X, an individual shareholder with a share greater (smaller) than one over the population size prefers a smaller (greater) decline in extraction if $\tilde{\varepsilon}$ *is positive. The result is reversed for* $\tilde{\varepsilon}$ *negative. The individual prefers an extraction rate coinciding with the first best if either the she individual holds a share equal to one over the population size or if* $\phi(L,K)$ *is Cobb-Douglas (unitary substitution elasticity).*

If $\phi(L,K)$ is CES with a substitution elasticity lower than one, then a shareholder with larger share prefers lower extraction rate.

Following a path with a less rapid decline in *X*, implies that the level of extraction is smaller at each level of the resource, *S*.

Our hypotheses are that if the substitution elasticity is smaller than unity, the extraction rate is smaller if the decisive shareholder holds a larger share, and that a higher rate of extraction in one period gives a lower decline in *X* in the next (follows from (3.19)). If the elasticity of substitution is high, the signs are reversed.

Since share ownership gives voting rights, the distribution of voting rights is not the same as the distribution of share ownership. If we look for the preferences of the median voter, the median voter will not be the individual who owns the median share, but the individual who is in the middle of the vote distribution, i.e. someone with larger share. As we increase the share ownership of the largest individual, keeping the distribution the same, the median voter share also tend to increase.

The shares sum to one

$$1 = \int_{\underline{\theta}}^{\bar{\theta}} \theta f(\theta) d\theta \qquad (3.21)$$

and the median in the voting distribution, θ^m , is given by

$$\tfrac{1}{2} = \int_{\underline{\theta}}^{\theta^m} \theta f(\theta) d\theta \qquad (3.22)$$

It is easily verified that for distribution like uniform $f(\theta)=n$, or inverse $f(\theta)=n/\theta$ (where n is a constant) an increase in the share of the largest shareholder, $\bar{\theta}$, implies an increase in the decisive individual's share, θ^m.

To conclude, we have formulated a simple open economy model with resource extraction where individuals differ in share ownership of the resource firm. The resource extraction decision is assumed to be taken by the median in the voting distribution (as her policy proposal cannot be defeated by an alternative proposal in a binary election). Given that shares carry voting rights, voting rights become naturally left skewed. We therefore expect to see the decisive individual owning a larger share when the larger shareholder owns a larger share. We can then take the share of the largest shareholder as a proxy for the share of the median in the voting distribution.

Our hypotheses are that if there is low substitution elasticity, the extraction rate is smaller if the largest shareholder holds a larger share, and that a higher rate of extraction in one period gives a lower decline in X in the next. If the elasticity of substitution is high, the signs are reversed.

We next test these hypotheses.

3.4 Data and Methodology

3.4.1 Sample selection

To assess the effect of share ownership distribution on non-renewable resources extraction rate, we consider only the firms which are engaging in oil and gas exploration and production and are listed on Standard and Poor's and the New York Stock Exchange. We start with a potential sample including 43 firms listed on Standard & Poor's and 63 firms listed on the New York Stock Exchange over 1993-2007. As for these 106 firms, oil production and price data and share ownership data are collected manually from annual company reports which condition the size and time frame of the overall sample. Other financial data are collected from the on-line Datastream Facility.

The choice of our panels is mainly determined by both the availability of reserves data and share ownership data. As for the availability of reserve data, it will be further explained in section 3.4.2.1. We remove the firms in which largest shareholders own less than 5% of the outstanding share[6] and the firms in which they did not provide the production and price for oil or natural liquid gas.

[6] For U.S. firms, the ownership data is not available in annual reports when the largest shareholder holds less than 5% of shareholdings.

Moreover, estimated equations are first-differenced, and values of the regressors lagged twice or more are used as instruments when using Generalized Method of Moments (GMM). For this reason, considering the lagged variables in our estimating equations, at least three years data for each firm are needed. Thus, only firms with a minimum of three observations are kept in the sample. We then drop firm-years that do not have complete records on the variables used in our regressions, namely average price of oil or natural liquid gas, annual production of oil or natural gas liquid, market capitalization, total debt and equity.

After these adjustments, we are left with 255 observations on 21 firms. One firm, Occidental Petroleum Corporation, is excluded since its operation is controlled by OPEC. This cut-off is aimed at eliminating observations not reflecting the effect of shareholder voting. Finally, we obtain 241 observations for 20 firms including ten S&P firms and ten NYSE firms over 1993-2007, which is the sample used for the OLS and Within Groups estimates. As GMM is based on first-differences, only 218 observations are used for the GMM estimates. Our sample has an unbalanced structure, with the number of years of observations on each firm varying between nine and 15. By allowing for both entry and exit, the usage of an unbalanced panel, to some extent, helps mitigate the potential selection and survivor bias (Carpenter and Guariglia, 2008). The data used for empirical estimation is reported in Appendix C.

3.4.2 Variables and Measurements

The key variables of interest consist of the extraction rate of oil firms and the share ownership of the largest shareholder. Three additional variables are used to control for effects on the extraction rate of firms which are not captured by the ownership variable. The descriptions of variables are summarized in Table 3.1.

3.4.2.1 Key variables

Extraction rate

Typical annual extraction rate for non-renewable resources is defined as the ratio of total production over total reserves for each year. This variable is called **ER** in our regressions. The selection of our panels is mainly determined by the availability of reserves data. Previous researchers encountered the same difficulty in collecting reserve data of non-renewable resources either at country or firm level (e.g. Young, 1992; Pickering, 2008). There are two main issues attributed to the difficulty in selection. First, the real amounts of total reserves for most firms are not disclosed to the public. Second, firm-level comparability of reserves data is a difficult matter. All reserves estimates involve uncertainty depending on the amount of reliable geologic and engineering data available and the interpretation of them. Generally the reserves are reported on two principal categories: proven and unproven. Unproven reserves are further classified into the probable and the possible from which the definitions problem of reserves arises. For example, some firms provided proven reserves or unproven reserves. Some firms simply gave new discoveries over years instead of reserves data.

To overcome the above problems, firm value is taken as a valid proxy for total reserves. It is considered as an equivalent measurement of the value of total reserves a firm owns, calculated by summation of the market values of a firm's common stock and total debt. The market value of common stock is equal to the number of common shares outstanding multiplied by the price per share at the end of the year. The market value of the firm's debt is calculated by the sum of the values of the short-term debt and the long-term debt. The measurement of extraction rate at firm level is formulated as:

$$ExtractionRate = \frac{price_{oil} * production_{oil} + price_{gas} \times production_{gas}}{FirmValue}$$

The denominator of extraction rate is equal to the sales of oil production which is equal to the product of annual average unit price and annual production of oil (i.e. crude oil and natural liquid gas combined).

Share ownership of the decisive individual

As stated in the theoretical part, the share of the decisive individual increases in the share of the largest shareholder due to left-skewed voting rights distribution. We then take the share of the largest shareholder as a proxy for the share of the median in the voting distribution. Moreover, the percentage of shares outstanding held by the largest shareholder (**LSH**) is the most employed in the literature and the most widely available and accurate measure to be a a proxy for share ownership distribution (see e.g. Leech and Leahy, 1991; Gedajlovic and Shapiro, 1998; Thomsen and Pedersen, 2000)[7].

3.4.2.2 Control variables

Additional variables are included in the extraction rate regression models to control for other potential influences on the extraction rate of firms, namely debt, firm size and time dummy.

The debt to equity ratio (**DEBT**) (also known as leverage ratio) is defined as the ratio of the book value of the firm's total debt to the value of the firm's equity. This ratio is included to control for a number of factors. Firstly, it controls for the likelihood that debt holders significantly affect production decisions and the operation of the firm as well as its management. Stiglitz (1985) suggests that lenders are more likely to control management actions effectively, particularly banks, relative to shareholders. Second, debt may be a solution to conflicts between managers and shareholders. As specified by Grossman and Hart (1982) and Jensen (1986), decision-makers may use debt to signal that they are responsible to achieve the cash flow to meet the debt repayment. The managers may, therefore, reduce their

[7] Prior studies indicate that alternative measures of ownership are highly correlated. For example, using ownership data across five countries, namely the U.S., the U.K., Germany, France and Canada, Gedajlovic and Shapiro (1998) have shown strong evidence that **LSH** highly correlated with the alternative Herfindahl index that is defined as the sum of the squares of the fractions of equity held by each individual shareholder. The correlation coefficient is 0.81 at 1% significance level.

discretion to consume excessive perquisites so that the firm's equity is increased (Jensen and Meckling, 1976; Grossman and Hart, 1982). Moreover, several studies, including Whited (1992), argue that firms with higher leverage are more likely to face binding financial constraints. Haushalter (2000) find a positive relation between the extent to which a firm hedges and its financial leverage. More specifically, the fraction of production that oil and gas producers hedge against price risk is positively related to the ratio of total debt to total assets and is greater for companies having little financial flexibility which is measured by the relative amount of debt outstanding and cash holdings.

The firm size variable used in our study is measured by the market value. We take the summation of market value of equity plus total liabilities and transform it into the logarithm to the base ten of the value. This measurement is advocated by Baumol (1959), who argues that the firm size is the amount of owned and borrowed money capital. In comparison with the sales and employment concept of firm size, market capitalization and total debt is a superior approximation to reflect the definition of Baumol (1959).

Firm size potentially affects the extraction rate of firms through three different avenues. First, all else being equal, companies with lower market value are likely to have greater informational asymmetries with potential public investors (Haushalter, 2000). Second, firm size affects both the willingness to enter agreements to control output and preferences for particular quota arrangements. Libbecap and Wiggins (1984) have shown that large firms tend to restrict the production of oil in the common pool, because the firm can achieve an optimum when price equals marginal extraction cost, which includes the direct cost of additional output and the increased cost of inframarginal production. Thereby, on the one hand, the firm decreases production to reduce the marginal extraction cost. On the other hand, considering the cross-unit cost effects from common pool production, as production shares decrease, firms internalize less of the cost increases from rival production. Third, according to Stiglitz (1976), the larger firm may have easier access to the capital market and be better able to pool risks. This suggests that the larger firm might have a lower required rate of return on capital and implies a more conservationist policy for non-renewable resources.

In addition, as Lehmann and Welgand (2000) suggested, macroeconomic shocks are common to all firms and can be subsumed by time dummy variables. Controlling over the time-specific effects is adequate since we are testing if the largest shareholder's share ownership determines extraction rather than constructing a complete model.

3.4.3 Descriptive statistics

The statistics summary of our sample and all sample data used in estimation are provided in Table 3.2. Extraction rate ranges from 5.35% (for Goodrich Petroleum Corporation in 2005) to 62.99% (for Meridian Resources Corporation in 2007). The average extraction rate of our sample is 22.8%. The share ownership of the largest shareholder varies from 5.2% (for Apache Corporation, 2005) to 80.07% (EOG Resources Inc, 1993). The average level of the share ownership owned by the largest shareholder is 14.1%. Although all of these firms are in the same industry, there is substantial variation in the debt ratio: it ranges from 0 (for Berry Petroleum Company in 1994, 1995 and for Meridian Resources Corporation in 1996) to 5.8861 (for Range Resources Corporation in 1998). The average firm value in our sample is 2870 million U.S. dollars, ranging from \$1.88e+07 to \$3.12e+10. Moreover, correlation is conducted between paired variables. It is clearly seen that share ownership of the largest shareholder is negatively correlated with extraction rate of oil and gas. Two control variables appear significantly related to extraction rate.

3.4.4 Estimation methods

To test the hypothesis that the extraction rate is smaller if the largest shareholder holds a larger share, the estimation equation is:

$$ER_{it} = \alpha ER_{i,t-1} + \beta_1 LSH_{it} + \beta_2 LSHSQ_{it} + \beta_3 DEBT_{it} + \beta_4 Log(V_{it}) + v_{it}$$
$$v_{it} = f_i + \varepsilon_{it} \tag{3.23}$$

where ER_{it} is the extraction rate of firm i in year t , $ER_{i,t-1}$ is the lagged extraction rate in order to capture the effect of past extraction. LSH_{it} is the percentage of shareholdings owned by the largest shareholder. $DEBT_{it}$ is the ratio of debt to equity used to capture the effect of financial leverage. $LSHSQ_{it}$ represents the squared term for the largest shareholdings. $\log V_{it}$ indicates the value of the firm in a logarithm measuring the firm size.

In our model, we allow for unobservable firm-specific effects and suppose that the error term, $v_{it} = f_i + \varepsilon_{it}$, where f_i is an unobserved time-invariant fixed effects, ε_{it} is idiosyncratic shocks. Clearly, OLS is inconsistent in this case, because $ER_{i,t-1}$ is correlated with f_i . Although first-differencing the equation eliminates the fixed effect, the component $\varepsilon_{i,t-1}$ in $\Delta\varepsilon_{it}$ is correlated with $\Delta ER_{i,t-1}$ and possibly also with $\Delta DEBT_{it}$ and $\Delta(\log V)_{it}$ via the two-way causality.

Therefore, Ordinary Least Squares (OLS) estimator is likely to suffer from bias due to unobserved firm-specific heterogeneity as well as possible endogeneity of the regressors. Within groups estimator (also known as Fixed-effects estimator) only accounts for the former bias. A pooled Instrumental Variables (IV) estimator only accounts for the latter bias. There is heteroskedasticity, 2SLS is not asymptotically efficient. Although a Within Groups IV estimator accounts both for unobservable firm-specific heterogeneity and for the possible endogeneity of the regressors, typically it is less efficient than first-difference Generalized Method of Moments (GMM) estimator proposed by Arellano and Bond (1991) that also controls for both biases.

Arellano and Bond (1991) demonstrate that the first-difference GMM estimator corrects not only for the bias introduced by heterogeneity across panels, but also permits the lagged endogenous variable and a certain degree of endogeneity in the other regressors. This estimator takes first difference for each variable so as to eliminate the firm specific effects and then uses two or more lagged variables as the instruments to eliminate the endogeneity problem. More specifically, we rewrite equation (1) as:

$$ER_{it} - ER_{i,t-1} = \alpha(ER_{i,t-1} - ER_{i,t-2}) + \beta_1 LSH_{it} + \beta_2 LSHSQ_{it}$$

$$+\beta_3(DEBT_{i,t-1} - DEBT_{i,t-2}) + \beta_4[Log(V_{i,t-1}) - Log(V_{i,t-2})]$$

$$+(\varepsilon_{it} - \varepsilon_{i,t-1})$$

Two critical assumptions must be satisfied for this GMM estimator to be consistent and efficient. First, the endogeneous regressors must be predetermined by at least one period:

$E[ER_{i,t-s}\Delta\varepsilon_{it}] = 0$ for $s \geq 2$

$E[DEBT_{i,t-s}\Delta\varepsilon_{it}] = 0$ for $s \geq 1$

$E[\log V_{i,t-s}\Delta\varepsilon_{it}] = 0$ for $s \geq 1$

Second, the error terms cannot be serially correlated:

$E[\varepsilon_{it}\varepsilon_{i,t-s}] = 0$ for all $s \geq 1$.

Meanwhile, Arellano-Bond test and Hansen J test are conducted. Arellano-Bond test sets the maximum lag distance to check for autocorrelation with the null hypothesis of no second-order serial correlation of the residuals. The GMM estimator is consistent if there is no second-order serial correlation in the residuals (i.e. the p-value is greater than 0.10). The Hansen J statistics is a test for overidentifying restriction with the null hypothesis of joint validity of the instruments. The J statistics are asymptotically distributed as chi-square distribution with degrees of freedom equal to the number of instruments minus the number of parameters. When p-value of J statistics is greater than 0.05, the instruments are valid.

The first-difference GMM suffers from finite-sample bias when instruments are weak (Blundell and Bond, 1998). Bond et al. (2003) give criteria to rectify the problem of weak instruments if the coefficients of the lagged dependent variable from first-difference GMM estimator are smaller than both Fixed-effects and OLS estimators. As for our estimations, we expect that the lagged dependent variable's coefficients are greater than Fixed-effects estimates and less than the OLS estimates;

then there is no finite-sample bias due to weak instruments problem. In line with this test, it is shown in Table 3.3 that first-differenced GMM has a weak instruments problem. System GMM, therefore, is advocated. It consists of two equations: the original equation as well as the first-differenced one. Particularly in samples with small N in presence of an autoregressive component, Soto (2010) demonstrates that the system GMM estimator has lower bias and higher efficiency than all the other standard estimators through Monte Carlo simulations of the properties of OLS, Fixed Effects and First-differenced GMM and system GMM in country growth studies.

3.5 Empirical Results and Discussions

Columns 1, 2, 3 of Table 3.3 report the results of the baseline regression equation (1). As discussed in section 3.4.4, we test whether the GMM estimator suffers from finite sample bias by comparing the coefficients of lagged dependent variables from GMM to those of pooled OLS and within fixed effect estimator. The estimated coefficient of the lagged dependent variable from GMM is 0.085 and insignificant, which is less than the estimations of both OLS (0.671) and fixed effect (0.277), suggesting that the instruments in the Arellano-Bond GMM estimator are weak so that the estimator is biased in finite samples (Blundell and Bond, 1998; Hahn, Hausman and Kuersteiner, 2004). To solve this problem, Blundell-Bond system GMM is used, which consists of two equations: the original equation as well as the first-differenced one.

In columns 2, 3, and 4 we control for firm-specific fixed effects, identifying the estimates only off the variation in extraction rate within firms over time. In these regressions, the share ownership variables are jointly significant and all have the sign expected on the basis of our model. The within-group estimator in column 2 is inconsistent and underestimates the coefficient on ER_{t-1}.

Column 4 presents the consistent and efficient system GMM estimator proposed by Blundell and Bond (1998). The coefficient of the lagged extraction rate is strongly significant. The share ownership has negative and significant effect on extraction rate (at 5% significance level) and the squared term indicates positive and significant correlation. We find evidence that the share ownership held by the largest shareholder impacts extraction rate negatively at increasing rate. There is a positive and significant relationship between debt ratio and extraction rate at 5% significance level. Firm size appears negatively correlated with extraction rate. The Hansen test cannot reject the over-identifying restrictions of the system estimator (p value is 1); the Arellano-Bond tests detect first-order autocorrelation in the error terms (p-value is 0), and the second-order autocorrelation (p-value is 10.1%) but do not find evidence for higher-order autocorrelation (p-value 59% for third-order). As we expected, the system estimator is correctly specified. Given system GMM's superior ability to control for the finite sample bias and problem of endogeneity and greater efficiency compared with the instrumental variables (IV) estimator, our results are discussed in line with the system GMM estimation.

In general, the results are consistent with our theoretical hypothesis that the more share ownership the largest shareholder has, the lower the extraction rate of non-renewable resources. Furthermore, using U.S. oil firms' data, we find a non-linear relationship between share ownership of the largest shareholder and extraction rate suggesting that extraction rate decreases in the largest shareholder's share ownership at an increasing change rate. Our results suggest that higher share ownership owned by the largest shareholder is likely to lead to smaller extraction rate. However, this is in contrast to Yalcin and Renstrom (2003) who demonstrate that with less share ownership by the decisive maker (i.e. the median voter), the firm tends to choose overproduction level than competitive economic equilibrium when production decisions are taken through shareholder voting via the median voter.

Moreover, firm size is found to be negatively correlated with extraction rate; larger firms are likely to choose lower extraction rate[8]. This may be explained by Stiglitz

[8] In our knowledge, firm value is the best available proxy for firm resource reserves in the extant literature. However, there is one controversial issue. All else being equal, bigger firms tend to have higher price-to-earnings ratio which is defined as market price per share divided by annual earnings per share. Accordingly, bigger firms are more likely to have greater market capitalization. Therefore, to some extent, extraction rate might be biased as result of firm size when we take firm value (i,e. the summation of market capitalization and total debt) as a proxy for resource reserves of the firm. Nevertheless, this is not a problem for this thesis since we are focusing on examining the relationship between share ownership and extraction rate rather than modelling extraction rate accurately. In addition, for future study, we can use average annual firm value to measure the firm size instead of at end-of-years.

(1976), who suggests that the larger firm may have easier access to the capital market and be better able to pool risks. This suggests that the larger firm might have a lower required rate of return on capital and implies a more conservative policy for non-renewable resources. In addition, debt appears to affect extraction rate positively. Firms with higher leverage are more likely to face binding financial constraints. The lenders are more likely to control management actions effectively, particularly banks, relevant to shareholders (Stiglitz, 1985).

This empirical study allows the investigation of whether concentrated share ownership is harmful for extraction of non-renewable resources. Our results may provide some policy implications for social planners and regulators. Share ownership distribution requires attention. In line with our results, the firm with dispersed share ownership structure appears to extract more non-renewable resources while the more concentrated ownership tends to be conservative.

3.6 Sensitivity analysis

To check the robustness of our main results in column (4) of Table 3.3, we concentrate on examining whether these estimations are independent of changing definitions of variables, possible combinations of variables and alternative estimation methods.

We tested the robustness of our results to alternative measurements of control variables. Firm size is replaced with total assets (FIRM SIZE2). Debt ratio is alternatively measured with the ratio of debt over total assets (DEBT2). In line with the efficiency and consistency, the system GMM estimator will be used in the estimation of the robustness test to follow. Our instrument set including FIRM-SIZE2 and DEBT2 is lagged twice. Column (1) of Table 3.4 presents the system GMM estimates of our alternative control variables. The largest share ownership is negatively and significantly related to extraction rate at 5% significance level. It is similar to our main results in Table 3.3 except the alternative firm size showing as insignificant. FIRM SIZE2 is excluded in column (2), the results have left our main results largely unchanged. While DEBT2 is excluded in column (3), in spite of the same sign with our main results in Table 3.3, the J-test only has a marginal significance 0.081, suggesting that the omission of the DEBT2 causes mis-specification in the model.

In addition to variable definitions, another concern with this paper is that estimation methods could affect results. We re-estimated our main model using Within Groups IV estimator which also corrects for both unobserved firm-specific heterogeneity and possible endogeneity of the regressors. Moreover, a number of researchers who participated in the debate on the factors of extraction of non-renewable resources did not include the lagged extraction (see Kellogg, 2011; Livernois and Uhler, 1987, etc). We therefore remove the lagged dependent variable from the set of regressors and from the instrument set. The results of this new specification are reported in column 4(a), and 4 (b) in which time dummies are included as over half of these time-specific coefficients are significant. The results are again qualitatively similar to those reported in column (4) of Table 3.3. The coefficient of largest shareholder's share ownership is significant and negative for both column 4(a) (at the 1% significance level) and 4(b) (at the 5% level). However, these two control variables possibly are affected by time effects. Debt ratio is only significant without the inclusion of time dummies. The signs of firm size factor appear inconsistent as well. Overall the results support our theory that the greater share ownership by the largest shareholder leads to lower extraction rate.

3.7 Conclusions

Our theoretical model is concentrated around understanding the effects of the largest shareholder on production decisions. We have formulated a simple open economy model with resource extraction where individuals differ in share ownership of the resource firm. The resource extraction decision is assumed to be taken by the median in the voting distribution (as her policy proposal cannot be defeated by an alternative proposal in a binary election). As voting rights distribution becomes naturally left-skewed, the decisive individual is expected to own a larger share when the larger shareholder owns a larger share. The share of the largest shareholder is taken as a proxy for the share of the median in the voting distribution. The hypothesis is that the extraction rate is smaller if the largest shareholder holds a larger share if substitution elasticity is low.

Our empirical study has examined whether there is a negative relationship between the share ownership owned by largest shareholder and the extraction rate of non-renewable resources. We use a panel of 20 U.S. oil firms over 1993-2007 to estimate extraction equation as a function of lagged extraction rate, share ownership held by the largest shareholder, and firm size and debt ratio. System GMM is used to ensure our small sample estimation in the presence of autocorrelation and endogeneity to be more efficient and less biased. Meanwhile sensitivity analysis is conducted to check the robustness of our empirical evidence. The results are found to be consistent with our theoretical hypothesis, suggesting that the largest shareholder's share ownership does matter for extraction rate of U.S. oil firms. The larger share ownership owned by the decisive individual, the smaller is the extraction rate of the firm. This may provide a policy implication for government or regulator to control and allocate non-renewable resources by regulating the share ownership structure.

Table 3.1 Description of variables

variables	Description
Dependent	
ER	Extraction rate of oil at the accounting year end, calculated by the value of oil productions divided by firm value
Ownership distribution variable	
LSH	Percentage of shares held by largest shareholder
Control variables	
DEBT	the ratio of total debt to equity to represents financial leverage
FV	Firm value in dollars to proxy for firm size
DUM	Time dummies in years

Table 3.2 Summary statistics

variable	mean	Std. Dev.	Minimum	Maximum	Median
ER	0.228	0.079	0.0535	0.6299	0.2173
LSH	0.141	0.109	0.052	0.8007	0.1063
DEBT	0.574	0.836	0	5.8861	0.3122
FV	2.87e+09	4.43e+09	1.88e+07	3.12e+10	1.18e+09

Correlation Matrix:

	Variable			
Variable	ER	LSH	DEBT	SIZE
ER	1			
LSH	-0.1371**	1		
DEBT	0.1146*	0.1195*	1	
FV	-0.1153*	-0.1078*	-0.2150***	1

*p<0.1, **p<0.05, ***p<0.01; Significance levels are based on two-tailed tests.

Table 3.2 reports descriptive statistics for the firms in sample.

Table 3.3 The effect of share ownership distribution on oil extraction rate: OLS, Fixed effects and GMM estimators

Dependent variable **ER**	***OLS Estimator*** (1)	***Within Estimator*** (2)	***First-differenced GMM*** (3)	***System GMM*** (4)
L.ER	0.671***	0.277***	0.085	0.664***
	(7.88)	(4.04)	(0.91)	(7.04)
LSH	-0.247**	-0.225*	-0.343*	-0.272**
	(-1.96)	(-1.77)	(-1.93)	(-2.11)
LSHSQ	0. 339*	0. 323*	0. 511	0. 372*
	(1.72)	(1.88)	(1.55)	(1.83)
DEBT	0.010**	0.014***	0.018***	0.011**
	(2.06)	(2.95)	(2.84)	(2.58)
Log(V)	-0.020***	-0.188***	-0.249***	-0.022*
	(-2.59)	(-4.86)	(-5.05)	(-1.89)
_cons	0.235***	1.999***		0.300**
	(3.18)	(5.26)		(2.57)
N	241	241	218	241
R square	0.54	0.6		
rho		0.81		
AR2			0.37	0.101
J (p-value)			1.00	1.00

a.) t-statistics in parenthesis. b.) Time dummies are included in all specifications. c.) AR2 tests for second-order serial correlation in the first-differenced residuals, under the null of no serial correlation. d.) The Hansen J statistics test of overidentifying restrictions under the null of instrument validity has a p-value of 1.00 in both columns. e.) *, **, *** denotes significance at the 10% level, 5% level, and 1% level respectively. f.) The first differenced GMM and system GMM estimator use lagged values of ER dated t-2 as instruments and other right side variables dated t-3 as instruments. g.) The Blundell-Bond system GMM estimator in column (4) is one-step estimates and assumes the regressors are predetermined, not necessarily exogenous.

Table 3.4 Sensitivity analysis

Dependent variable:	SYSTEM GMM	SYSTEM	SYSTEM	Within	Within
		GMM	GMM	Groups IV	Groups IV
ER	(1)	(2)	(3)	(4a)	(4b)
L.ER	0.6408016***	0.63224***	0.634601***		
	(0.08938)	(0.10544)	(0.11152)		
LSH	-0.199580**	-0.22779**	-0.16862	-0.66209***	-0.30534**
	(0.10404)	(0.10037)	(0.11118)	(0.18984)	(0.15411)
LSHSQ	0.27545*	0.32990*	0.23914	0.70**	0.382*
	(0.17669)	(0.18281)	(0.21352)	(0.281)	(0.229)
FIRM SIZE2	0.006615		-0.00304		
	(0.00979)		(0.01198)		
DEBT2	0.053826***	0.07356**			
	(0.03107)	(0.04118)			
FIRM SIZE1				0.0229	-0.12747***
				(0.01664)	(0.0293)
DEBT1				0.03791**	0.01702
				(0.01554)	(0.0116)
CONS	0.13067	0.06765**	0.10751	0.07151	1.48964***
	(0.098003)	(0.03028)	(0.12644)	(0.15805)	(0.28201)
N	217	217	217	241	241
AR4	0.129	0.135	0.226		
Sargan(p value)	0.284	0.334	0.056		
Year Dummy	Yes	Yes	Yes	No	Yes

Notes: a.) The figures reported in parentheses are asymptotic standard errors. b.) Arellano-Bond tests for autocorrelation under the null of no serial correlation. We find no serial correlation for fourth-order AR (4) in the first-differenced residuals, c.) The Hansen J statistics test of overidentifying restrictions under the null of instrument validity has a p-value of 1.00 for column 1-3. d.) Sargan test is also satisfied, although it is less meaningful because it requires that the error terms are independently and identically distributed (and error terms in this model are heteroskedastic). e.) *, **, *** denotes significance at the 10% level, 5% level, and 1% level respectively. f.) The system GMM estimator is one-step estimates and assumes the regressors are predetermined, not necessarily exogenous. We use lagged values of ER dated t-2 as instruments and other right side variables dated t-3 as instruments.

Appendix A

The current value Hamiltonian of an individual' s problem is the following:

$$H = u\big(c(t,\theta)\big) + q(t)\big[r(t)a(t,\theta) + w(t) + \theta\pi - c(t,\theta)\big] \qquad \text{(i)}$$

The first order conditions of the problem imply:

$$\frac{\partial H}{\partial c(t)} = u_c\big(c(t,\theta)\big) - q(t) = 0 \qquad \text{(ii)}$$

$$\frac{\partial H}{\partial K(t)} = \rho q(t) - \dot{q}(t) \Rightarrow \dot{q}(t) = q(t)\big[\rho - r(t)\big] \qquad \text{(iii)}$$

and the transversality condition

$$\lim_{t\to\infty} e^{-\rho t} q(t)a(t,\theta) = 0$$

Log differentiating (18) with respect to time gives

$$-\varepsilon\frac{\dot{X}}{X} + \rho - r(t) - \frac{\dot{\varepsilon}(\theta - 1/L)}{(\theta - 1/L)(1-\varepsilon) + 1/L} = \frac{\dot{\lambda}(t,\theta)}{\lambda(t,\theta)} \qquad \text{(v)}$$

or

$$\frac{\dot{X}}{X} = -\frac{r(t)}{\varepsilon} - \frac{\dot{\varepsilon}}{\varepsilon}\frac{\theta - 1/L}{(\theta - 1/L)(1-\varepsilon) + 1/L} \qquad \text{(vi)}$$

implying

$$\frac{\dot{X}}{X}\left[1 + \frac{\varepsilon_X X}{\varepsilon}\frac{\theta - 1/L}{(\theta - 1/L)(1-\varepsilon) + 1/L}\right] = -\frac{r(t)}{\varepsilon} \qquad \text{(vii)}$$

which in turn gives (19) and (20).

Appendix B

Summaries of Empirical Studies—the relationship between firm profitability and share ownership

Authors	Data	Performance	Ownership concentration	Method	Findings and Conclusions
Morck et al. (2000)	373 Japanese manufacturing firms (1986)	Tobin's Q	Sum of 10 largest shareholders	Cross-sectio n	The positive relation between firm value and corporate block holdings.
Gedojlovic and Shapiro (2002)	334 Japanese corporations (1986-1991)	ROA (Return on Assets)	Sum of 5 largest shareholders	Fixed- and random-effect panel data methods	The positive relationship between ownership structure and financial performance of Japanese corporations with panel data.
Leech and Leahy (1991)	470 UK-listed companies with wide range of industries (1983-85)	VAL, TPM, RSHC ,TSG , NAG, HDS	1, 5, 10, 20 largest shareholders and Herfindahl	Pooled OLS	Concentration has negative coefficients in valuation ratio, profit margin and return on shareholders' capital, growth rate of sales and net assets.
Mudambi and Nicosia (1998)	111 UK firms in financial industries (1992-94)	Actual Rate of Return	Herfindahl	OLS and WLS	Increased concentration is inversely related to the same performance.
Lehmann and Weigand (2000)	361 German firms (1991-96)	ROA and ROE (Return on Equity)	Largest shareholder	Panel regression	Ownership concentration affects profitability significantly negatively.
Thomsen and Pederson (2000)	435 largest European companies (1990)	ROA and Market-to-boo k value of equity	Largest shareholder	OLS	Find evidence of a bell-shaped effect with a maximum at an ownership share of 83 percent. It is shown that a positive effect of ownership concentration on shareholder value (market-to-book value of equity) and profitability (asset returns), but the effect levels off for high ownership shares.
Demsetz and Lehn (1985)	511 US firms (1976-80)	ROA	Largest shareholder	OLS	No significant relationship between ownership concentration and profitability
Demsetz & Villalonga (2001)	223 US firms (1976-80)	Tobin's Q	Largest shareholder, Managerial ownership	2-equation system, OLS, 2SLS	OLS results suggest that ownership is significant in explaining performance, 2SLS results

Appendix C

Data of oil extraction rate and share ownership and financial characteristics for U.S. energy firms over 1993-2007

Firm name	year	Extraction rate	LSH (%)	DEBT ratio	FIRM SIZE
APACHE CORPORATION	1993	0.25503	12.55	0.3236	9.28
APACHE CORPORATION	1994	0.245423	8.05	0.4281	9.34
APACHE CORPORATION	1995	0.194488	7.25	0.471	9.53
APACHE CORPORATION	1996	0.189915	9.05	0.3913	9.64
APACHE CORPORATION	1997	0.205623	10.63	0.4642	9.68
APACHE CORPORATION	1998	0.197933	8.29	0.549	9.58
APACHE CORPORATION	1999	0.187501	8.65	0.4479	9.79
APACHE CORPORATION	2000	0.211529	7.35	0.2561	10.04
APACHE CORPORATION	2001	0.310827	9.2	0.3282	9.96
APACHE CORPORATION	2003	0.271236	10.1	0.1768	10.19
APACHE CORPORATION	2004	0.277287	5.4	0.1563	10.28
APACHE CORPORATION	2005	0.300561	5.2	0.0969	10.39
EOG RESOURCES INC	1993	0.167424	80.07	0.0587	9.52
EOG RESOURCES INC	1994	0.162052	80.01	0.064	9.5
EOG RESOURCES INC	1995	0.115477	60.65	0.0754	9.62
EOG RESOURCES INC	1996	0.154718	53.28	0.1155	9.65
EOG RESOURCES INC	1997	0.196724	54.97	0.219	9.62
EOG RESOURCES INC	1998	0.185421	53.52	0.431	9.58
EOG RESOURCES INC	1999	0.258653	9.7	0.4734	9.49
EOG RESOURCES INC	2000	0.205324	9.8	0.1345	9.86
EOG RESOURCES INC	2001	0.286574	9.9	0.1896	9.73
EOG RESOURCES INC	2002	0.192972	9	0.25	9.76
EOG RESOURCES INC	2003	0.281157	9	0.2072	9.81
EOG RESOURCES INC	2004	0.240003	10.15	0.127	9.98
EOG RESOURCES INC	2005	0.192357	9.9	0.0555	10.27
EOG RESOURCES INC	2006	0.223622	12.5	0.0482	10.2
EOG RESOURCES INC	2007	0.173571	12	0.0539	10.37
Forest Oil Corporation	1993	0.334026	6.48	1.7174	8.52
Forest Oil Corporation	1994	0.423258	8.92	3.3604	8.44
Forest Oil Corporation	1995	0.251944	34.9	1.4678	8.52
Forest Oil Corporation	1996	0.180234	30.8	0.3263	8.85
Forest Oil Corporation	1997	0.181811	39.5	0.4251	8.93
Forest Oil Corporation	1998	0.196307	40.2	1.3322	8.95
Forest Oil Corporation	1999	0.179399	36.7	0.5241	9.03
Forest Oil Corporation	2000	0.260076	32.1	0.3499	9.38
Forest Oil Corporation	2001	0.373972	33.3	0.4506	9.28
Forest Oil Corporation	2002	0.22799	16.3	0.5901	9.32

Forest Oil Corporation	2003	0.259918	14.54	0.5851	9.4
Forest Oil Corporation	2004	0.327005	12.94	0.4694	9.44
Forest Oil Corporation	2005	0.283911	14.84	0.3097	9.57
Forest Oil Corporation	2006	0.249355	12.55	0.5864	9.51
Forest Oil Corporation	2007	0.172896	14.94	0.3937	9.8
MURPHY OIL CORPORATION	1993	0.185668	14.92	0.0615	9.32
MURPHY OIL CORPORATION	1994	0.215614	13.77	0.0945	9.32
MURPHY OIL CORPORATION	1995	0.229164	8	0.11	9.31
MURPHY OIL CORPORATION	1996	0.2039	9.3	0.0863	9.43
MURPHY OIL CORPORATION	1997	0.221931	12.8	0.0881	9.42
MURPHY OIL CORPORATION	1998	0.127435	13.8	0.1841	9.34
MURPHY OIL CORPORATION	1999	0.188672	13.6	0.1523	9.47
MURPHY OIL CORPORATION	2000	0.278435	13.4	0.2064	9.52
MURPHY OIL CORPORATION	2001	0.205814	11.9	0.1494	9.64
MURPHY OIL CORPORATION	2002	0.197208	6.6	0.2341	9.69
MURPHY OIL CORPORATION	2003	0.130544	7.4	0.1929	9.85
MURPHY OIL CORPORATION	2004	0.180873	6.9	0.0897	9.91
MURPHY OIL CORPORATION	2005	0.183211	8.5	0.0612	10.03
MURPHY OIL CORPORATION	2006	0.180412	14.5	0.0888	10.02
MURPHY OIL CORPORATION	2007	0.128169	13.5	0.095	10.25
NOBLE ENERGY, INC.	1993	0.086466	14.7	0.4151	9.27
NOBLE ENERGY, INC.	1994	0.18688	13.6	0.3045	9.21
NOBLE ENERGY, INC.	1995	0.174664	13.3	0.2514	9.27
NOBLE ENERGY, INC.	1996	0.168794	15	0.3119	9.55
NOBLE ENERGY, INC.	1997	0.28739	8.1	0.3216	9.42
NOBLE ENERGY, INC.	1998	0.28359	8.1	0.531	9.33
NOBLE ENERGY, INC.	1999	0.328979	8.3	0.3641	9.22
NOBLE ENERGY, INC.	2000	0.203468	8.9	0.2037	9.49
NOBLE ENERGY, INC.	2001	0.247154	10.6	0.4383	9.46
NOBLE ENERGY, INC.	2002	0.194479	10.5	0.4731	9.5
NOBLE ENERGY, INC.	2003	0.251175	9.4	0.3659	9.54
NOBLE ENERGY, INC.	2004	0.267022	10.5	0.2419	9.66
NOBLE ENERGY, INC.	2005	0.226871	14.2	0.2869	9.96
NOBLE ENERGY, INC.	2006	0.279933	14.1	0.2131	10.01
NOBLE ENERGY, INC.	2007	0.205183	9.7	0.137	10.19
Pioneer Natural Resources	1997	0.109939	8.8	0.6653	9.69
Pioneer Natural Resources	1998	0.233094	26.4	2.4787	9.48
Pioneer Natural Resources	1999	0.245915	26.6	1.9468	9.42
Pioneer Natural Resources	2000	0.268055	26.7	0.8148	9.55
Pioneer Natural Resources	2001	0.235061	24.8	0.7879	9.55
Pioneer Natural Resources	2002	0.148575	17.5	0.5636	9.67
Pioneer Natural Resources	2003	0.260714	15.8	0.4084	9.73
Pioneer Natural Resources	2004	0.276694	9.5	0.4693	9.87
Pioneer Natural Resources	2005	0.17885	12.9	0.3122	9.94
Pioneer Natural Resources	2006	0.224807	19	0.3105	9.8

Pioneer Natural Resources	2007	0.193107	20	0.4792	9.93
SM ENERGY COMPANY	1994	0.125041	.	0.1001	8.4
SM ENERGY COMPANY	1995	0.168997	.	0.2638	8.36
SM ENERGY COMPANY	1996	0.117695	10.7	0.0585	8.68
SM ENERGY COMPANY	1997	0.108614	10.2	0.2621	8.8
SM ENERGY COMPANY	1998	0.178381	9.6	0.4847	8.81
SM ENERGY COMPANY	1999	0.195035	7.9	0.1531	8.88
SM ENERGY COMPANY	2000	0.294185	5.7	0.0835	9.11
SM ENERGY COMPANY	2001	0.271292	7.7	0.4124	9.16
SM ENERGY COMPANY	2002	0.288711	11.1	0.4912	9.12
SM ENERGY COMPANY	2003	0.340827	7.5	0.3301	9.17
SM ENERGY COMPANY	2004	0.322888	10.7	0.4007	9.23
SM ENERGY COMPANY	2005	0.353578	12.2	0.4552	9.26
SM ENERGY COMPANY	2006	0.387593	6.4	0.8188	9.25
SM ENERGY COMPANY	2007	0.442751	8.9	0.3073	9.23
STONE ENERGY CORPORATION	1994	0.163615	6.2	0.8588	8.08
STONE ENERGY CORPORATION	1995	0.126068	10.3	0.1915	8.25
STONE ENERGY CORPORATION	1996	0.092673	11.27	0.2536	8.75
STONE ENERGY CORPORATION	1997	0.147087	10.8	0.3545	8.67
STONE ENERGY CORPORATION	1998	0.209813	10.1	2.174	8.58
STONE ENERGY CORPORATION	1999	0.227568	11.1	0.9983	8.68
STONE ENERGY CORPORATION	2000	0.178513	8.9	0.1455	9.03
STONE ENERGY CORPORATION	2001	0.237035	8.9	0.5092	8.88
STONE ENERGY CORPORATION	2002	0.240582	8	1.2328	8.77
STONE ENERGY CORPORATION	2003	0.262695	9.9	0.7347	8.9
STONE ENERGY CORPORATION	2004	0.266077	12.7	0.4398	9.07
STONE ENERGY CORPORATION	2005	0.255621	12.7	0.2677	9.22
STONE ENERGY CORPORATION	2006	0.350986	11	0.2862	9.23
STONE ENERGY CORPORATION	2007	0.362908	7.8	0.4418	9.28
SWIFT ENERGY COMPANY	1996	0.217278	5.9	0.20005508	8.42
SWIFT ENERGY COMPANY	1997	0.186214	5.9	0.05882414	8.61
SWIFT ENERGY COMPANY	1998	0.31755	6	0.09538749	8.35
SWIFT ENERGY COMPANY	1999	0.202099	.	0.03766075	8.55
SWIFT ENERGY COMPANY	2000	0.193519	.	0.0231	8.99
SWIFT ENERGY COMPANY	2001	0.312653	5.6	0.1088	8.81
SWIFT ENERGY COMPANY	2002	0.228594	10.8	0.1624	8.91
SWIFT ENERGY COMPANY	2003	0.398947	5.7	0.1375	8.96
SWIFT ENERGY COMPANY	2004	0.311829	6	0.1151	9.12
SWIFT ENERGY COMPANY	2005	0.334494	6.9	0.0478	9.34
SWIFT ENERGY COMPANY	2006	0.297407	6.2	0.2164	9.39
SWIFT ENERGY COMPANY	2007	0.30339	10.4	0.2354	9.48
XTO ENERGY	1996	0.198135	13.1	0.7401	8.87
XTO ENERGY	1997	0.154908	14.4	0.8218	9.08
XTO ENERGY	1998	0.189483	13	2.7603	9.1
XTO ENERGY	1999	0.227408	10.6	2.2368	9.16

XTO ENERGY	2000	0.199853	9.9	0.3573	9.47
XTO ENERGY	2001	0.273959	6.6	0.3952	9.48
XTO ENERGY	2002	0.187201	7.23	0.3565	9.63
XTO ENERGY	2003	0.179273	10.38	0.2361	9.82
XTO ENERGY	2004	0.171073	5.49	0.2217	10.05
XTO ENERGY	2005	0.181048	6.29	0.1946	10.28
XTO ENERGY	2006	0.216553	6.22	0.1996	10.32
XTO ENERGY	2007	0.17342	5.33	0.2536	10.49
Berry Petroleum Company	1994	0.188214	9.8	0	8.32
Berry Petroleum Company	1995	0.204234	9.4	0	8.35
Berry Petroleum Company	1996	0.152937	9	0.136	8.55
Berry Petroleum Company	1997	0.161123	9	0.0834	8.62
Berry Petroleum Company	1998	0.116768	9	0.0961	8.53
Berry Petroleum Company	1999	0.172833	9	0.1562	8.59
Berry Petroleum Company	2000	0.371542	9	0.0848	8.5
Berry Petroleum Company	2001	0.272773	9	0.0733	8.56
Berry Petroleum Company	2002	0.26385	9	0.0404	8.59
Berry Petroleum Company	2003	0.300816	9	0.1132	8.69
Berry Petroleum Company	2004	0.235141	8.8	0.0267	9.03
Berry Petroleum Company	2005	0.294083	8.6	0.0687	9.13
Berry Petroleum Company	2006	0.262175	8.6	0.311	9.23
Berry Petroleum Company	2007	0.200666	8.5	0.2328	9.39
Cabot oil and gas corporation	1993	0.192339	11.8	0.3899	8.78
Cabot oil and gas corporation	1994	0.084412	10.2	0.4583	9.2
Cabot oil and gas corporation	1995	0.196313	16.6	0.7473	8.77
Cabot oil and gas corporation	1996	0.234979	16.6	0.6338	8.81
Cabot oil and gas corporation	1997	0.256939	15.4	0.415	8.83
Cabot oil and gas corporation	1998	0.208013	15.2	0.9274	8.85
Cabot oil and gas corporation	1999	0.23362	11.2	0.7364	8.84
Cabot oil and gas corporation	2000	0.186378	12.26	0.2955	9.07
Cabot oil and gas corporation	2001	0.300862	8.44	0.5122	9.06
Cabot oil and gas corporation	2002	0.251991	10.3	0.4628	9.06
Cabot oil and gas corporation	2003	0.334105	12.5	0.2882	9.09
Cabot oil and gas corporation	2004	0.259157	12.62	0.1882	9.23
Cabot oil and gas corporation	2005	0.221184	13.6	0.1505	9.41
Cabot oil and gas corporation	2006	0.208947	15	0.0823	9.5
Cabot oil and gas corporation	2007	0.148678	15	0.0889	9.63
Callon Petroleum Company	1995	0.399482	34.63	0.0017	7.76
Callon Petroleum Company	1996	0.192523	34.72	0.2216	8.13
Callon Petroleum Company	1997	0.224188	26.41	0.4711	8.27
Callon Petroleum Company	1998	0.205214	29.3	0.823	8.24
Callon Petroleum Company	1999	0.132014	16.33	0.553	8.45
Callon Petroleum Company	2000	0.157808	14.57	0.6025	8.55
Callon Petroleum Company	2001	0.206245	16.81	2.1692	8.46
Callon Petroleum Company	2002	0.206749	14.19	5.3598	8.47

Callon Petroleum Company	2003	0.162843	14.08	2.1321	8.66
Callon Petroleum Company	2004	0.26777	10.78	0.7574	8.65
Callon Petroleum Company	2005	0.266238	8.38	0.5534	8.72
Callon Petroleum Company	2006	0.339045	8.14	0.7239	8.73
Callon Petroleum Company	2007	0.232079	9.27	1.1407	8.87
Comstock resources Inc	1994	0.213583	14.21	0.9276	7.9
Comstock resources Inc	1995	0.152336	13.46	0.9876	8.16
Comstock resources Inc	1996	0.175104	5.27	0.2557	8.59
Comstock resources Inc	1997	0.161303	6.3	0.8996	8.74
Comstock resources Inc	1998	0.263215	12.7	3.7287	8.55
Comstock resources Inc	1999	0.275633	16.3	3.4834	8.51
Comstock resources Inc	2000	0.254748	13.1	0.5504	8.82
Comstock resources Inc	2001	0.290109	13.3	1.8635	8.76
Comstock resources Inc	2002	0.223604	13.2	1.3633	8.8
Comstock resources Inc	2003	0.242832	8.3	0.4631	8.99
Comstock resources Inc	2004	0.21997	7.9	0.5129	9.08
Comstock resources Inc	2005	0.195196	7.1	0.1854	9.19
Comstock resources Inc	2006	0.278628	7.8	0.3323	9.26
Comstock resources Inc	2007	0.297942	8.1	0.4937	9.36
GOODRICH PETROLEUM CORPORATION	1995	0.12528	19.6	0.2869	7.64
GOODRICH PETROLEUM CORPORATION	1996	0.19829	23.3	0.3477	7.59
GOODRICH PETROLEUM CORPORATION	1997	0.1801	21.8	0.4158	7.8
GOODRICH PETROLEUM CORPORATION	1998	0.270123	21.1	4.2816	7.56
GOODRICH PETROLEUM CORPORATION	1999	0.277288	29.4	2.9492	7.69
GOODRICH PETROLEUM CORPORATION	2000	0.30714	20.3	0.3364	7.96
GOODRICH PETROLEUM CORPORATION	2001	0.288308	17.8	0.3259	8
GOODRICH PETROLEUM CORPORATION	2002	0.292546	32.8	0.4131	7.8
GOODRICH PETROLEUM CORPORATION	2003	0.27582	24.2	0.2109	8.06
GOODRICH PETROLEUM CORPORATION	2004	0.124358	24.6	0.0809	8.56
GOODRICH PETROLEUM CORPORATION	2005	0.053542	22.3	0.0481	8.82
GOODRICH PETROLEUM CORPORATION	2006	0.060522	19.9	0.1974	9.09
GOODRICH PETROLEUM CORPORATION	2007	0.110357	18.3	0.2736	9
MERIDIAN RESOURCES CORPORATION	1995	0.186593	8.82	0.0001	8.29
MERIDIAN RESOURCES CORPORATION	1996	0.223026	13.67	0	8.39
MERIDIAN RESOURCES	1997	0.134571	42.6	0.3353	8.63

CORPORATION					
MERIDIAN RESOURCES CORPORATION	1998	0.189907	42.5	1.6437	8.59
MERIDIAN RESOURCES CORPORATION	1999	0.321451	41.9	1.8993	8.62
MERIDIAN RESOURCES CORPORATION	2000	0.313135	14.8	0.5391	8.85
MERIDIAN RESOURCES CORPORATION	2001	0.413368	14.2	1.2317	8.63
MERIDIAN RESOURCES CORPORATION	2002	0.428328	14.1	4.5382	8.4
MERIDIAN RESOURCES CORPORATION	2003	0.264183	6	0.416	8.72
MERIDIAN RESOURCES CORPORATION	2004	0.364783	5.6	0.1586	8.74
MERIDIAN RESOURCES CORPORATION	2005	0.443111	6.3	0.2087	8.64
MERIDIAN RESOURCES CORPORATION	2006	0.535265	9.7	0.2823	8.55
MERIDIAN RESOURCES CORPORATION	2007	0.629935	10.39	0.4805	8.38
NEWFIELD EXPLORATION COMPANY	1996	0.152902	18.3	0.0657	8.99
NEWFIELD EXPLORATION COMPANY	1997	0.206157	17.9	0.1546	8.99
NEWFIELD EXPLORATION COMPANY	1998	0.186558	12.9	0.2472	9.02
NEWFIELD EXPLORATION COMPANY	1999	0.227054	11.4	0.1117	9.09
NEWFIELD EXPLORATION COMPANY	2000	0.241771	12.6	0.0662	9.33
NEWFIELD EXPLORATION COMPANY	2001	0.37268	13.4	0.2737	9.3
NEWFIELD EXPLORATION COMPANY	2002	0.24219	9.3	0.3865	9.41
NEWFIELD EXPLORATION COMPANY	2003	0.322582	5.9	0.258	9.5
NEWFIELD EXPLORATION COMPANY	2004	0.288995	7.1	0.2692	9.67
NEWFIELD EXPLORATION COMPANY	2005	0.24226	10.6	0.1362	9.86
NEWFIELD EXPLORATION COMPANY	2006	0.234565	10.8	0.1974	9.85
NEWFIELD EXPLORATION COMPANY	2007	0.222709	10.7	0.1517	9.9
Petroquest Energy	1998	0.172695	17.3	0.2455	7.27
Petroquest Energy	1999	0.198183	13.7	0.1276	7.63
Petroquest Energy	2000	0.155385	12.7	0.1141	8.16
Petroquest Energy	2001	0.266537	14.6	0.1926	8.31
Petroquest Energy	2002	0.257674	8.5	0.0506	8.27
Petroquest Energy	2003	0.283873	8	0.1948	8.23
Petroquest Energy	2004	0.325346	7.7	0.1737	8.42

Petroquest Energy	2005	0.21906	7.5	0.4041	8.74
Petroquest Energy	2006	0.241031	7.7	0.3212	8.91
Petroquest Energy	2007	0.304541	8.2	0.2149	8.92
Range Reources corporation	1995	0.175841	8.9	0.6396	8.33
Range Reources corporation	1996	0.184031	16.64	0.4624	8.57
Range Reources corporation	1997	0.156658	16.64	1.4162	8.92
Range Reources corporation	1998	0.159147	16.64	5.8861	8.93
Range Reources corporation	1999	0.25115	51.79	3.7978	8.76
Range Reources corporation	2000	0.21741	6.2	1.3547	8.9
Range Reources corporation	2001	0.386225	7.6	1.2629	8.73
Range Reources corporation	2002	0.298348	10.8	0.9537	8.76
Range Reources corporation	2003	0.321921	12.4	0.6719	8.95
Range Reources corporation	2004	0.18215	9.1	0.3734	9.36
Range Reources corporation	2005	0.160699	14.3	0.1801	9.61
Range Reources corporation	2006	0.14232	14.6	0.2749	9.69
Range Reources corporation	2007	0.097265	15	0.1498	9.95
Southwestern energy company	1993	0.134893	5.5	0.2747	8.77
Southwestern energy company	1994	0.152734	.	0.3725	8.72
Southwestern energy company	1995	0.120333	5.79	0.6694	8.72
Southwestern energy company	1996	0.133313	5.79	0.7443	8.81
Southwestern energy company	1997	0.161615	6.64	0.9369	8.79
Southwestern energy company	1998	0.182973	7.3	1.5156	8.67
Southwestern energy company	1999	0.160472	9.8	1.8391	8.67
Southwestern energy company	2000	0.162113	7.5	1.5158	8.82
Southwestern energy company	2001	0.249787	9.9	1.321	8.79
Southwestern energy company	2002	0.191309	7.1	1.1526	8.81
Southwestern energy company	2003	0.185934	5.7	0.3248	9.06
Southwestern energy company	2004	0.146237	.	0.1761	9.34
Southwestern energy company	2005	0.078128	6.87	0.0166	9.79
Southwestern energy company	2006	0.078864	8.8	0.0233	9.78
Southwestern energy company	2007	0.068588	6.68	0.1029	10.02

Chapter 4

Share ownership distribution and Extraction rate of petroleum in oil fields

4.1 Introduction

Both chapter 3 and chapter 4 aim to investigate the effect of share ownership distribution on the extraction rate of oil. In chapter 3, due to the unavailability of reserves at firm level, we take the firm value as a proxy. Nevertheless, fortunately the reserves for oil fields are available. Hence, this chapter differs from chapter 3 in that we shall show the relationship between share ownership distribution and the extraction rate of oil in oil fields, particularly when the real reserves data is given.

Existing models provide possible meaning of petroleum production decisions (e.g. Mabro et al., 1986; Pesaran, 1990; Favero, 1992). Related theoretical literature is given in section 2.2.2. However, production decisions in practice are not always made simply according to the models of optimal production. On the one hand, as Nygreen et al. (1998) suggested, accompanying political effects might make the models more reliable and applicable. On the other hand, the aggregation of the output equation may undermine the efficiency of the parameter estimates (Pesaran, 1990). Inspired by the former arguments, we consider both the role of the largest licensee for the oil field and the effect of the largest shareholder in the multinational company to which the largest licensee belongs when firm decisions are taken through shareholder voting. For the latter problem, we estimate the determinants of extraction through disaggregating the output equation by major oil fields.

Rather than modeling petroleum production, we will explore the main determinants influencing the extraction rate in oil fields especially the effects of the largest licensee's and the largest shareholder's share ownership. Firstly, the economics model is developed to theorize the relationship between share ownership and extraction rate for oil fields. Then, we conduct empirical estimation with 216 annual observations on 44 oil fields in the U.K. Continental Shelf covering the periods 1997-2001. Strong evidence is found that share ownership, regardless of the largest licensee and the largest shareholder of the multinational company, has significant and positive effect on the extraction rate of oil fields. The results suggest that the more share ownership the largest licensee (or the largest shareholder) holds, the extraction rate of the oil field is higher, which is contrary to the results generated by firm-level data in chapter 3.

This paper makes several contributions. First, we will address two important factors, i.e. the largest shareholder's share ownership and the largest licensee's share ownership, in extraction decisions and estimate their effects on extraction rate. Second, the effects of typical factors influencing non-renewable resources extraction rate, i.e. remaining reserves and pay thickness, are controlled and estimated with U.K. Continental Shelf data at disaggregated oil fields level [9]. Third, the heterogeneity across oil fields is captured by incorporating variables which account for both the geological features of each field and individual operator characteristics (i.e. the relationship-specific learning through accumulative working experience of the producer and the driller) in panel data models.

The rest of the paper proceeds as follows. Section 4.2 concentrates on reviewing the related empirical studies concerning production models and other determinants of the extraction rate of oil fields. Section 4.3 describes data and summary statistics. Section 4.4 provides estimation methods and related diagnostics tests. Section 4.5 presents empirical results and discussions. Sensitivity analysis is given in section 4.6 and the chapter concludes in section 4.8.

4.2 Literature Review - Empirical Part

There are three parts of the literature related to our study. First, our empirical estimation is on the basis of the UK Continental Shelf (UKCS) so that relevant production models of oil supply applied to UKCS by Pesaran (1990) and Favero (1992) are surveyed. Second, extraction cost is introduced as the factors included in cost function also determine the extraction rate of oil fields. Third, literature related to the producer-specific characteristics which affect the production of oil fields are introduced.

[9] Most previous studies are based on aggregated oil fields, such as Pesaran (1990) and Favero (1992). The aggregation of the output equation may undermine the efficiency of the parameter estimates (Pesaran, 1990).

4.2.1 Oil Production Modeling for UK Continental Shelf

4.2.1.1 The Pesaran (1990) model

Building on the theoretical contribution of Pindyck (1978) and Uhler (1979) and Devarajan and Fisher (1982), Pesaran (1990) developed an econometric model for the analysis of the exploration and extraction policies of 'price taking' suppliers of oil. Given the specification of the extraction cost function, $C(q_t, R_{t-1})$, he considers the cost function as below:

$$C(q_t, R_{t-1}) = \delta_0 + \delta_1 q_t + \frac{1}{2}(\delta_2 + \frac{\delta_3}{R_{t-1}})q_t^{\ 2} + \varepsilon_t q_t \tag{4.1}$$

where ε_t represents unobserved random shocks to marginal extraction cost, δ_3 concerning the effect of the pressure dynamics of petroleum reserves on marginal extraction costs is expected to have a positive sign. Favero (1992) suggested that the separation of overall cost function into its two components – operating costs and development costs – and including the rate of development in the decision variables of the firms will allow the model to capture explicitly the dependence of the production stage on the development stage.

In addition, for parameters of the cost function, the following restrictions are expected to be satisfied:

$$E_{t-1}(\frac{\partial C_t}{\partial q_t}) = \delta_1 + (\delta_2 + \delta_3 / R_{t-1})q_t > 0,$$

$$E_{t-1}(\frac{\partial^2 C_t}{\partial^2 q_t}) = \delta_2 + \delta_3 / R_{t-1} > 0.$$

These conditions ensure the convexity of the cost function and the expected marginal cost of extraction is positive. Associated (4.1) with the Euler equation (4.2),

$$E_{t-1}(\frac{\partial C_t}{\partial q_t}) = E_{t-1}(p_t - \beta p_{t+1}) + \beta E_{t-1}(\frac{\partial C_{t+1}}{\partial q_{t+1}} + \frac{\partial C_{t+1}}{\partial R_t}) \tag{4.2}$$

the output equation can be solved. The optimum or the desired rate of extraction:

$$q_t^* = [-(1-\beta)\delta_1 / \delta_2]z_{t-1} + \delta_2^{-1} z_{t-1} E_{t-1}(p_t - \beta p_{t+1}) + \beta z_{t-1} E_{t-1}(q_{t+1}) + \beta\gamma z_{t-1} E_{t-1}(h_{t+1}) \tag{4.3}$$

where $z_t = \delta_2 R_t / (\delta_2 R_t + \delta_3) = R_t / (R_t + \gamma), \quad \gamma = \delta_3 / \delta_2,$

$$h_t = (q_t / R_{t-1}) - \frac{1}{2}(q_t / R_{t+1})^2$$

According to Pesaran (1990), the relationship between the actual rate of extraction and the firm's desired rate of extraction can be characterized by the simple partial adjustment model $q_t - q_{t-1} = \phi(q_t - q_{t-1}), 0 < \phi < 1.$

Under this specification equation (3) yields:

$$q_t = (1-\phi)q_{t-1} + \alpha_0 z_{t-1} + \alpha_1 z_{t-1} E_{t-1}(p_t - \beta p_{t+1}) + \alpha_2 z_{t-1} E_{t-1}(q_{t+1}) + \alpha_3 z_{t-1} E_{t-1}(h_{t+1}) \quad (4.4)$$

As possible models of oil price expectations, rational expectations hypothesis and the adaptive expectations hypothesis are considered. Under the former hypothesis, the price expectations term in (4.3) can be replaced by:

$$E_{t-1}(p_t - \beta p_{t+1}) = p_t - \beta p_{t+1} + \xi_{tp},$$

Under the adaptive hypothesis,

$$E_{t-1}(p_t - \beta p_{t+1}) = (1-\beta)(1-\theta)\sum_{i-1}^{\infty} \theta^{i-1} p_{t-i} = (1-\beta)\tilde{p}_t(\theta),$$

Therefore, using the above results (4.4), we get the output equation under the rational expectations hypothesis:

$$q_t = (1-\phi)q_{t-1} + \alpha_0 z_{t-1} + \alpha_1 z_{t-1}(p_t - \beta p_{t+1}) + \alpha_2 z_{t-1} q_{t+1} + \alpha_3 z_{t-1} h_{t+1} + u_t \quad (4.5)$$

Under the adaptive hypothesis, we have

$$q_t = (1-\phi)q_{t-1} + \alpha_0 z_{t-1} + \alpha_1 (1-\beta) z_{t-1} \tilde{p}_t(\theta) + \alpha_2 z_{t-1} q_{t+1} + \alpha_3 z_{t-1} h_{t+1} + v_t \quad (4.6)$$

Furthermore, Pesaran (1990) has applied it to the UKCS. Estimation equations (4.5) and (4.6) take explicit account of the intertemporal nature of exploration and production decisions. The non-linear version of Sargan's (1958) generalized instrumental variable (NLIV) method is used. In addition, lagged values of q_t, h_t, p_t and R_t and their cross-productions are taken as instruments.

Using quarterly data for the UKCS oil over the period 1978-1986, the estimates of the structural parameters based on (4.5) have a priori expected signs and all are statistically significant at conventional levels. The estimate of the discount factor β, is within the admissible range and is well determined. The δ_3 confirms the existence of an inverse relationship between extraction costs and the initially available reserves. But average marginal extraction costs over the sample take an implausibly high value of over $100 and the shadow price of oil in the ground is not always positive. Sensitivity analysis reveals that one important reason for the most implausible marginal extraction costs is obtained by setting the discount rate to infinity.

However, the estimates based on equation (4.6), the supply function with adaptive formed price expectations, are very poorly determined. None of the parameters of the cost function are statistically significant. The value of 1.05 estimated for the discount factor is implausible. In line with the above results, they dropped the statistically insignificant variable z_{t-1} but added seasonal dummies. A preferred output equation is adopted:

$$q_t = -0.212(s_{1t} - s_{4t}) - 5.622(s_{2t} - s_{4t}) + 0.614(s_{3t} - s_{4t}) + 0.712 q_{t-1} + 5.552 z_{t-1} \tilde{p}_t + \hat{\upsilon}_t \tag{4.7}$$

This equation passes the diagnostic tests and fits well, and its coefficients have the correct signs. It indicates that current production depends on lagged production and price positively.

4.2.1.2 The Favero (1992) model

Producers are assumed to be risk neutral and decide on the rates of extraction q_t, q_{t+1}... and the rates of exploratory effort, x_t, x_{t+1}, by maximizing the discounted future streams of profits. In order to obtain the desired extraction and exploration function, the intertemporal optimization problem is solved.

The net profit function can be written as

$$\Pi_t = \alpha_{1t} p_t q_t - \alpha_{2t} C(q_t, R_{t-1}) - \alpha_{3t} w_t x_t \tag{4.8}$$

where

$$\alpha_{1t} = (1 - \tau_{2t})(1 - \tau_{1t} - \tau_{4t})(1 - \tau_{ct}), \quad \alpha_{2t} = [1 - \tau_{2t} - \tau_{ct}\tau_{2t}], \quad \alpha_{3t} = [1 - \tau_{2t} up_t - \tau_{ct}\tau_{2t} up_t] \tag{4.9}$$

q_t rate of extraction	x_t rate of exploratory effort
R_t level of proven reserves	w_t unit cost of exploratory effort
p_t well-head price	τ_{1t} royalty

τ_{2t} petroleum revenue tax $\quad$ up_t 1+uplift on exploration costs

τ_{4t} supplementary petroleum duty $\quad$ τ_{ct} corporation tax

Then combined with proven reserves change $R_{t+\tau} - R_{t+\tau-1} = d_{t+\tau} + e_{t+\tau} - q_{t+\tau}$ and exploratory effort constraints $X_t = X_{t-1} + x_t$ where d_t denotes the addition to proven reserves during period t-1 to t from new discoveries and e_t the revisions/extensions to previously discovered reserves, represents the level of cumulative exploratory effort at time t. Lagrange technique is adopted to obtain the Euler equations. The optimal level of output function with taxation is derived as

$$\begin{aligned} q_t^* = {} & (\delta_1/\delta_2)E_{t-1}[\frac{\beta\alpha_{2t+1}}{\alpha_{2t}} z_{t-1}] - (\delta_1/\delta_2)z_{t-1} + \delta_2^{-1} z_{t-1} E_{t-1}[(\alpha_{1t}/\alpha_{2t})p_t] \\ & - \delta_2^{-1} z_{t-1} E_{t-1}[\frac{\beta\alpha_{1t+1}}{\alpha_{2t}} p_{t+1}] \\ & + \beta z_{t-1} E_{t-1}(\frac{\alpha_{2t+1}}{\alpha_{2t}} q_{t+1}) + \beta\gamma z_{t-1} E_{t-1}(\frac{\alpha_{2t+1}}{\alpha_{2t}} h_{t+1}) \end{aligned} \tag{4.10}$$

We can see that the output depends on the ratios and let $\alpha_{1t}/\alpha_{2t} = \theta_{1t}$, $\alpha_{1t+1}/\alpha_{2t} = \theta_{2t}$ and $\alpha_{2t+1}/\alpha_{2t} = \theta_{3t}$, suggesting that the tax system has an effect on output function unless the ratios are constant over time.

Following Pesaran (1990), the relationship between the actual rate of extraction and the firm's desired rate of extraction can be characterized by the simple partial adjustment model $q_t - q_{t-1} = \phi(q_t^* - q_{t-1})$, $0 < \phi < 1$ This specification equation, combines with (4.10) and yields:

$$\begin{aligned} q_t = {} & (1-\phi)q_{t-1} + b_0 z_{t-1} E_{t-1}\theta_{3t} + b_1 z_{t-1} + b_2 z_{t-1} E_{t-1}[\theta_{1t} p_t - \beta\theta_{2t} p_{t+1}] \\ & + b_3 z_{t-1} E_{t-1}(\theta_{3t} q_{t+1}) + b_4 z_{t-1} E_{t-1}(\theta_{3t} h_{t+1}) \end{aligned}$$

where

$b_0 = \phi\beta\delta_1/\delta_2$ $\quad$ $b_1 = -\phi\delta_1/\delta_2 \le 0$

$b_2 = \phi\beta\delta_2^{-1} \ge 0$ $\quad$ $b_2 = \phi\beta \ge 0$ $\quad$ $b_4 = \phi\beta\gamma \ge 0$

As possible models of oil price expectations, the rational expectations hypothesis and the adaptive expectations hypothesis are considered. Under the former hypothesis, the price expectations term in (4.10) can be replaced by:

$$E_{t-1}(\theta_{1t} p_t) = \theta_{1t} p_t + \xi_{1t}$$

$$E_{t-1}(\theta_{2t} p_{t+1}) = \theta_{2t} p_{t+1} + \xi_{1t+1}$$

where ξ_{1t+1} satisfies the orthogonality property $E_{t-1}(\xi_{1t+1} \mid \Omega_{t-1}) = 0$

The second alternative for expectations formation is constituted by an adaptive expectation scheme for price combined with a rational expectations scheme for the tax parameters. We have

$$E_{t-1} p_t = E_{t-1} p_{t+1} = (1-v)\sum_{i=1}^{\infty} \theta^{i-1} p_{t-i} = \tilde{p}(v) \quad \text{Where} \quad 0 \le v \le 1$$

$$E_{t-1}\theta_{2t} = \theta_{2t} + \xi_{2t}$$

Under this alternative, Favero (1992) consider the possibility of a backward looking behaviour by agents in the formation of price expectations. Finally, Favero (1992) has used the two following empirical alternatives for the supply equation with the above two price expectations formula.

(i) Rational expectations model

$$q_t = (1-\phi)q_{t-1} + b_0 z_{t-1}\theta_{3t} + b_1 z_{t-1} + b_2 z_{t-1}[\theta_{1t} p_t - \beta\theta_{2t} p_{t+1}] + b_3 z_{t-1}(\theta_{3t} q_{t+1}) + b_4 z_{t-1}(\theta_{3t} h_{t+1}) + \varepsilon_{1t} \tag{4.11}$$

(ii) Mixed adaptive and rational expectations model

$$q_t = (1-\phi)q_{t-1} + b_0 z_{t-1}\theta_{3t} + b_1 z_{t-1} + b_2 z_{t-1}[\theta_{1t}\tilde{p}(v) - \beta\theta_{2t}\tilde{p}(v)] + b_3 z_{t-1}(\theta_{3t} q_{t+1}) + b_4 z_{t-1}(\theta_{3t} h_{t+1}) + \varepsilon_{2t} \tag{4.12}$$

Using the same dataset with Pesaran (1990), Favero (1992) concludes that the most satisfactory model of oil supply in UKCS supports the hypothesis with the discount factor of zero. More importantly the results do not modify the results estimated by Pesaran (1990) with the inclusion of taxation. The production of oil appears to be irrelevant to past oil supply decisions. That is the main reason why we do not consider the effect of taxation for our theoretical and econometrical models.

4.2.2 Extraction cost

In this section, we use the literature on extraction cost function to determine which factors should be included in a typical production decision for oil fields. In the theoretical literature on non-renewable resource economics, a variety of assumptions about the structure of extraction cost function have been made in line with two main factors, namely the rate of extraction and the decline in quality accompanied by the depletion of the resource.

Weitzman (1976) assumes that the unit costs of extracting a resource from a given stock depend not only on the current rate of extraction but also on cumulative extraction. Farzin (1984) and Gamponia and Mendelsohn (1985) assume that cost function is linearly homogeneous in the extraction rate and independent of quality changes that resource depletion causes. Eswaran et al. (1983) consider extraction cost as a non-linear function in terms of extraction rate and independent of quality changes. Pindyck (1978) assumes the cost function is non-linearly decreasing in the remaining reserves but linear in the extraction rate, and suggesting unit cost is independent of the extraction rate but rises with the depletion of the stock.

In contrast, Levhari and Liviatan (1977) model extraction cost as a non-linear function of both cumulative extraction and the rate of extraction. Halvorsen and Smith (1984) and Heaps (1985) allow extraction cost to be non-linear in the stock of remaining reserves and rate of extraction. The cost function is assumed to be convex which varies positively with the rate of extraction and negatively with the level of remaining reserves in Pesaran (1990) and Favero (1992).

There is the earliest formal model linking the complications of mining practice to the empirical estimates of Hotelling model by Farrow (1985). The theoretical conditions for efficient extraction from a known stock resource by a competitive mining firm are tested using proprietary data from a mining firm. Output price data and coefficient estimates from a trans-log cost system are used to compute the in situ value of the resource and the stock effect. Changes in the in situ value over time are then statistically compared with the expected price path. The results reject the hypothesis that the data are consistent with the theoretical model and the maintained hypotheses. Variations of the basic model that incorporate a time-varying discount rate, an alternative expected price series, and a constraint on the rate of output are also tested and rejected.

Following Farrow (1985), Young (1992) investigates cost specifications and their corresponding Euler equations and examines the behaviour of a panel of small Canadian copper-mining firms. Her examination takes place in two stages. In the first stage, the cost structures of the firms are considered. Starting with simple, but flexible specifications of the individual firm's cost function, a series of Lagrange Multiplier (LM) (Engle, 1982; Breusch and Pagan 1980) and Wald tests are undertaken. In this way, the suitability of altering the original cost specification can be gauged. Once a final specification has been chosen, the firms' optimal output path is examined in the context of a Hotelling model of resource-owner behaviour. In this second stage, the chosen cost function is entered into the firms' intertemporal profit-maximization problems. The first-order conditions (Euler equations) are then derived and estimated directly via the Generalized Method of Moment (GMM) procedure (Hansen and Singleton, 1982). Nevertheless, even with the preliminary specification search and the use of GMM estimation, the behaviour of the panel of fourteen Canadian copper mining firms in the data set examined do not seem to be consistent with the basic Hotelling model used.

Turning to the costs of oil fields, in order to capture the effect of declining quality in a way that does not rely on observing the physical characteristics of a deposit, Livernois and Uhler (1987) propose the specification of the extraction cost function for the Nth deposit discovered:

$$C\left[q(N,t), R'(N,t), N\right]$$

It is hypothesized that costs for the Nth deposit, at time t, depend on the extraction rate, $q(N,t)$ and the fraction of reserves remaining $R'(N,t) = \left[S(N) - X(N,t)\right] / S(N)$, where $S(N)$ is the initial deposit size and $X(N,t)$ is cumulative extraction, and a vector of exogenous physical characteristics, $G(N)$. As the cumulative number of discoveries rises, quality declines, so the condition that $C_N > 0$ is consistent with the notion that the best deposits are found first. They also assume the cost function has the properties that $C_q > 0, C_{qq} > 0, C_R < 0$, and $C_{qR} < 0$. Then a linear form of the cost function $C_t = C(q_{t,} R_t', N_i)$ is estimated and obtained strong results to support the proposed model.

Livernois and Uhler (1987) use a cross-sectional random sample of 166 oil pools in Alberta that were producing in 1976 and that were discovered in various years between and including 1950 and 1973. They estimated a linear form of the cost function and obtained strong results in support of the proposed mode. They find that extraction rate and number of oil wells have a positive effect on extraction cost. Remaining reserves is correlated with extraction cost negatively. Moreover, using a sample of 80 oil reservoirs in the province of Alberta in 1973, Livernois (1987) analyses how geological characteristics affect extraction cost in oil pools. Marginal costs including the marginal user cost of reservoir pressure are independent of the rate of oil extraction. The geographical factors of production are found to have a significant impact on marginal costs. Moreover, Livernois (1987) finds that differences in the natural factors of production result in significantly different production possibilities among deposits under simultaneous exploitation.

4.2.3 Oil production and other firm characteristics

In chapter 3, we used some firm specific factors (i.e. firm size and debt ratio) as control variables in empirical estimation. However, these variables are not available for oil fields in this chapter. Therefore, we use fixed effects and random effects models to capture the unobservable specific characteristics for oil fields which potentially influence the extraction rate of oil. According to the literature, we consider the relationship-specific learning through accumulative working experience of the producer and the driller as firm characteristics influencing the oil extraction rate for each oil field.

In macroeconomics, on-the-job learning and knowledge spillovers are widely considered as an important driving force for endogenous economic growth (Arrow, 1962; Stokey, 1988; Parente, 1994; Jovanovic and Nyarko, 1996). When two firms accumulate experience working together, relationship-specific intellectual capital is created that cannot be appropriated to pairings with other firms (Kellogg, 2011).

In oil cases, obtaining leases from the holders of that field's mineral rights, the production company aims to extract oil reserves for processing and sale. Typically, producers have more geologic information than do drillers due to their knowledge from seismic imaging and previously drilled wells. The actual drilling of wells is conducted by drilling companies which own drilling rigs and drilling crews. Although producers do not necessarily physically drill their own wells, they do design wells and write drilling procedures. Kellogg (2011) argues that the relationship-specific learning through accumulative working experience of the producer and the driller plays a role in productivity improvements.

According to Kellogg (2011), production function is

$$\log(y_{fprt}) = \log(h(E)) + \gamma_f + \delta_p + \phi_r + \theta X_{fprt} + \varepsilon_{fprt} \quad (4.13)$$

where y denotes drilling efficiency, measured as the number of days required to drill each well for producers and rigs and producer-rig pairs. $h(E)$ denotes the learning process by which experience improves the efficiency of the rig crew and the decisions the firms make regarding how to drill the well. p denotes the producer and r is rig drilling the well, f is the field in which the well is drilled. We denote the fixed effects for fields and producers as well as rigs. X_{fprt} denotes a vector of observable variables that may impact drilling productivity.

Using a data set from the U.S. onshore oil and gas drilling industry with a sample of 1354 fields and 704 producers and 1339 rigs over 1991-2005, Kellogg (2011) demonstrates that productivity of an oil production company and its drilling contractor increases in their joint experience. He shows that a drilling rig that accumulates experience with one producer improves its productivity more than twice as quickly as a rig that frequently changes contracting partners. As a consequence, producers and rigs have a strong incentive to maintain their relationships, and the data demonstrate that producers are more likely to work with rigs with which they have substantial prior experience than those with which they have worked relatively little. Moreover, the observed relationship-specific learning appears to be driven primarily by the accumulation of personal interactions between the firms' personnel, rather than by just the accumulation of field or firm-specific technical knowledge.

4.3 Data and Descriptive Statistics

4.3.1 Data collection

To examine the effect of share ownership distribution on the extraction rate of UK Continental Shelf oil fields, we gather data from various databases. Table 4.1 shows the data sources. From the historical statistics and Brown books provided by Department of Energy and Climate Change (DECC) of the UK government, we obtain the annual production and reserves for 121 offshore oil and gas fields over the period 1997-2001[10]. We restrict our focus to oil fields. Hence those fields producing gas are removed from our sample. Moreover, data on share ownership the largest licensee holds is collected from Brown books.

From the Thomson One Banker database, we also draw data on share ownership owned by the largest shareholder of the multinational company to which the largest licensee belongs. Accounting for geological factors, the reserves of initial oil in place and thickness of the oil field are mainly collected from United Kingdom Oil and Gas fields Commemorative and Millennium: volume No.20 (Gluyas and Hichens, 2003) and supplemented by United Kingdom Oil and Gas fields: 25 years commemorative volume (Abbotts, 1991).

For each field and variable, we go as far back as the data permit. We then dropped the oil fields that do not have complete records on three key variables used in our regressions, namely the extraction rate, share ownership of largest licensee and share ownership of the largest shareholders of the multinational companies. This left us

[10] On the one hand, year 2001 is the last year which is easily accessible; on the other hand, the oil price is calm and low before year 2003.

with a sample of 216 annual observations on 44 oil fields for 1997-2001. The sample has an unbalanced structure, with the number of years of observations on each firm varying between 3 and 5.

4.3.2 Measurements of variables

The dependent variable in our estimation is the annual extraction rate of oil fields, denoted as **ER**. It is measured by dividing annual production over recoverable reserves for each oil field. The recoverable reserve is defined as the oil that can be recovered from the oil reservoir, which is calculated by multiplying the amount of oil initially in place by the recovery factor.

During a licensing round companies generally working together in consortia invest for the field on offer. According to the Department of Energy and Climate Change in the U.K., one of the consortium companies (generally the company with the largest interest in a field) takes responsibility for operating the field under the control of a joint operating committee of all the licensees. To examine the impact of share ownership (**SH**) to extraction, we use the share ownership that the largest licensee holds. Meanwhile, we also consider the role of the multinational company to which the largest licensee belongs (**MSH**). For instance, for one oil field named Andrew, its largest licensee is BP Exploration Operating Company Limited. In addition, to explore the effect of the largest licensee on extraction, we would identify if its parent firm, BP plc, affects the extraction decision of the oil field. The relating multinational companies list for each oil field is given in Appendix A.

The variable of remaining reserves is treated as a controllable factor of production and denoted by **RR**. Following Livernois and Uhler (1987), it is calculated as $RR_{it} = (S_i - Y_{it}) / S_i$, where S_i is the initial reserves in place and Y_t is cumulative extraction before year t. It accounts for the factors of initial deposit and age of the oil field. Pickering (2008) uses panel data and finds a positive and highly significant relationship between extraction rates and remaining reserves wherein differences in costs and pricing behaviour are all contained within the intercept term.

Therefore, we expect that the fraction of remaining reserves is positively correlated with extraction rate.

Cost functions in which current and cumulative extraction (or equivalently for known initial stock, current extraction and remaining reserves) are the major arguments are also found in some other theoretical and empirical studies (Levhari and Leviatan, 1977; Dasgupta and Heal, 1979; Cairns, 1981; Epple ad Hansen, 1981; Stollery, 1984; Epple, 1985). In some applied papers other elements, such as input prices and geological characteristics, also appear in the cost function (Zimmerman, 1977; Slade, 1984; Farrow, 1985; Young, 1992), but current and cumulative extraction rates remain as the main arguments of interest with regard to the determination of production profiles.

The assumption of an inverse relationship between extraction costs and the size of the reserve base is of great significance in models of exploration such as in Pindyck (1978, 1980), Devarajan and Fisher (1982), and Lasserre (1985). In particular, as mentioned above, the cost structure of the Pindyck model is based upon the assumptions that extraction cost rises as reserves are depleted, and that discovery cost rises as the stock of undiscovered sites decreases as the sites remaining are lower in ‘quality’.

Moreover, the differences in exogenous physical characteristics would determine the extraction rate for oil fields. According to Livernois (1987), the production is increasing in the thickness of the pay zone of the reservoir into which the well is drilled. This physical factor is measured with net pay thickness in feet, **Z**, which is defined as the thickness of rock that can deliver hydrocarbons to the well bore at a profitable rate. It is computed by oil column multiplied by net/gross thickness ratio. The effect of pay thickness on extraction rate is expected to be positive in our estimations.

4.3.3 Descriptive statistics

The statistics summary of our sample is presented in Table 4.2. All sample data used in estimation are provided in Appendix B. Our sample consists of 44 oil fields over 1997-2001. We have a total of 305 observations for the dependent variable, i.e. annual extraction rate for North Sea oil fields. The average rate of extraction is 6%, and the range goes from 0 to 56%. The largest licensee holds 58% of share ownership on average. There are five oil fields owned by the licensee with 100% of shareholdings, namely Andrew, Cyrus, Highlander, Miller and Tartan.

The lowest maximum for shareholdings is 20%. The share ownership distribution is apparently concentrated, while the relating multinational company's share ownership distribution is dispersed with the average share ownership 7% as well as a range from 0.0014 to 0.26. The statistics show that 70% of initial reserves are remaining in oil fields on average. The minimum level of remaining reserve is 29% and the maximum proportion of remaining reserve is 100%. Net pay thickness as the geological factor which impacts the oil reserve and production has skewed data. The average thickness of rock is 537 feet and the sample value ranges from 75 feet to 2135 feet. Thereby it is transformed into a logarithm with base 10 to achieve the data normality.

Moreover, Table 4.2 also shows the paired correlation for variables estimated in our regressions. The multinational company is correlated with extraction rate of oil field positively and significantly. The physical characteristics factors, remaining reserves and net pay thickness, are related to oil extraction strongly significantly ($p<0.01$).

4.4 Methodology

4.4.1 Estimation methods

Controlling for the potential effects of geological factors, the following equation is used to estimate the effect of share ownership distribution on extraction rate of oil fields,

$$ER_{it} = \beta_0 + \beta_1 SH_{it} + \beta_2 MSH_{it} + \beta_3 RR_{it} + \beta_4 \lg Z_{it} + e_{it} \qquad (4.13)$$
$$e_{it} = u_i + v_{it}, \quad i = 1,...,N, \; t = 1,...,T$$

where ER_{it} is the extraction rate of oil field i in year t. β_0 is the intercept. SH_{it} is the percentage of shareholdings owned by the largest shareholder in the field. MSH_{it} is the percentage of shareholdings owned by the largest shareholder of the responsive multinational company for variable SH_{it}. RR_{it} is the ratio of remaining reserves over total initial oil in place. $\lg Z_{it}$ indicates the logarithm of pay thickness for oil reservoir as measurement of field size, e_{it} is the error term for firm i at time t and consist of the unobservable time-invariant field-specific effect u_i and an ordinary white noise term v_{it}. As section 4.2.3 suggested, the specific factor u_i is considered as the relationship-specific learning through accumulative working experience of the producer and the driller as firm characteristics influencing the oil extraction rate for each oil field.

Estimation is performed using panel data techniques. On the one hand, it can address the panel structure of the collected data on extraction rate of oil fields. On the other hand, the panel data models can capture both the heterogeneity across oil fields and the heterogeneity across time periods.

Our econometric analysis utilizes two specific standard panel data models: fixed-effects model and random-effects model (Hsiao, 1986). Each specific model stems from a more general model that captures differences across the various producers by incorporating an individual term for each oil field. If it is uncorrelated with the other regressors in, then a random-effects model is appropriate. The one-way random-effects model captures differences across the various producers by including a random disturbance term that remains constant over time and captures the effects of unobservable factors specific to each oil field. The two-way random effects model captures differences over time periods by additionally including a random disturbance term that is generic to all producers but captures the effects of excluded factors specific to each time period.

If the oil field-specific term is correlated with the other regressors, then a fixed effects model is appropriate. It removes any variable that does not vary within the groups. The one-way fixed effects model captures differences across oil fields by estimating a constant term for each oil field. The two-way fixed effects model captures differences over time periods by additionally estimating an individual constant term for each time period.

4.4.2 Diagnostics and robust variance estimators

This section will explore how well our data meet the assumptions of ordinary least squares regression and give the reasons why the results generated by panel data models are substantially robust. We will consider the following assumptions: homogeneity of variance, independence, model specification.

Table 4.4 shows a summary of diagnostics tests for regressions. Breusch-Pagan test statistics with 52.88 strongly rejects the null hypothesis that the variance of the residuals is constant. It suggests that the residual has a heteroskedasticity problem. Moreover, as the degree of multicollinearity increases, the regression model estimates of the coefficients become unstable and the standard errors for the coefficients can get wildly inflated. To test the multicollinearity, variance inflation factor is measured. Generally, if a variable whose VIF values are greater than 10, the variable could be considered as a linear combination of other independent variables. In our regression model, the VIF equals 1.1 suggesting there is no multicollinearity problem. In addition, the specification error is found as Ramsey reset test with statistics 4.04 at significance level below 1%, which indicates that the estimation has omitted variables. To end, we use Wooldridge test to check the autocorrelation in panel data. We reject the null hypothesis that there is no first-order autocorrelation in panel data.

In order to ensure valid statistical inference when some of the underlying regression model's assumptions are violated, we rely on panel models regressions. As stated in section 4.4.1, the fixed-effects model and random-effects model (Hsiao, 1986) are applied. Each specific model stems from a more general model that captures differences across the various producers by incorporating an individual term for each oil field. Thereby, to some extent, the specification error problem is mitigated. Finally, considereing the above problems such as panel-specific AR1 autocorrelation and panel-level heteroskedastic error term, we correct them by clustering at the panel level. It will produce consistent estimates of the standard errors.

4.5 Estimation Results and Discussions

In this section, we report and interpret estimation results with alternative estimators shown in Table 4.5. Due to the coefficients of time-specific factors showing insignificant in all estimations, only one-way fixed-effects estimator and one-way random-effects estimator are used. Model 1 shows that right-skewed share ownership distribution of licensees has a significant and positive effect on the oil extraction rate of oil fields. Moreover, the share ownership distribution of parent companies to which the largest licensee belongs also impacts the extraction rate positively at significance level of 1%. The greater the right-skewed share ownership distribution, the higher is the extraction rate for oil fields. Apart from the effect of share ownership distribution, oil extraction rate is determined by geological factors of individual fields proxied by remaining reserves and net pay thickness. The results show that the oil fields with more remaining reserves tend to extract more oil. Moreover, as we expected, higher extraction rate depends on smaller thickness of rock that can deliver hydrocarbons to the well bore.

Although the pooled OLS model generates solid results, it disregards the expected heterogeneity inherent in the panel data. To exploit the heterogeneity across individual oil fields, we turn to one-way panel data models. If appropriate, the one-way random effects model is preferred to the one-way fixed effects model as fixed effects model precludes estimation of one key time-invariant factor: net pay thickness of oil fields. Much of the subsequent analysis focuses on this factor when examining heterogeneity across oil fields.

The one-way random effects model dominates the pooled OLS model according to Breusch-Pagan Lagrange multiplier (LM) test under the null hypothesis that variances of groups are zero. We find strong evidence of significant differences across oil fields as LM statistics equals 44.56 at significance level below 1%. Moreover, according to Hausman test for random effects, we could not reject the null hypothesis that the individual specific term is uncorrelated with the regressors as the test statistics equals 2.69 and P value is 0.442. Therefore, the random effects model domains the fixed effects model.

Model 2 reports the estimation results from the one-way fixed effects model. There is a significant and positive relationship between extraction rate and the share ownership distribution of the parent company to which the largest licensee belongs. However, the share ownership of licensees and remaining reserves are found to be insignificant. Moreover, the appropriate F-test for joint significance of all the fixed effects – oil field-specific – confirms their importance at levels far below 1% (statistic equals 5.14). Thus, the one-way fixed-effects model dominates the comparable pooled OLS model.

As mentioned above, the one-way random effects model not only dominates the one-way fixed effects model but also the pooled OLS model. Therefore, we focus more on the random-effects model. Model 3 reports the estimation results from the one-way random effects model. The results for factors involving share ownership distributions of oil fields and the parent company of the largest licensee, the proportion of remaining reserves and the net pay thickness of oil fields are very similar to the pooled OLS results in sign and statistical significance. Inclusion of these oil field-specific factors increases the coefficient of the share ownership distribution controlled by parent company to which the largest licensee of oil field belongs, from 0.288 to 0.308. Moreover, the coefficient of remaining reserves also increases from 0.135 to 0.151.

Overall, we find evidence that share ownership owned by the operator (i.e. the largest shareholder of the oil field is the operator) has a positive effect on oil extraction rate at 5% significant level. The largest shareholder from the operator's multinational company shows a strong relationship with the extraction rate of the oil field at 0.1% significant level. In particular, when the multinational firm's largest shareholder increases 1 per cent of ownership, extraction rate would increase by 0.3%. In addition, geological factor, pay thickness and remaining reserves are found to be strongly correlated with extraction rate.

As for chapter 3, our study is focusing on resource firm which delegate the decision of extraction rate of oil to the median voter directly. In contrast, chapter 4 examine the extraction decision for an oil field where there are many resource firms involved in production and operation. Moreover, these oil fields with several resource firms are engaging in exploration and production of petroleum on the same plateau, UKCS. There is no doubt the model of chapter 3 does not fit chapter 4.

Our results may have some implications for policy makers or regulators. First, both the largest licensee and the largest shareholder of the multinational company to which the largest licensee belongs play an important role in extraction decisions for each oil field. Both have positive effects on the annual extraction rate. Second, annual extraction rate increases as share ownership distribution of the oil field and the largest licensee's multinational company become more right-skewed.

4.6 Sensitivity Analysis

Using OLS as the reference point, the robustness across these models has been evaluated in model 1 of Table 4.5. The results generated by OLS are consistent with our main results estimated by one-way random-effects model. Nevertheless, since this positive relationship between share ownership distribution and extraction rate challenges our previous econometric work in chapter 3, this section thoroughly tests the robustness of the results across sample selection and model specification as well as different estimation methods.

Firstly, we test whether the results are driven by outliers by excluding various groups of oil fields from the sample. Two methods are used to detect outliers and influential points: the plots of leverage against residual squared in Figure 4.1 and the partial regression plots in Figure 4.2. We found that field no.41 was a point of major concern. Then, we performed random effects estimation with the outlier and without it separately in Table 4.3. Deleting field no.41 made little change in the coefficients. For instance, the most change is of coefficient for MSH and simply dropped from 0.28 to 0.25. Therefore, oil field no.41 did not affect the regression. Thus, there is no influential point which has a large effect on regression results to remove.

It is interesting to test for non-linearities by augmenting the regressions of Table 4.5 with quadratic and cubic terms of the share ownership distribution. The relationship between inequality of share ownership distribution and extraction rate could depend on an oil field’s stage of development. We test for this by experimenting with different functional forms, such as including a squared and/or cubed term for inequality. We do not find any evidence for a significant quadratic or cubic relationship between changes in share ownership inequality and changes in extraction rate.

As a further robustness check, we enquire whether the estimation method matters. Equation (1) is re-estimated using Feasible Generalized Least Squares estimator (FGLS) and OLS with Panel-Corrected standard errors (PCSE) which are specified in section 5.5. Both panel-specific AR1 autocorrelation and panel-level heteroskedastic errors are controlled. We estimate a set of regressions where the dependent variable (pollution emission) is regressed on the core variable (share ownership distribution) and all possible combinations of other control variables. The results are presented in Table 4.6. In comparison with PCSE estimations, results using FGLS appear overconfident. This problem is explored by Beck and Katz (1995) who attribute this overconfidence to time-series cross-section data where the error process has a large number of parameters as the FGLS assume the error process is known but not estimated. This oversight causes estimates of the standard errors of the estimated coefficients to understate their true variability.

Summing up, for most regressions, the coefficients of share ownership distribution variables indicate high significance with positive sign regardless of FGLS estimator and PCSE estimator. The results are again qualitatively similar to those reported in column (3) of Table 4.5.

4.7 Conclusions

This chapter examines the influence of share ownership distribution on extraction rate differences between oil fields. Results based on data from an unbalanced panel set of 44 UKCS oil fields covering the period 1997-2001 show that there is positive relationship between the share ownership of the largest licensee and the largest shareholder of the largest licensee's multinational company and extraction rate. It suggests that an oil field with more right-skewed share ownership distribution tends to extract more oil after controlling geological characteristics such as remaining reserves and pay thickness. In particular, when the multinational firm's largest shareholder increases 1 per cent of ownership, extraction rate increases by 0.3%.

There is inconsistency between chapter 3 and chapter 4 regarding the role of share ownership distribution in extraction rate. However, these are as we expected. The main explanation attributed to the inconsistency is decision mechanism. Therefore, the most important issue for future research is that a theoretical model would be developed for chapter 4. We would capture a game between resource extracting firms (different firms on the same plateau). It will be strategic interaction between those firms and incentives to strategically delegate among shareholders.

Moreover, some limitations must be taken into consideration. For instance, the identity of the largest licensee and the largest shareholder possibly affects extraction decisions. Hence to have a better picture of how extraction rate is determined by share ownership, it would be worthwhile further examining the link between the identities of these decisive shareholders and level of extraction rate.

Figure 4.1 Influential observations and outliers

It is the leverage against residual squared plot. An observation with an extreme value on a independent variable is called a point with high leverage. Leverage is a measure of how far an independent variable deviates from its mean. An outlier is an observation with large residual. The upper left corner of the plot will be points that are high in leverage and the lower right corner will be points that are high in the absolute of residuals. The upper right portion will be those points that are both high in leverage and in the absolute of residuals. There is one point in this plot that stands out so much differently from any other point. The observation of field no.41 (Fergus oil field) is associated with the largest residual on the plot.

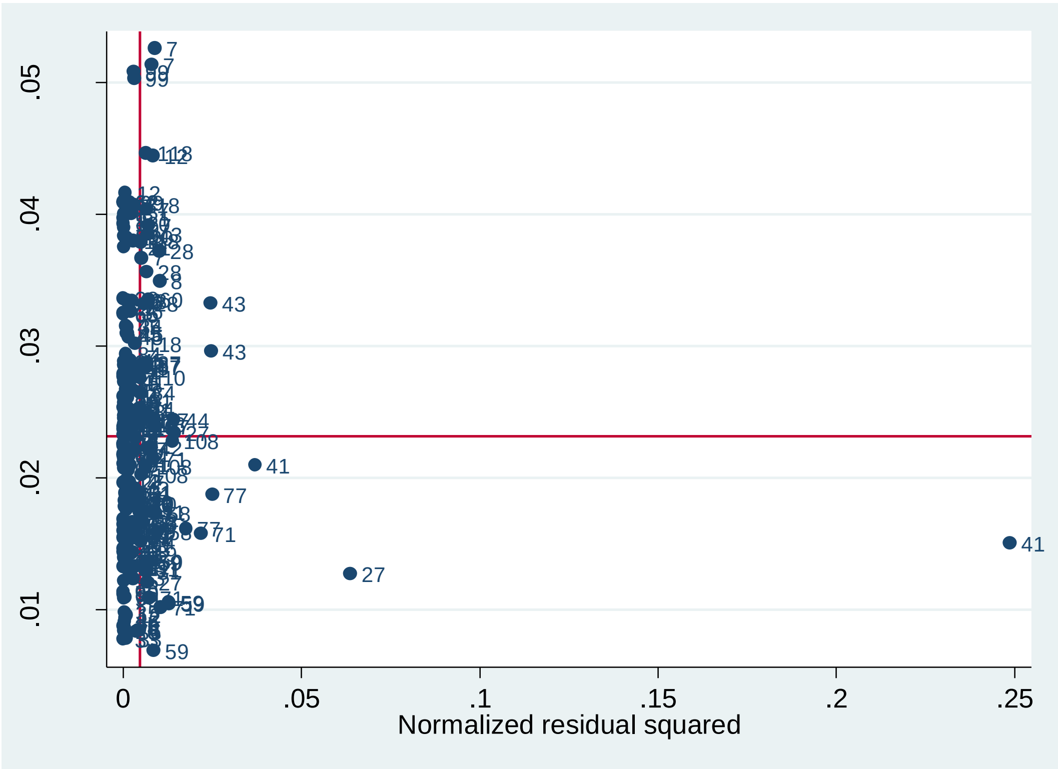

Figure 4.2 Problematic observations

It is called a partial-regression plot and is very useful in identifying influential points. These plots show that field no.41 is potentially problematic.

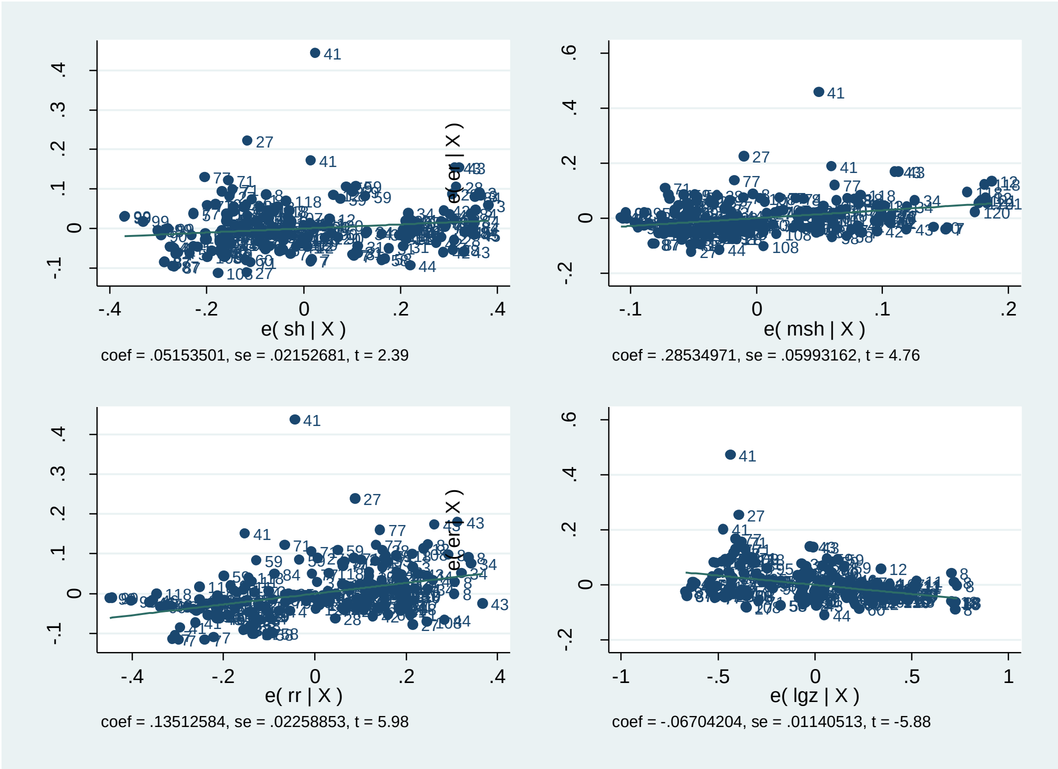

Table 4.1 Definitions and sources of the variables

Variable name	Definition
Extraction Rate (**ER**)	the ratio of annual oil production over recoverable reserves of oil field
share ownership distribution of licensees (**SH**)	the percentage of share ownership the largest licensee holds
share ownership distribution of the multinational company (**MSH**)	the percentage of share ownership controlled by the largest shareholder of the multinational company in which the largest licensee is belonged to
Remaining Reserves	the ratio(initial deposit - cumulative production)/initial deposit
Thickness of oil fields	net pay thickness in feet
	Sources
ER, SH	DECC historical statistics and Brown book https://www.og.decc.gov.uk/pprs/pprsindex.htm https://www.og.decc.gov.uk/information/index.htm
MSH	Thomson ONE Banker
RR, Z	United Kingdom Oil and Gas fields Commemorative and Millennium and 25years commemorative volume edited by Gluyas and Hichens (2003) and United Kingdom Oil and Gas fields: 25 years commemorative volume edited by Abbotts (1991).

Table 4.2 Descriptive Statistics

Variable	Mean	SD	Minimum	Maximum	Median
ER	0.061704	0.066767	0	0.556317	0.034822
SH	0.575081	0.224240	0.2	1	0.5
MSH	0.078709	0.071028	0.0014	0.2576	0.0527
RR	0.697046	0.185114	0.290815	1	0.697502
Z	537.7958	475.6533	75.9	2135.182	337.5

Correlation Matrix:

	Variable			
Variable	ER	SH	MSH	RR
SH	0.0785			
MSH	0.1261**	-0.1865**		
RR	0.3171***	0.0162	-0.1337**	
Z	-0.3413***	-0.2528***	0.0107	-0.0632

*p<0.1, **p<0.05, ***p<0.01; Significance levels are based on two-tailed tests.

Table 4.3 Regression including/deleting outlier observations

Field no.41—Fergus oil field has appeared as an outlier point in above graphs (appendix 4.1A, B). We use random effects estimator to test whether the results are driven by outliers by excluding oil field 41. The below results suggest that the outliers, field 41, did not affect the estimation. The relationship between share ownership distributions and extraction rate are positive and significant. Deleting field 41 made little change in the coefficients. The most change is of coefficient for RR and simply dropped from 0.151 to 0.128.

	Random-effects with outliers	**Random-effects without outliers**
SH	0.046048**	0.040287*
	(0.023)	(0.02208)
MSH	0.308415***	0.296462***
	(0.079)	(0.08073)
RR	0.151005***	0.128239***
	(0.03376)	(0.02894)
LGZ	-0.06727***	-0.06158***
	(0.01683)	(0.01674)
_cons	0.088391	0.091083
	(0.0595)	(0.06365)
N	216	211
Adjusted R^2: Overall	0.326	0.373

Note: robust standard errors are in the parenthesis.

Table 4.4 Diagnostics tests summary

Breusch-Pagan test statistics with 52.88 strongly rejects the null hypothesis that the variance of the residuals is constant. It suggests that the residual has heteroscedastics problem. Moreover, as the degree of multicollinearity increases, the regression model estimates of the coefficients become unstable and the standard errors for the coefficients can get wildly inflated. To test the multicollinearity, variance inflation factor is measured. Generally if a variable whose VIF values are greater than 10, it means that the variable could be considered as a linear combination of other independent variables. In our regression model, the VIF equals 1.1 suggesting there is no multicollinearity problem. In addition, the specification error is found as Ramsey reset test with statistics 4.04 at significance level below 1%, which indicates that the estimation has omitted variables. To end up, we use Wooldridge test to check the autocorrelation in panel data. We reject the null hypothesis that there is no first-order autocorrelation in panel data.

Diagnostics		
Breusch-Pagan test (*p value*)	chi2 (1)	52.88 (*0.000*)
variance inflation factor		1.1
Ramsey reset test(*p value*)	F(3, 208)	4.04 (*0.008*)
Wooldridge test for serial correlation(*p value*)	F(1, 43)	25.928 (*0.000*)

Therefore, given above problems such as panel-specific AR1 autocorrelation and panel-level heteroskedastic in the idiosyncratic error term, we correct them by clustering at the panel level. It will produce consistent estimates of the standard errors (Baltagi, 2001; Wooldridge, 2002).

Table 4.5 Estimations of oil extraction rate: Fixed and Random effects models

Dependent Variable **ER**	**Pooled OLS Model 1**	**Fixed Effects Model 2**	**Random effects Model 3**
SH	0.047***	0.008	0.046**
	(2.64)	(0.36)	(2.00)
MSH	0.288***	0.340**	0.308***
	(4.96)	(2.71)	(3.90)
RR	0.135***	0.235	0.151***
	(6.76)	(1.43)	(4.47)
LGZ	-0.068***	*N/A*	-0.067***
	(-5.53)		(-4.00)
_cons	0.102**	-0.123	0.088
	(2.41)	(-1.18)	(1.49)
rho		0.538	0.348
R-squared : overall	0.327	0.173	0.102
within		0.109	0.492
between		0.2267	0.326
No. of observations	216	216	216

t values are shown in parentheses;***** for p<0.10, ****** for p<0.05, and ******* for p<0.01; N/A indicates that a particular regressor is not applicable to the noted model; Time dummies are not included as time-specific coefficients are insignificant. In case of OLS only the values of R-squared is reported. rho is the fraction of variance due to ui. Panel-specific AR1 autocorrelation and panel-level heteroskedastic in the idiosyncratic error term are corrected by clustering at the panel-level.

Table 4.6 Sensitivity analysis: alternative estimator FGLS and PCSE

Dependent Variable **ER**	**FGLS AR1** (1)	**FGLS AR1** (2)	**FGLS AR1** (3)	**FGLS AR1** (4)	**PCSE AR1** (5)	**PCSE AR1** (6)	**PCSE AR1** (7)	**PCSE AR1** (8)
SH	0.024393***	0.039632***	0.020502**	0.041799***	0.03773	0.059652**	0.028873	0.056044**
	(0.00688)	(0.01096)	(0.00938)	(0.01132)	(0.02837)	(0.02346)	(0.02651)	(0.02551)
MSH	0.199431***	0.085001***	0.121079***	0.151949***	0.338382***	0.214831***	0.272279***	0.150215**
	(0.02837)	(0.02321)	(0.02761)	(0.00255)	(0.08585)	(0.08025)	(0.0895)	(0.07507)
RR	0.099261***	0.156953***			0.085605	0.113648***		
	(0.01321)	(0.01587)			(0.05573)	(0.04359)		
LGZ	-0.07576***		-0.09235***		-0.10038***		-0.10614***	
	(0.00813)		(0.00714)		(0.03276)		(0.02084)	
_cons	0.16696***	-0.06826***	0.29417***	0.040656***	0.231309**	-0.04443	0.322227***	0.051624***
	(0.02756)	(0.01193)	(0.02193)	(0.00674)	(0.1244)	(0.03569)	(0.05873)	(0.01755)
R-squared					0.4887	0.4237	0.4620	0.3602
N	216	271	216	276	216	271	216	276

Note: a) robust standard errors are in parenthesis. b) *, **, *** denotes significance at the 10% level, 5% level, and 1% level respectively. c) Both panel-specific AR1 autocorrelation and panel-level heteroskedastic errors are corrected.

Appendix A

Names of sampled oil fields and the multinational companies in which their largest licensee of oil fields are belonged to

Name of Oil field	year	Multinational company
ALBA	1997	chevron corp.
	1998	chevron corp.
	1999	chevron corp.
	2000	chevron corp.
	2001	chevron corp.
ANDREW	1997	BG group
	1998	BG group
	1999	BP PLC
	2000	BP PLC
	2001	BP PLC
ARBROATH	1997	Enterprise Oil inc.
	1998	Enterprise Oil inc.
	1999	Enterprise Oil inc.
	2000	Enterprise Oil inc.
	2001	Enterprise Oil inc.
ARKWRIGHT	1997	Enterprise Oil inc.
	1998	Enterprise Oil inc.
	1999	Enterprise Oil inc.
	2000	Enterprise Oil inc.
	2001	Enterprise Oil inc.
AUK	1997	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1998	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1999	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2000	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2001	Royal Dutch Petroleum co. &Exxon Mobil corp.
BALMORAL	1997	ENI S.P.A
	1998	ENI S.P.A
	1999	ENI S.P.A
	2000	ENI S.P.A
	2001	ENI S.P.A
BANFF	1997	Conocophillips
	1998	Conocophillips
	1999	Conocophillips
	2000	Conocophillips
	2001	Conocophillips
BEATRICE	1997	Talisman Energy inc.
	1998	Talisman Energy inc.
	1999	Talisman Energy inc.
	2000	Talisman Energy inc.

	2001	Talisman Energy inc.
BEINN	1997	Marathon Oil Corp.
	1998	Marathon Oil Corp.
	1999	Marathon Oil Corp.
	2000	Marathon Oil Corp.
	2001	Marathon Oil Corp.
BERYL	1997	Exxon mobil Corp.
	1998	Exxon mobil Corp.
	1999	Exxon mobil Corp.
	2000	Exxon mobil Corp.
	2001	Exxon mobil Corp.
BIRCH	1997	ENI S.P.A
	1998	ENI S.P.A
	1999	ENI S.P.A
	2000	CENTRICA PLC
	2001	CENTRICA PLC
BRENT	1997	Royal Dutch Petroleum co.--operator &Exxon Mobil corp.
	1998	Royal Dutch Petroleum co.--operator &Exxon Mobil corp.
	1999	Royal Dutch Petroleum co.--operator &Exxon Mobil corp.
	2000	Royal Dutch Petroleum co.--operator &Exxon Mobil corp.
	2001	Royal Dutch Petroleum co.--operator &Exxon Mobil corp.
BRIMMOND	1997	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1998	BP PLC
	1999	Exxon mobil Corp.
	2000	Exxon mobil Corp.
	2001	Exxon mobil Corp.
BUCHAN	1997	Talisman Energy inc.
	1998	Talisman Energy inc.
	1999	Talisman Energy inc.
	2000	Talisman Energy inc.
	2001	Talisman Energy inc.
CAPTAIN	1997	.
	1998	.
	1999	.
	2000	.
	2001	.
CHANTER	1997	Total SA
	1998	Total SA
	1999	Total SA
	2000	Talisman Energy inc.

	2001	Talisman Energy inc.
CLAYMORE	1997	ENI S.P.A & BP PLC
	1998	ENI S.P.A & BP PLC
	1999	ENI S.P.A & BP PLC
	2000	ENI S.P.A & BP PLC
	2001	ENI S.P.A & BP PLC
CORMORANT NORTH	1997	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1998	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1999	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2000	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2001	Royal Dutch Petroleum co. &Exxon Mobil corp.
CURLEW	1997	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1998	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1999	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2000	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2001	Royal Dutch Petroleum co. &Exxon Mobil corp.
CYRUS	1997	BP PLC
	1998	BP PLC
	1999	BP PLC
	2000	BP PLC
	2001	BP PLC
DEVERON	1997	BP PLC
	1998	BP PLC
	1999	BP PLC
	2000	BP PLC
	2001	BP PLC
DON	1997	BP PLC
	1998	BP PLC
	1999	BP PLC
	2000	BP PLC
	2001	BP PLC
DOUGLAS	1997	BHP Billiton
	1998	BHP Billiton
	1999	BHP Billiton
	2000	BHP Billiton
	2001	BHP Billiton
DUNBAR	1997	Total SA
	1998	Total SA
	1999	Total SA
	2000	Total SA
	2001	Total SA
DUNLIN	1997	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1998	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1999	Royal Dutch Petroleum co. &Exxon Mobil corp.

	2000	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2001	Royal Dutch Petroleum co. &Exxon Mobil corp.
EIDER	1997	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1998	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1999	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2000	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2001	Royal Dutch Petroleum co. &Exxon Mobil corp.
FERGUS	1997	Amerada Hess Ltd
	1998	Amerada Hess Ltd
	1999	Amerada Hess Ltd
	2000	Amerada Hess Ltd
	2001	Amerada Hess Ltd
FIFE	1997	Amerada Hess Ltd
	1998	Amerada Hess Ltd
	1999	Amerada Hess Ltd
	2000	Amerada Hess Ltd
	2001	Amerada Hess Ltd
FLORA	1998	Amerada Hess Ltd
	1999	Amerada Hess Ltd
	2000	Amerada Hess Ltd
	2001	Amerada Hess Ltd
FOINAVEN	1997	BP PLC
	1998	BP PLC
	1999	BP PLC
	2000	BP PLC
	2001	BP PLC
FORTIES	1997	BP PLC
	1998	BP PLC
	1999	BP PLC
	2000	BP PLC
	2001	BP PLC
FULMAR	1997	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1998	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1999	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2000	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2001	Royal Dutch Petroleum co. &Exxon Mobil corp.
HAMISH	1997	Amerada Hess Ltd
	1998	Amerada Hess Ltd
	1999	Amerada Hess Ltd
	2000	Amerada Hess Ltd
	2001	Amerada Hess Ltd
HARDING	1997	BP PLC
	1998	BP PLC
	1999	BP PLC
	2000	BP PLC

	2001	BP PLC
HEATHER {AND EXT}	1997	DNO&BG&Texaco
	1998	DNO&BG&Texaco
	1999	DNO&BG&Texaco
	2000	DNO&BG&Texaco
	2001	DNO&BG&Texaco
HIGHLANDER	1997	.
	1998	.
	1999	.
	2000	Talisman Energy inc.
	2001	Talisman Energy inc.
HUTTON NORTH WEST	1997	Royal Dutch Petroleum co.
	1998	Royal Dutch Petroleum co.
	1999	Royal Dutch Petroleum co.
	2000	Kerr-McGee North Sea (U.K.) Ltd.
	2001	Kerr-McGee North Sea (U.K.) Ltd.
IVANHOE	1997	Amerada Hess Ltd
	1998	Amerada Hess Ltd
	1999	Amerada Hess Ltd
	2000	Amerada Hess Ltd
	2001	Amerada Hess Ltd
KINGFISHER	1997	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1998	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1999	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2000	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2001	Royal Dutch Petroleum co. &Exxon Mobil corp.
LENNOX	1997	BHP Billiton
	1998	BHP Billiton
	1999	BHP Billiton
	2000	BHP Billiton
	2001	BHP Billiton
MACCULLOCH	1997	Conocophillips&ENI
	1998	Conocophillips&ENI
	1999	Conocophillips&ENI
	2000	Conocophillips&ENI
	2001	Conocophillips&ENI
MAGNUS	1997	BP PLC
	1998	BP PLC
	1999	BP PLC
	2000	BP PLC
	2001	BP PLC
MILLER	1997	BP PLC
	1998	BP PLC

	1999	BP PLC
	2000	BP PLC
	2001	BP PLC
MONTROSE	1997	Enterprise Oil inc.
	1998	Enterprise Oil inc.
	1999	Enterprise Oil inc.
	2000	Enterprise Oil inc.
	2001	Enterprise Oil inc.
MURCHISON	1997	.
	1998	.
	1999	.
	2000	.
	2001	.
NELSON	1997	Enterprise Oil inc.
	1998	Enterprise Oil inc.
	1999	Enterprise Oil inc.
	2000	Enterprise Oil inc.
	2001	Enterprise Oil inc.
NINIAN	1997	.
	1998	.
	1999	.
	2000	.
	2001	.
OSPREY	1997	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1998	Royal Dutch Petroleum co. &Exxon Mobil corp.
	1999	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2000	Royal Dutch Petroleum co. &Exxon Mobil corp.
	2001	Royal Dutch Petroleum co. &Exxon Mobil corp.
PIERCE	1997	Enterprise Oil inc.
	1998	Enterprise Oil inc.
	1999	Enterprise Oil inc.
	2000	Enterprise Oil inc.
	2001	Enterprise Oil inc.
PIPER	1997	Total SA
	1998	Total SA
	1999	Total SA
	2000	Talisman Energy inc..
	2001	Talisman Energy inc..
ROB ROY	1997	Amerada Hess Ltd
	1998	Amerada Hess Ltd
	1999	Amerada Hess Ltd
	2000	Amerada Hess Ltd
	2001	Amerada Hess Ltd
SCAPA	1997	Total SA
	1998	Total SA

	1999	Total SA
	2000	Talisman Energy inc..
	2001	Talisman Energy inc..
SCOTT	1997	Amerada Hess Ltd
	1998	Amerada Hess Ltd
	1999	Amerada Hess Ltd
	2000	Amerada Hess Ltd
	2001	Amerada Hess Ltd
SEDGWICK	1997	Marathon Oil Corp.
	1998	Marathon Oil Corp.
	1999	Marathon Oil Corp.
STATFJORD	1997	BP PLC & Conocophillips (the latter is operator)
	1998	BP PLC & Conocophillips (the latter is operator)
	1999	BP PLC & Conocophillips (the latter is operator)
	2000	BP PLC & Conocophillips (the latter is operator)
	2001	BP PLC & Conocophillips (the latter is operator)
STIRLING	1997	ENI SPA
	1998	ENI SPA
	1999	ENI SPA
	2000	ENI SPA
	2001	ENI SPA
STRATHSPEY	1997	.
	1998	.
	1999	.
	2000	.
	2001	.
TARTAN	1997	.
	1998	.
	1999	.
	2000	Talisman Energy inc.
	2001	Talisman Energy inc.
THELMA	1997	ENI SPA
	1998	ENI SPA
	1999	ENI SPA
	2000	ENI SPA
	2001	ENI SPA
THISTLE	1997	BP PLC
	1998	BP PLC
	1999	BP PLC
	2000	BP PLC
	2001	BP PLC
TIFFANY	1997	ENI SPA
	1998	ENI SPA
	1999	ENI SPA
	2000	ENI SPA

	2001	ENI SPA
TONI	1997	ENI SPA
	1998	ENI SPA
	1999	ENI SPA
	2000	ENI SPA
	2001	ENI SPA

Appendix B

Data of oil extraction rate and share ownership and geological factors for UKCS oil fields over 1997-2001

Field Name	Year	SH %	MSH %	R	Q	Q/R	S	X	RR	Z
ALBA	1997	33.17	4.78	50.72	4849.8	0.095619	400	14734.79	0.73109	.
	1998	21.17	2.92	50.72	4381.38	0.086384	400	19116.17	0.65113	.
	1999	21.17	7.38	61.4	3993.49	0.065041	400	23109.66	0.578249	.
	2000	21.17	2.81	61.4	4156.16	0.06769	400	27265.82	0.502399	.
	2001	21.17	3.35	61.4	4319.12	0.070344	400	31584.94	0.423575	.
ANDREW	1997	100	0.9	17.49	2797.68	0.159959	292	3653.78	0.908656	184.3
	1998	100	1.02	18.67	3243.62	0.173734	292	6897.4	0.827565	184.3
	1999	100	5.27	18.67	3297.62	0.176627	292	10195.02	0.745125	184.3
	2000	100	3	20	2540	0.127	292	12735.02	0.681625	184.3
	2001	62.75	3.03	20	1855.6	0.09278	292	14590.62	0.635235	184.3
ARBROATH	1997	41.03	1.33	22	1109.25	0.05042	334	11644.72	0.74549	110
	1998	41.03	1.51	22	1114.87	0.050676	334	12759.59	0.721123	110
	1999	41.02	1.38	22.61	1100.35	0.048667	334	13859.94	0.697073	110
	2000	41.02	5.18	22.57	931.22	0.041259	334	14791.16	0.67672	110
	2001	41.02	4.69	22.57	778.44	0.03449	334	15569.6	0.659706	110
ARKWRIGHT	1997	41.03	1.33	2.904	462.41	0.159232	73	527.1	0.94729	117.78
	1998	41.03	1.51	2.904	299.65	0.103185	73	826.75	0.917325	117.78
	1999	41.02	1.38	3.39	184.76	0.054501	73	1011.51	0.898849	117.78
	2000	41.02	5.18	3.39	260.56	0.076861	73	1272.07	0.872793	117.78
	2001	41.02	4.69	3.39	253.22	0.074696	73	1525.29	0.847471	117.78
AUK	1997	50	0.54	20.4	646.54	0.031693	795	14924.91	0.862954	382.5
	1998	50	0.43	21.55	783.99	0.03638	795	15708.9	0.855755	382.5
	1999	50	7.18	21.55	621.27	0.028829	795	16330.17	0.85005	382.5
	2000	50	6.11	19.19	557.9	0.029072	795	16888.07	0.844927	382.5
	2001	50	0.66	19.19	392.1	0.020433	795	17280.17	0.841327	382.5
BALMORAL	1997	62	25.76	13.33	466.94	0.035029	151.1111	12852.86	0.379093	126.15
	1998	62	25.76	14	391.68	0.027977	151.1111	13244.54	0.360172	126.15
	1999	62	18.47	14	354.14	0.025296	151.1111	13598.68	0.343064	126.15

	2000	75.29	18.47	15	275.29	0.018353	151.1111	13873.97	0.329765	126.15
	2001	75.29	18.47	15	291.53	0.019435	151.1111	14165.5	0.315681	126.15
BANFF	1997	34.5	5.54	10	278.23	0.027823	304	658.4	0.98419	2135.182
	1998	34.5	5.35	10	0	0	304	658.4	0.98419	2135.182
	1999	34.5	8.51	10.2	1101.97	0.108036	304	1760.37	0.957728	2135.182
	2000	34.5	13.59	6.7	711.44	0.106185	304	2471.81	0.940644	2135.182
	2001	34.5	6.17	6.7	833.88	0.12446	304	3305.69	0.92062	2135.182
BEATRICE	1997	65	4.86	22.26	151.37	0.0068	486.6667	19578.52	0.706322	.
	1998	65	4.83	22.26	365.4	0.016415	486.6667	19943.92	0.700841	.
	1999	75	4.44	20.83	194.05	0.009316	486.6667	20137.97	0.69793	.
	2000	75	3.87	20.83	137.32	0.006592	486.6667	20275.29	0.695871	.
	2001	75	4.31	20.83	96.83	0.004649	486.6667	20372.12	0.694418	.
BEINN	1997	38	6.84	3	286.06	0.095353	.	1389.93	.	.
	1998	38	6.88	3	213.86	0.071287	.	1603.79	.	.
	1999	38	11.2	3	115.72	0.038573	.	1719.51	.	.
	2000	38	7.79	3	29.68	0.009893	.	1749.19	.	.
	2001	38	5.04	3	47.25	0.01575	.	1796.44	.	.
BERYL	1997	45	2.8	101.6	3748.27	0.036892	1488	91816.18	0.549558	1665.15
	1998	45	2.96	128.42	2960.71	0.023055	1488	94776.89	0.535033	1665.15
	1999	45	2.94	128.42	2295.54	0.017875	1488	97072.43	0.523771	1665.15
	2000	45	4.12	128.42	1620.52	0.012619	1488	98692.95	0.515821	1665.15
	2001	45	4.07	128.42	1541.33	0.012002	1488	100234.3	0.508259	1665.15
BIRCH	1997	46.79	25.76	4.035	767.97	0.190327	75	2079.19	0.797626	786.01
	1998	46.79	25.76	4	499.78	0.124945	75	2578.97	0.74898	786.01
	1999	46.79	18.47	4	225.92	0.05648	75	2804.89	0.726991	786.01
	2000	46.79	11.09	3.02	94.03	0.031136	75	2898.92	0.717838	786.01
	2001	46.79	10.88	3.02	101.44	0.033589	75	3000.36	0.707965	786.01
BRENT	1997	50	0.54	227.2	6263.8	0.02757	3800	236741.6	0.545207	.
	1998	50	0.43	264.1	6053.65	0.022922	3800	242795.2	0.533578	.
	1999	50	7.18	264.09	4535.99	0.017176	3800	247331.2	0.524864	.
	2000	50	6.11	263.16	3537.6	0.013443	3800	250868.8	0.518068	.
	2001	50	0.66	263.16	2843.41	0.010805	3800	253712.2	0.512605	.
BRIMMOND	1997	50	2.8	0.47	60.21	0.1281	14.8	78.27	0.9613	.

						06			94	
	1998	96.14	1.13	0.47	80.32	0.170894	14.8	158.59	0.921777	.
	1999	50	2.94	0.47	48.31	0.102787	14.8	206.9	0.897948	.
	2000	50	4.12	0.47	47.65	0.101383	14.8	254.55	0.874445	.
	2001	50	4.07	0.47	31.15	0.066277	14.8	285.7	0.85908	.
BUCHAN	1997	71.11	4.86	16.65	444.72	0.02671	490.9091	14522.66	0.784043	1573.58
	1998	68.17	4.83	16.65	401.96	0.024142	490.9091	14924.62	0.778065	1573.58
	1999	71.1	4.44	20.3	344.34	0.016963	490.9091	15268.96	0.772945	1573.58
	2000	71.1	3.87	20.3	350.57	0.017269	490.9091	15619.53	0.767732	1573.58
	2001	71.1	4.31	20.3	384.51	0.018941	490.9091	16004.04	0.762014	1573.58
CAPTAIN	1997	85	.	51.94	1461.11	0.028131	1000	1461.11	0.989334	256.5
	1998	85	.	45.22	2835.97	0.062715	1000	4297.08	0.968631	256.5
	1999	85	.	46.27	2524.6	0.054562	1000	6821.68	0.950202	256.5
	2000	85	.	41.4	2458.44	0.059383	1000	9280.12	0.932255	256.5
	2001	85	.	41.4	3106.85	0.075045	1000	12386.97	0.909575	256.5
CHANTER	1997	24.33	17.06	0.56	48.5	0.086607	17	502.84	0.784075	.
	1998	24.33	16.65	0.6	15.15	0.02525	17	517.99	0.777569	.
	1999	24.33	11.66	0.74	6.75	0.009122	17	524.74	0.77467	.
	2000	23.5	3.87	0.74	8.14	0.011	17	532.88	0.771175	.
	2001	23.5	4.31	0.74	6.07	0.008203	17	538.95	0.768569	.
CLAYMORE	1997	20	25.76	78.7	2096.27	0.026636	1452.9	63419.49	0.681353	.
	1998	20	25.76	81.2	1818.28	0.022393	1452.9	65237.77	0.672217	.
	1999	20	18.47	86.16	1658.02	0.019244	1452.9	66895.79	0.663887	.
	2000	20	18.47	86.16	1564.09	0.018153	1452.9	68459.88	0.656028	.
	2001	20	18.47	86.16	1410.75	0.016374	1452.9	69870.63	0.64894	.
CORMORANT NORTH	1997	50	0.54	63.4	1477.3	0.023301	1075	45061.1	0.694004	798.75
	1998	50	0.43	62.16	1638.21	0.026355	1075	46699.31	0.682879	798.75
	1999	50	7.18	56.07	1540.84	0.027481	1075	48240.15	0.672416	798.75
	2000	50	6.11	55.07	1513.44	0.027482	1075	49753.59	0.662138	798.75
	2001	50	0.66	55.07	1468.88	0.026673	1075	51222.47	0.652164	798.75
CURLEW	1997	50	0.54	11.4	86.17	0.007559	132	86.17	0.995235	149.64
	1998	50	0.43	10.33	1437.79	0.139186	132	1523.96	0.91572	149.64
	1999	50	7.18	4.5	1508.22	0.33516	132	3032.18	0.832311	149.64

	2000	50	6.11	4.68	817.03	0.174579	132	3849.21	0.787127	149.64
	2001	50	0.66	4.68	386.04	0.082487	132	4235.25	0.765778	149.64
CYRUS	1997	100	1.22	2.6	603.28	0.232031	82	1407.64	0.874686	75.9
	1998	100	1.13	2.6	540.94	0.208054	82	1948.58	0.826529	75.9
	1999	100	5.27	2.8	402.42	0.143721	82	2351	0.790704	75.9
	2000	100	2.96	2.8	252.9	0.090321	82	2603.9	0.768189	75.9
	2001	100	3.03	2.8	180.64	0.064514	82	2784.54	0.752108	75.9
DEVERON	1997	77.5	1.22	2.12	26.03	0.012278	54	1918.59	0.740635	.
	1998	81.72	1.13	2.12	51.61	0.024344	54	1970.2	0.733658	.
	1999	81.72	5.27	2.16	40.26	0.018639	54	2010.46	0.728216	.
	2000	81.72	2.96	2.13	9.69	0.004549	54	2020.15	0.726906	.
	2001	81.72	3.03	2.13	10.91	0.005122	54	2031.06	0.725431	.
DON	1997	80.29	1.22	2.28	107.9	0.047325	151	1742.69	0.915751	250
	1998	77.5	1.13	2.33	99.73	0.042803	151	1842.42	0.910929	250
	1999	69.79	5.27	2.31	89.14	0.038589	151	1931.56	0.90662	250
	2000	69.79	2.96	1.29	69	0.053488	151	2000.56	0.903284	250
	2001	69.79	3.03	1.29	44.92	0.034822	151	2045.48	0.901113	250
DOUGLAS	1997	46.1	0.14	11.4	1604.32	0.14073	202	2372.59	0.914258	337.5
	1998	46.1	2.08	11.69	1324.02	0.113261	202	3696.61	0.86641	337.5
	1999	46.1	5.9	12.33	937.36	0.076023	202	4633.97	0.832535	337.5
	2000	46.1	8.72	13.31	778.63	0.0585	202	5412.6	0.804396	337.5
	2001	46.1	11.01	13.31	1117.73	0.083977	202	6530.33	0.764003	337.5
DUNBAR	1997	66.67	17.06	16.3	2491.26	0.152838	821	6764.25	0.939855	551.6
	1998	66.67	16.65	16.3	2100.94	0.128892	821	8865.19	0.921174	551.6
	1999	66.67	11.66	26.39	1885.58	0.071451	821	10750.77	0.904409	551.6
	2000	66.67	3.85	25.66	1627.2	0.063414	821	12377.97	0.88994	551.6
	2001	66.67	3.06	25.66	1440.13	0.056124	821	13818.1	0.877135	551.6
DUNLIN	1997	50	0.54	53.5	807.08	0.015086	825	47651.68	0.578355	705
	1998	50	0.43	51.63	642.57	0.012446	825	48294.25	0.572669	705
	1999	50	7.18	51.29	627.1	0.012227	825	48921.35	0.56712	705
	2000	50	6.11	50.56	525.22	0.010388	825	49446.57	0.562473	705
	2001	28.8	0.66	50.56	573.92	0.011351	825	50020.49	0.557394	705
EIDER	1997	50	0.54	15.2	653.9	0.0430	202.38	12376.	0.5535	.

					8	25	1	73	64	
	1998	50	0.43	15.16	616.44	0.040662	202.381	12993.17	0.531329	.
	1999	50	7.18	14.84	600.67	0.040476	202.381	13593.84	0.509662	.
	2000	50	6.11	14.5	355.72	0.024532	202.381	13949.56	0.496831	.
	2001	50	0.66	14.5	241.94	0.016686	202.381	14191.5	0.488104	.
FERGUS	1997	65	12.9	1.01	561.88	0.556317	16.3	810.96	0.636809	126
	1998	65	15.09	1.01	276.47	0.273733	16.3	1087.43	0.512991	126
	1999	65	14.95	1.59	161.09	0.101314	16.3	1248.52	0.440847	126
	2000	65	15.13	1.59	80.56	0.050667	16.3	1329.08	0.404768	126
	2001	65	14	1.59	56.74	0.035686	16.3	1385.82	0.379357	126
FIFE	1997	85	12.9	6.62	1077.23	0.162724	132	3446.71	0.809386	212.22
	1998	85	15.09	6.62	819.73	0.123826	132	4266.44	0.764053	212.22
	1999	85	14.95	6.62	361.52	0.05461	132	4627.96	0.74406	212.22
	2000	85	15.13	6.62	584.84	0.088344	132	5212.8	0.711716	212.22
	2001	85	14	6.62	449.24	0.067861	132	5662.04	0.686872	212.22
FLORA	1998	85	15.09	1.73	151.86	0.08778	69	151.86	0.983934	208.25
	1999	85	14.95	1.73	505.53	0.292214	69	657.39	0.93045	208.25
	2000	85	15.13	1.73	495.42	0.28637	69	1152.81	0.878036	208.25
	2001	85	14	1.73	278.2	0.160809	69	1431.01	0.848603	208.25
FOINAVEN	1997	80	1.22	31.2	252.21	0.008084	1097	252.21	0.998322	259.875
	1998	80	1.13	34.4	3690.99	0.107296	1097	3943.2	0.97376	259.875
	1999	80	5.27	34.4	4261.6	0.123884	1097	8204.8	0.945401	259.875
	2000	80	2.96	49.6	4588.34	0.092507	1097	12793.14	0.914868	259.875
	2001	45	3.03	49.6	4419.28	0.089098	1097	17212.42	0.88546	259.875
FORTIES	1997	98.15	1.22	336.46	4109.2	0.012213	4196	311708.8	0.457704	399.1
	1998	98.25	1.13	344.51	3997.95	0.011605	4196	315706.7	0.450749	399.1
	1999	98.94	5.27	345.29	3227.17	0.009346	4196	318933.9	0.445134	399.1
	2000	98.94	2.96	347.42	2720.3	0.00783	4196	321654.2	0.440401	399.1
	2001	98.94	3.03	347.42	2827.62	0.008139	4196	324481.8	0.435482	399.1
FULMAR	1997	45.25	0.54	74.7	547.36	0.007327	822	70840.74	0.370879	874.2
	1998	45.25	0.43	74.44	468.09	0.006288	822	71308.83	0.366722	874.2
	1999	45.25	7.18	78.94	373	0.004725	822	71681.83	0.36341	874.2
	2000	45.25	6.11	73.42	227.83	0.003103	822	71909.66	0.361386	874.2

	2001	45.25	0.66	73.42	172.45	0.002349	822	72082.11	0.359855	874.2
HAMISH	1997	43.33	12.9	0.5	16.67	0.03334	7	420.2	0.561791	212
	1998	43.33	15.09	0.5	10.44	0.02088	7	430.64	0.550904	212
	1999	43.33	14.95	0.5	8.32	0.01664	7	438.96	0.542227	212
	2000	76.56	15.13	0.5	5.98	0.01196	7	444.94	0.535991	212
	2001	76.56	14	0.5	3.2	0.0064	7	448.14	0.532654	212
HARDING	1997	70	1.22	25.33	3859.55	0.152371	322	5789.9	0.868738	412.14
	1998	70	1.13	28.33	4655.26	0.164323	322	10445.16	0.7632	412.14
	1999	70	5.27	29.57	4281.39	0.144788	322	14726.55	0.666137	412.14
	2000	70	2.96	30.03	4328.24	0.144131	322	19054.79	0.568013	412.14
	2001	70	3.03	30.03	3177.95	0.105826	322	22232.74	0.495966	412.14
HEATHER {AND EXT}	1997	31.25	.	14.2	251.49	0.017711	464	14516.42	0.771617	767.04
	1998	31.25	22.5	14.2	225.11	0.015853	464	14741.53	0.768075	767.04
	1999	31.25	14.9	18.2	204.21	0.01122	464	14945.74	0.764862	767.04
	2000	31.25	13.08	18.2	190.75	0.010481	464	15136.49	0.761861	767.04
	2001	31.25	12.72	18.2	221.81	0.012187	464	15358.3	0.758372	767.04
HIGHLANDER	1997	100	.	9.94	149.16	0.015006	149.4286	9137.62	0.553602	1264.3
	1998	100	.	9.94	187.84	0.018897	149.4286	9325.46	0.544425	1264.3
	1999	100	.	9.95	101.93	0.010244	149.4286	9427.39	0.539446	1264.3
	2000	100	3.87	9.95	159.61	0.016041	149.4286	9587	0.531648	1264.3
	2001	100	4.31	9.95	165.54	0.016637	149.4286	9752.54	0.523561	1264.3
HUTTON NORTH WEST	1997	28.46	0.54	15.9	307.92	0.019366	1000	15854.5	0.884262	1415.4
	1998	28.46	0.43	15.9	262.22	0.016492	1000	16116.72	0.882348	1415.4
	1999	28.46	7.18	16.94	294.8	0.017403	1000	16411.52	0.880196	1415.4
	2000	28.46	.	17.13	83.46	0.004872	1000	16494.98	0.879587	1415.4
	2001	28.46	.	17.13	113.2	0.006608	1000	16608.18	0.87876	1415.4
IVANHOE	1997	43.33	12.9	9.69	400.78	0.04136	100	7792.56	0.431143	913.836
	1998	43.33	15.09	9.69	281.82	0.029084	100	8074.38	0.41057	913.836
	1999	43.33	14.95	9.69	239.47	0.024713	100	8313.85	0.393089	913.836
	2000	76.56	15.13	9.69	326.77	0.033722	100	8640.62	0.369235	913.836
	2001	76.56	14	9.69	308.82	0.03187	100	8949.44	0.346691	913.836
KINGFISHER	1997	50	0.54	7.6	211.47	0.027825	104	211.47	0.985156	174.3

	1998	50	0.43	7.6	1314.71	0.172988	104	1526.18	0.892874	174.3
	1999	50	7.18	5.48	988.09	0.180308	104	2514.27	0.823518	174.3
	2000	50	6.11	4.332	803.63	0.18551	104	3317.9	0.767109	174.3
	2001	50	0.66	4.332	874.13	0.201784	104	4192.03	0.705752	174.3
LENNOX	1997	46.1	0.14	8.8	454.18	0.051611	184	559.36	0.977808	135.85
	1998	46.1	2.08	8.8	893.72	0.101559	184	1453.08	0.942351	135.85
	1999	46.1	5.9	9.82	857.49	0.087321	184	2310.57	0.908331	135.85
	2000	46.1	8.72	10.11	1375.99	0.136102	184	3686.56	0.85374	135.85
	2001	46.1	11.01	10.11	1798.06	0.17785	184	5484.62	0.782404	135.85
MACCULLOCH	1997	40	5.54	8	583.39	0.072924	200	583.39	0.978706	156
	1998	40	5.35	8	2000.65	0.250081	200	2584.04	0.905683	156
	1999	40	8.51	7.7	1754.75	0.22789	200	4338.79	0.841634	156
	2000	40	13.59	7.7	1353.58	0.17579	200	5692.37	0.792228	156
	2001	40	6.17	7.7	1086.51	0.141105	200	6778.88	0.752571	156
MAGNUS	1997	85	1.22	106.27	3090.73	0.029084	1662.5	84793.02	0.627676	912.76
	1998	85	1.13	106.27	3147.72	0.02962	1662.5	87940.74	0.613854	912.76
	1999	85	5.27	106.27	3045.73	0.02866	1662.5	90986.47	0.60048	912.76
	2000	85	2.96	121.07	2923.74	0.024149	1662.5	93910.21	0.587642	912.76
	2001	85	3.03	121.07	2213.72	0.018285	1662.5	96123.93	0.577922	912.76
MILLER	1997	100	1.22	41.11	5195.28	0.126375	586	33019.82	0.588661	288.8
	1998	100	1.13	43.33	3441.15	0.079417	586	36460.97	0.545793	288.8
	1999	100	5.27	44.67	2732.46	0.06117	586	39193.43	0.511754	288.8
	2000	100	2.96	46.67	2056.72	0.044069	586	41250.15	0.486133	288.8
	2001	100	3.03	46.67	1382.88	0.029631	586	42633.03	0.468906	288.8
MONTROSE	1997	41.03	1.33	11.35	61.5	0.005419	236	11295.66	0.6506	105
	1998	41.03	1.51	11.35	63.66	0.005609	236	11359.32	0.648631	105
	1999	41.02	1.38	12.71	54.83	0.004314	236	11414.15	0.646935	105
	2000	41.02	5.18	12.71	36.81	0.002896	236	11450.96	0.645797	105
	2001	41.02	4.69	12.71	33.76	0.002656	236	11484.72	0.644752	105
MURCHISON	1997	88.33	.	41.06	806.14	0.019633	790.6977	35185.6	0.675154	420
	1998	88.33	.	41.06	791.57	0.019278	790.6977	35977.17	0.667846	420
	1999	88.33	.	41.06	743.52	0.018108	790.6977	36720.69	0.660982	420
	2000	88.33	.	41.73	495.0	0.0118	790.69	37215.	0.6564	420

				7	64	77	76	11		
	2001	88.33	.	41.73	410.79	0.009844	790.6977	37626.55	0.652618	420
NELSON	1997	68.09	1.33	64.1	5602.96	0.08741	790	24693.22	0.771822	194.6
	1998	68.09	1.51	64.1	4695.35	0.07325	790	29388.57	0.728435	194.6
	1999	68.09	1.38	61.4	4514.5	0.073526	790	33903.07	0.686718	194.6
	2000	68.09	5.18	61.4	4088.96	0.066595	790	37992.03	0.648934	194.6
	2001	36.88	4.69	61.4	2913.47	0.047451	790	40905.5	0.622012	194.6
NINIAN	1997	63.03	.	160	2366.55	0.014791	2786.667	142566.7	0.62653	116.9
	1998	63	.	158.42	2197.42	0.013871	2786.667	144764.2	0.620773	116.9
	1999	63	.	158.63	2053.76	0.012947	2786.667	146817.9	0.615393	116.9
	2000	63	.	158.89	1722.93	0.010844	2786.667	148540.8	0.61088	116.9
	2001	44.9	.	158.89	1763.84	0.011101	2786.667	150304.7	0.606259	116.9
OSPREY	1997	50	0.54	14	1204.04	0.086003	157.8947	9146.92	0.577107	262.5
	1998	50	0.43	14	764.27	0.054591	157.8947	9911.19	0.541773	262.5
	1999	50	7.18	14.55	618.32	0.042496	157.8947	10529.51	0.513186	262.5
	2000	50	6.11	13.51	295.27	0.021856	157.8947	10824.78	0.499534	262.5
	2001	50	0.66	13.51	450.37	0.033336	157.8947	11275.15	0.478712	262.5
PIERCE	1999	40	1.38	14.392	1415.85	0.098378	387	1415.85	0.973293	.
	2000	40	5.18	14.392	2507.96	0.174261	387	3923.81	0.925985	.
	2001	42.79	4.69	14.392	1792.97	0.124581	387	5716.78	0.892164	.
PIPER	1997	24.33	17.06	138	2416.31	0.017509	1360	126568	0.320627	968
	1998	24.33	16.65	141.7	1951.43	0.013772	1360	128519.5	0.310153	968
	1999	24.33	8.15	144.66	1489.62	0.010297	1360	130009.1	0.302157	968
	2000	23.5	3	144.66	1155.79	0.00799	1360	131164.9	0.295953	968
	2001	23.5	3.06	144.66	957.31	0.006618	1360	132122.2	0.290815	968
ROB ROY	1997	43.33	12.9	14.54	570.21	0.039217	155	12729.06	0.400502	734.568
	1998	43.33	15.09	14.54	288.94	0.019872	155	13018	0.386894	734.568
	1999	43.33	14.95	14.54	271.6	0.01868	155	13289.6	0.374103	734.568
	2000	76.56	15.13	14.54	179.59	0.012351	155	13469.19	0.365645	734.568
	2001	76.56	14	14.54	184.75	0.012706	155	13653.94	0.356943	734.568
SCAPA	1997	24.33	17.06	14.9	914.73	0.061391	206	12055.11	0.572804	.
	1998	24.33	16.65	15.65	769.94	0.049197	206	12825.05	0.54552	.
	1999	24.33	8.15	16.01	638.45	0.039878	206	13463.5	0.522895	.

	2000	23.5	3.87	16.01	444.43	0.02776	206	13907.93	0.507146	.
	2001	23.5	4.31	12.4	370.07	0.029844	206	14278	0.494032	.
SCOTT	1997	43.33	12.9	63.4	5569.3	0.087844	946	30982.2	0.76092	1000
	1998	43.33	15.09	63.4	4531.35	0.071472	946	35513.55	0.725953	1000
	1999	43.33	14.95	59.41	4017.46	0.067623	946	39531.01	0.694951	1000
	2000	43.33	15.13	59.21	2770.85	0.046797	946	42301.86	0.673569	1000
	2001	43.33	14	59.21	2162.21	0.036518	946	44464.07	0.656884	1000
SEDGWICK	1997	40	6.84	2.5	51.92	0.020768	116	51.92	0.996733	162.69
	1998	40	6.88	2.6	496.62	0.191008	116	548.54	0.96548	162.69
	1999	38	8.58	8.95	514.07	0.057438	116	1062.61	0.933129	162.69
STATFJORD	1997	33.33	5.54	545	3580.53	0.00657	6348	67078.62	0.922862	1131.9
	1998	33.33	5.35	78.68	2345.66	0.029813	6348	69424.28	0.920164	1131.9
	1999	33.33	8.51	78.68	1768.08	0.022472	6348	71192.36	0.918131	1131.9
	2000	33.33	13.59	81	1187.29	0.014658	6348	72379.65	0.916766	1131.9
	2001	33.33	6.17	81	797.19	0.009842	6348	73176.84	0.915849	1131.9
STIRLING	1997	62	25.76	0.317	37.21	0.117382	44.8	202.23	0.967047	.
	1998	62	25.76	0.317	8.88	0.028013	44.8	211.11	0.9656	.
	1999	62	18.47	0.317	16.11	0.05082	44.8	227.22	0.962975	.
	2000	75.29	18.47	0.4	16.65	0.041625	44.8	243.87	0.960262	.
	2001	75.29	18.47	0.4	27.95	0.069875	44.8	271.82	0.955708	.
STRATHSPEY	1997	67	.	11.2	1330.87	0.118828	101	2830.23	0.795439	220.8
	1998	67	.	10.23	1006.06	0.098344	101	3836.29	0.722724	220.8
	1999	67	.	10.23	643.49	0.062902	101	4479.78	0.676214	220.8
	2000	67	.	10.54	413.85	0.039265	101	4893.63	0.646302	220.8
	2001	67	.	10.54	352.31	0.033426	101	5245.94	0.620838	220.8
TARTAN	1997	100	.	13.8	333.43	0.024162	830.303	12658.7	0.888705	.
	1998	100	.	14	331.86	0.023704	830.303	12990.56	0.885787	.
	1999	100	.	14	272.02	0.01943	830.303	13262.58	0.883396	.
	2000	100	3.87	14	239.92	0.017137	830.303	13502.5	0.881286	.
	2001	100	4.31	14	176.91	0.012636	830.303	13679.41	0.879731	.
THELMA	1997	47.48	25.76	5.79	1309.19	0.226112	52	1474.36	0.793023	164.32
	1998	47.48	25.76	5.79	1051.49	0.181604	52	2525.85	0.64541	164.32
	1999	47.48	18.47	5.79	905.3	0.1563	52	3431.1	0.5183	164.32

						56		5	19	
	2000	47.48	18.47	5.8	772.8	0.133241	52	4203.95	0.40983	164.32
	2001	47.48	18.47	5.8	669.08	0.115359	52	4873.03	0.315902	164.32
THISTLE	1997	81.72	1.22	54.42	429.67	0.007895	824	51174.04	0.546638	493.2
	1998	81.72	1.13	54.42	362.87	0.006668	824	51536.91	0.543423	493.2
	1999	81.72	5.27	54.37	305.15	0.005612	824	51842.06	0.54072	493.2
	2000	81.72	2.96	54.52	287.65	0.005276	824	52129.71	0.538171	493.2
	2001	81.72	3.03	54.52	191.18	0.003507	824	52320.89	0.536478	493.2
TIFFANY	1997	47.48	25.76	12.2	1204.79	0.098753	156	6720.8	0.685501	812
	1998	47.48	25.76	12.2	762.14	0.06247	156	7482.94	0.649837	812
	1999	47.48	18.47	10.3	425.04	0.041266	156	7907.98	0.629947	812
	2000	47.48	18.47	8.1	275.29	0.033986	156	8183.27	0.617065	812
	2001	47.48	18.47	8.1	189.57	0.023404	156	8372.84	0.608194	812
TONI	1997	47.48	25.76	5.3	683.6	0.128981	121	3690.16	0.777371	411.95
	1998	47.48	25.76	6	794.17	0.132362	121	4484.33	0.729458	411.95
	1999	47.48	18.47	6	655.01	0.109168	121	5139.34	0.689941	411.95
	2000	47.48	18.47	6.4	467.44	0.073038	121	5606.78	0.66174	411.95
	2001	47.48	18.47	6.4	383.38	0.059903	121	5990.16	0.63861	411.95

Chapter 5

Pollution emissions and Share Ownership Distribution

5.1 Introduction

Pollution is an inevitable by-product of negative externality of the firm production process, particularly when using non-renewable resources such as petroleum refining, and metal mining. In terms of pollution decisions, most models assume that firms maximize profits. According to the justification for profit maximisation-Fisher Separation theorem (see Milne 1974, 1981), profit or net market value can be derived from the shareholders if there are no externalities, the firm is a price-taker and financial markets are complete.

In the presence of incomplete market, however, Fisher Separation theorem breaks down in two ways. Firstly, no shareholders will wish to maximize profits. On the one hand, these pollutants enter positively into the profit function of the firm. For instance, less pollution control equipment means greater profits. On the other hand, pollution enters negatively into shareholders' utility function. Therefore, shareholders will not only be concerned about the effect of firm's decisions on their wealth but also care about the pollution effects on their utility. Secondly, the definition of profit maximization is dubious because of the price normalization problem (Gabszewicz and Vial, 1972). Different real outputs would be obtained under a different price system. Moreover, if the firm changes its production plan, shareholders' old budget set will not be taken into account. Consequently, shareholders could not reach unanimity for firm objectives.

As argued above, when a firm has market power, shareholders may not agree on the objectives the firm should undertake. To reconcile or aggregate shareholder interests, Hart and Moore (1996) and Yalçin and Renström (2003) propose shareholder voting as the solution and assume that production decisions are made by a majority of shareholders. In terms of the role of share ownership distribution in pollution decisions in particular, Roemer (1993) has analyzed an economy where individuals differ in share ownership of a firm. The individuals, depending on their share endowments, would prefer different levels of production (and thereby of the externality) by the firm. The firm's decision is taken through a majority vote. The conclusion is that the more unequal the distribution of shares induces greater externality. Similar conclusions to Roemer’s are reached by related studies such as Renström and Roszbach (1998) and Persson and Tabellini (1994).

Different from Roemer (1993), we construct a duopoly model which can capture strategic interaction among firms. It adds an incentive of strategically delegating to a CEO with different preferences, in order to affect the equilibrium of the game between the firms. We demonstrate that in a Nash equilibrium, the larger the share of the decision maker of firm 1, the larger firm 1 production and pollution, and the smaller the production and pollution of firm 2. Furthermore, if the revenue elasticity is smaller than unity, then the pollution intensity is smaller as the share of the decision maker is larger.

Moreover, to test our theoretical hypothesis, we use a firm level panel data set from the Toxicity Release Inventory of the U.S. Environmental Protection Agency (EPA) covering the period 1997-2005. Firms from three industries are included: metal mining, petroleum refining and related industry, and primary metal (SIC-codes 10, 29, 33 respectively). More importantly, we improve the measurement of pollution emissions at firm level which accounts for weighted Human Toxicity Potential (HTP) pollution value and deflated value of firm sales. Feasible Generalized Least Squares fit panel data technique is applied.

After controlling for the effects of observable firm characteristics on pollution emissions, we find that pollution decreases with right-skewed share ownership distribution, suggesting that the more share ownership is controlled by the largest shareholders, the less pollution level will be chosen. This is counter to Roemer’s argument that if the median shareholder owns a larger-than-per-capita share for the locality, the economic democratization will lower his/her share and the pollution will be reduced.

The rest of paper is organised as follows. Section 5.2 presents related empirical literature. In section 5.3, we formulate our theoretical model. We use the model to derive the role of share ownership distribution in pollution and spell out its empirical implications. In section 5.4 and section 5.5, we describe the data and methodology respectively. Section 5.6 provides our empirical results and discussion. Sensitivity analysis is given in section 5.7 and section 5.8 concludes.

5.2 Literature Review-Empirical Part

The empirical equation developed in this paper mainly relies on three streams of empirical literature. First, given pollution might be endogenous, i.e. pollution could affect profitability, we consider the related literature in terms of the relationship between environmental performance and firm performance. Second, empirical studies concern the effect of ownership structure on environmental practices of firms with respect to powerful parties' preferences, for example, managers, board members and block holders. Third, empirical evidence shows that firm characteristics may affect a firm's pollution level like regulation stringency and financial factors. A summary of all the relevant empirical studies is given in Table 5.1.

5.2.1 Relationship between environmental performance and firm performance

A growing body of empirical study focuses on addressing the relationship between environmental performance and financial performance. It is argued that a firm with a better environmental profile tends to improve the energy efficiency of the firm and control cost for production and in return might obtain high market profitability (Filbeck and Gorman, 2004). However, the results are not in consensus and even conflicting due to several factors like estimation methods (see e.g. Telle, 2006), small samples (see e.g. Cormier et al., 1993) and lack of objective environmental performance criteria (see e.g. Filbeck and Gorman, 2004).

Using a panel data set consisting of 85 Norwegian plants from four industries including chemicals, basic metals, pulp and paper and other non-metallic minerals covering the period 1990-2001, Telle (2006) analyses the effect of environmental performance on economic performance by performing pooled OLS and fixed effects model and random effects model separately. Therefore, two equations are separately estimated.

For pooled OLS, the model is $ECP_{it} = a + bENP_{it} + dX_{it} + u_{it}$. For Panel data models, the equation is $ECP_{it} = a + bENP_{it} + dX_{it} + v_i + e_{it}$ .The ECP_{it} is economic performance measured by return on sales (ROS) for plant $i = 1,...,N$ in period $t = 1,...,T$ .The ENP_{it} denotes environmental performance (see calculation formula for variable NJFI in paper by (Telle, 2006)), X_{it} is a set of control variables including sub-industry's difference (JFI) and number of employees and capital and risk class dummies as well as year dummies. u_{it} is an error term. However, in the panel data models, e_{it} is an error term. v_i is included controlling for unobservable plant characteristics such as plant location or time invariant elements of plant technology, management, or employee education.

After controlling for above firm characteristics, a pooled regression shows that environmental performance affects economic performance positively. However, when the regression model accounts for unobservable plant heterogeneity by fixed effects model or random effects model, the effect is not statistically significant. It is found that estimation methodology matters for results. In addition to omitted variable bias, Telle (2006) suggests that environmental performance might be endogenous for firm performance. Therefore it is concluded that "it pays to be green" by prior studies is a premature conclusion.

Cormier and Magnan and Morard (1993) evaluate the relationship between corporate pollution indices and a firm's market valuation. The sample is from three major Canadian industries (i.e. pulp and paper; chemicals and oil refiners; steel, metals and mines) and includes 74 Canadian firms over 1986-1988. The pollution data is simply focused on wastewater discharge provided by the Environment Ministries of the provinces of Quebec and Ontario (Canada). The firm pollution index is measured as the ratio between the summation of actual pollution levels of plants by the firm and the responding pollution standard sets. Applying an accounting identity framework, the following equation is estimated:

$$\frac{MV(equity)_{it}}{BV(equity)_{it}} = \beta_0 + \beta_1 \frac{BV(NetMonetaryWorkingCapital)_{it}}{BV(equity)_{it}} + \beta_2 \frac{BV(inventories)_{it}}{BV(equity)_{it}}$$
$$+ \beta_3 \frac{BV(fixedassets)_{it}}{BV(equity)_{it}} + \beta_4 \mathrm{Pr}iceEarningRatio_{it} + \beta_5 \frac{BV(debt)_{it}}{BV(equity)_{it}}$$
$$+ \beta_6 \frac{BV(preferredStock)_{it}}{BV(equity)_{it}} + \beta_7 pollutionIndex_{it} + e_{it}$$

where MV and BV represent market value and book value. They find that a firm's pollution performance has weak and negative impacts on market valuation. This weakly supports that corporations with a good environmental record should be valued at a premium by the stock market.

In line with the well-established CAPM (Capital asset pricing model) frameworks by Sharpe (1964), Derwall et al. (2005) show that the influence of environmental screening on investment performance is the difference between the alpha on the high-ranked portfolio and the alpha on the low-ranked portfolio in the following equation.

$$R_{it} - R_{ft} = \alpha_i + \beta_{0i}(R_{mt} - R_{ft}) + \beta_{1i} SMB_t + \beta_{2i} HML_t + \beta_{3i} MOM_t + \beta_{4i} IP_{1-3t} + \varepsilon_{it}$$

where

R_{it} = return on portfolio i in month t

R_{ft} = one-month U.S. T-bill rate at t

R_{mt} =return on a value-weighted market proxy in month t

SMB_t = return difference between a small-cap and a large-cap portfolio in month t

HML_t = return difference between a value (high-BV/MV) portfolio and a growth low-BV/MV) portfolio in month t

MOM_t = return difference between a portfolio of past 12-month 'winners' and a portfolio of past 12- month 'losers' in month t

IP_{1-3t} = represents three factors (principal components) capturing industry effects.

Eco-efficiency is used to measure environmental performance for a firm, which is defined as the ratio of the value a company outputs over the waste the company generates during the production process. Using rating data from Innovest as a proxy for eco-efficiency, Derwall et al. (2005) estimate above equation and find evidence that a stock portfolio with high ranked eco-efficiency value outperformed a lower eco-efficiency over the period 1995-2003 for U.S. companies after adjusting returns for market risk, investment style and industry effects. They confirmed that the benefits of corporate social or environmental responsible investing outweigh their costs. This is consistent with the argument by Porter and Van der Linde (1995) who point out that active policies to improve environmental performance can enhance a company's input-output efficiency because of the more cost-efficient use of resources.

Filbeck and Gorman (2004) use Student's t test statistics to compare raw returns between 12 "less compliant (below-industry-average scores on the compliance index)" firms and 12 "more compliant (above-industry-average scores on the compliance index)" firms drawn from the IRRC/S&P 500 electric industry during the period 1996-1998. Return for each portfolio is calculated by using the geometric mean of the equally weighted monthly returns of each portfolio. The firm's compliance index as a benchmark for environmental performance is the total cost of the penalties divided by domestic revenues. They find a negative relationship between financial performance and environmental performance. This result is consistent with King and Lenox (2002) who use panel data analysis of U.S. manufacturing firms. Moreover, they also regress the returns on the compliance index using the following equation:

$$R_{it} = B_0 + B_1 CI_{it} + B_2 D1_{it} + B_3 D2_{it} + B_4 MVE_{it} + e_{it}$$

where R_{it} is the three-year holding period return for a company for 1997-1999; CI_{it} is the level of the average compliance index for a company during 1996-1998; $D1_{it}$ is an indicator variable =1 if the firm is ranked with an above average regulatory climate for at least two of the three years within the period 1997-1999, and 0 otherwise; $D2_{it}$ is an indicator variable =1 if the firm is ranked with an above average regulatory climate for at least two of the three years within the period 1997-1999, and 0 otherwise; MVE_{it} is the market value of equity for company i during 1999 where the market value of equity is calculated as the stock price at mid-year multiplied by the number of shares outstanding. However, the negative relationship no longer holds after controlling for regulatory climate and company size. Filbeck and Gorman (2004) attribute their unexpected results to three main reasons. First, they restrict focus to the electric utility industry which is different from most other industries in regulation rules. Second, the primary measure of environmental performance might be problematic, which is computed by total cost of the penalties divided by the domestic revenues. It is a measure of how well a company is complying with existing statutes and regulations rather than how a company is attempting to control pollution beyond the compliance. Third, the relationship between environmental and financial performance has been incorporated into prices so that there is no benefit to induce new investors to control pollution.

Konar and Cohen (2001) explore the relationship between environmental and financial performance for 321 manufacturing firms listed in the S&P500 in 1989. Tobin's q is used to measure firm performance, which is defined as

$$q = \frac{marketValue(equity + debt + preferenceStock)}{replacementValue(plant + equipment + inventory + shortTermAssets)}$$

Two environmental performance measures are applied: TRI88, the aggregate pounds of toxic chemicals emitted per dollar revenue of the firm; and LAW89, the number of environmental lawsuits pending against the firm in 1989. Finally two regression equations are estimated:

$$q - 1 = \alpha + \sum \beta X + \varepsilon \qquad \ln(q) = \alpha + \sum \beta X + \varepsilon$$

In addition to environmental performance on the right side of the equation, control variables include market share of the firm, growth in revenues, age of assets, advertising intensity, research and development intensity, age of assets, and the import penetration. They find evidence that there is a significantly negative effect of environmental performance on financial performance and confirm that a 10% reduction in emissions of toxicity results in a $34 million increase in market value for their samples.

5.2.2 Ownership structure and its impact on environmental practices

Environmental outcomes are determined by a complex interplay of individual and group preferences and the institutional situations whose preferences are aggregated into social choices (Scruggs, 1998). A large volume of empirical studies has highlighted the internal struggle among corporate actors – blockholders, CEO, the top management team and board members who often pursue their own goals (see Kroll et al., 1993; Werner et al., 2005).

Kassinis and Vafeas (2002) use primary data drawn from 209 publicly traded U.S. firms over the period 1994-1998 and investigate the determinants of likelihood that firms violate environmental laws in logit regressions. Both characteristics of firms' governance structure and stakeholder pressures are taken into account. Inside share ownership is measured by the fraction of common stock owned by officers and directors. They find that environmental violation increases as the fraction of inside ownership becomes larger. In line with the argument that concentrated ownership entrenches managers, more inside ownership is more likely to lead to socially irresponsible behaviour. They also find evidence that the likelihood of a litigation decrease with the number of directorships held by outside directors suggesting that more reputable directors may act to reduce environmental litigation. This result is similar to Konar and Cohen (2000) who shows that there is a significant and negative relationship between the ownership controlled by managers and directors and pollution emissions. Besides, Harford (1997) suggests that due to investor portfolio diversification, publicly traded firms will pollute less.

Firms will exhibit a range of responses to environmental concerns (Murrillo-Luna et al., 2008). Berrone et al. (2010) attribute this variation in responses to those who control the organisation and how much the controlling party values achieving social worthiness apart from economic gains. Therefore, using a sample of 194 U.S. firms required to report their emissions to EPA's TRI programme, Berrone et al. (2010) examine the effect of family owners for public corporations on pollution control between 1998 and 2002. They confirm that family-controlled public firms have a better environmental performance than their non-family counterparts, particularly at the local level. As for the non-family firms, stock ownership by the chief executive officer (CEO) has a negative environmental impact.

5.2.3 Firm characteristics influencing pollution emissions levels

Firm characteristics are considered as proxy for abilities and incentives to control pollution. Firm-level pollution varies depending on firm-specific factors (Konar and Cohen, 2000). King and Lenox (2002) find that the several firm-specific factors are correlated with emissions. Firm size, which is measured by a company's assets, shows a positive correlation. R&D intensity, calculated by the ratio of research and development expenses over total assets, is negatively correlated with total emissions. They also find that total emissions would be higher as financial leverage, i.e. debt ratio, increases. More importantly, King and Lenox create a measurement of regulation stringency at firm-level by weighting average of the state regulatory stringency of all the states in which a firm has facilities operating. However, contrary to their expectation, the estimation indicates positive correlation with emissions suggesting that more stringent regulation leads to more pollution.

Nelson and Tietenberg and Donihue (1993) specify an emission function in terms of firm's fuel mix, age of plants, other operating characteristics and the extent of regulation for electric utilities. They conduct panel data analysis in fixed effects model based on the sample of 44 privately owned electric utilities in the U.S. over the period 1969-1983. The results show that the increased age of plants does not have a significant impact on emissions. This is consistent with the results of Dasgupta et al. (2000), who find no evidence that plants with newer equipment have better environmental performance. Negative effect of regulation is found but not significant. Moreover, combined with age function and regulation function, simulations indicate that emissions would have increased by 34.6% on average in the absence of regulation. In addition, emissions are found to be independent of output and capacity utilization.

Wu (2009) collects primary data of U.S. facilities through surveys and address argues that the market forces (or competitive pressure), regulatory pressures and personal values and beliefs of upper management toward environmental stewardship significantly influence a firm's environmental decision. Especially, Wu finds that market forces and facility characteristics are the most influential factors impacting environmental violation, while personal environmental values and beliefs are the most significant factors affecting over-compliance. Contrary to Wu (2009), Dasgupta et al. (2000) use survey evidence from Mexico to show that the environmental management system is strongly independent of pollution control, even after controlling for simultaneity and other determinants of emissions intensity. Besides, small facilities are found to be more likely to violate environmental standards. This is consistent with previous findings that larger firms (measured either by total sales or number of employees) are more likely to reduce pollution voluntarily (Khanna et al., 2007; Arora and Cason, 1995; DeCanio and Watkins, 1998; Videras and Alberini, 2000; Dasgupta et al., 2000; Konar and Cohen, 2000).

In addition to financial factors effects, much empirical evidence is concentrated on exploring the effect of environmental regulation on pollution emissions for firms. Earnhart (2004) explores the effects of various regulatory factors containing inspections and penalties and permit conditions on wastewater discharges from large Kansas municipal wastewater treatment plants and finds that inspection- and enforcement-related deterrence strongly induces better pollution control. This evidence is supported by Eckert (2004), who examines the use of inspections and warnings to enforce environmental regulations and suggests that, even in the absence of frequent prosecutions, inspections deter future violations. Moreover, a number of empirical studies find that firms facing higher regulatory pressure are more likely to participate in voluntary environmental programmes (Konar and Cohen, 1997; Khanna and Anton, 2002; Rivera and De Leon, 2004; Potoski and Prakash, 2005; Rivera et al., 2006; Sam and Innes, 2008).

Finally, previous studies also show that pollution information disclosure could result in pollution reduction. For example, Konar and Cohen (1997) examine U.S. firm behaviour in response to a significant stock market reaction after disclosure of toxic chemical emissions levels. They identify all firms with significant negative abnormal returns upon the public announcement of their TRI emissions in 1989. They also find that the largest firms are most likely to reduce emissions subsequent to the new pollution information being made public (Konar and Cohen, 2000). Pargal and Wheeler (1996) also reach a similar conclusion. They argue that such informal regulations, i.e. information disclosure, define a shadow price or an implicit penalty for environmental pollution and it is an effective solution to reduce pollutions especially in regions where formal regulation is weak or absent.

5.3 A Duopoly Model with Shareholder Voting

We present a duopoly model which can capture strategic interaction among firms. It adds an incentive of strategically delegating to a CEO with different preferences, in order to affect the equilibrium of the game between the firms.

5.3.1 Firms

We assume that there are two non-price taking firms producing a homogenous good. The quantities produced by firms 1 and 2 are denoted *y* and $\tilde{y}$ tilde, respectively. Pollution, *x* (and $\tilde{x}$), is a by-product of production, but can be reduced/abated at a cost. We also assume that managing/monitoring production requires effort. Thus we make the cost function a function of both pollution and effort, $c=c(y,x,s)$, where *c* is increasing in *y*, decreasing in *x* (i.e. production is less costly when more pollution is created) and decreasing in *s* (i.e. when more effort is exerted, production is less costly). For simplicity we assume the cost function to be quadratic in *y* and inverse in *x* and *s*. Denoting the revenue functions *R* and $\tilde{R}$, respectively, we have the profit functions

$$\pi = R(y, \tilde{y}) - cy^2 x^{-1} s^{-1} \quad (5.1)$$

$$\tilde{\pi} = \tilde{R}(\tilde{y}, y) - \tilde{c}\tilde{y}^2 \tilde{x}^{-1} \tilde{s}^{-1} \quad (5.2)$$

We denote the partial derivatives of R by subscripts (e.g. $R_1 \equiv \partial R(y,\tilde{y})/\partial y$, etc). We shall assume that marginal revenue is positive, i.e. $R_1>0$, that $R_{11}<0$ (which turns out to be necessary and sufficient for the objective function to be concave), and that R_{21} is non-positive (i.e. y and $\tilde{y}$ are strategic substitutes). We shall also assume $R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12} > 0$, (which holds for plausible demand functions). [11]

5.3.2 Share ownership

Individuals differ in their share ownership, $\theta \in [\underline{\theta},\bar{\theta}]$. For simplicity we assume that there is no cross ownership in the sense that if an individuals holds shares in firm one, the individual does not hold shares in firm 2 (this could be relaxed without altering the fundamental incentives present when choosing production plans and voting on representatives). Shares are distributed according to $F(\theta)$, which density function is denoted $f(\theta)$. To focus on the role of the distribution, we assume that no single individual owns half of the shares or more, i.e. $\bar{\theta} < 1/2$. Voting rights are proportional to share ownership in the sense that one share equals one vote (for simplicity we do not introduce preferential shares).

In each firm, the production, pollution, and effort decisions are taken by a majority elected representative, CEO, chosen among and by the shareholders of the firm. We look for a Condorcet winning representative.

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[11] It is convenient to use the notation of a revenue function throughout the analysis. What we have in mind is a situation where $R = p(y+\tilde{y})y$ where p is the equilibrium price derived from a consumer's demand function. Marginal revenue, R_1, is positive if $y\partial p/\partial y+p>0$. Sufficient for this to hold is that the demand elasticity is greater than unity, or equal to unity if firm 2 is also operating ($\tilde{y}>0$). This condition also implies that marginal revenue is falling more rapidly in own production than in the other firm's production, i.e. $-R_{11}>-R_{12}$, in turn implying $R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12} > 0$.

5.3.3 Firms' decision making

The representative chooses *y,x,s* taking $\tilde{y}, \tilde{x}, \tilde{s}$ as given, so as to maximise own utility. We assume for simplicity that utility is linear in profits and quadratic in pollution and effort (and that the pollution externality is local):

$$V(\theta, y, x, s) = \theta\pi - x^2 - (\eta s)^2 \tag{5.3}$$

$$\tilde{V}(\tilde{\theta}, \tilde{y}, \tilde{x}, \tilde{s}) = \tilde{\theta}\tilde{\pi} - \tilde{x}^2 - (\eta\tilde{s})^2 \tag{5.4}$$

The first order conditions with respect to *x* and *s* for the individual in firm 1 are (corresponding ones for firm 2 with 'tilde'):

$$\frac{\partial V(\theta)}{\partial x} = \theta c y^2 x^{-2} s^{-1} - 2x = 0 \tag{5.5}$$

$$\frac{\partial V(\theta)}{\partial s} = \theta c y^2 x^{-1} s^{-2} - 2\eta^2 s = 0 \tag{5.6}$$

That the second-order conditions hold can be easily verified. Solving (5.5) and (5.6) for x and s gives:

$$x = \left(\frac{\theta c \eta}{2}\right)^{\frac{1}{4}} y^{\frac{1}{2}} \tag{5.7}$$

$$s = \frac{1}{\eta}\left(\frac{\theta c \eta}{2}\right)^{\frac{1}{4}} y^{\frac{1}{2}} \tag{5.8}$$

Substituting back into (3), and using (1), gives:

$$V(\theta, y, \tilde{y}) = \theta R(y, \tilde{y}) - 2^{\frac{3}{2}}(\theta c \eta)^{\frac{1}{2}} y \tag{5.9}$$

Similarly for firm 2:

$$\tilde{V}(\tilde{\theta}, \tilde{y}, y) = \tilde{\theta}\tilde{R}(\tilde{y}, y) - 2^{\frac{3}{2}}(\tilde{\theta}\tilde{c}\,\eta)^{\frac{1}{2}} \tilde{y} \tag{5.10}$$

The Nash equilibrium is the solution to the first-order conditions to (5.9) and (5.10):

$$\frac{\partial V(\theta, y, \tilde{y})}{\partial y} = \theta R_1(y, \tilde{y}) - 2^{\frac{3}{2}}(\theta c \eta)^{\frac{1}{2}} = 0 \tag{5.11}$$

$$\frac{\partial \tilde{V}(\theta, \tilde{y}, y)}{\partial \tilde{y}} = \tilde{\theta}\tilde{R}_1(\tilde{y}, y) - 2^{\frac{3}{2}}(\tilde{\theta}\tilde{c}\,\eta)^{\frac{1}{2}} = 0 \tag{5.12}$$

Notice that the second order conditions are fulfilled if and only if $R_{11}<0$ and $\tilde{R}_{11} < 0$.

We shall now see how the Nash equilibrium quantities vary with share ownership and the cost parameter. Solving (5.11)-(5.12) for the partial derivatives we obtain (see Appendix A):

$$\frac{\partial y}{\partial \theta} = -\frac{1}{\theta}\left(\frac{2c\eta}{\theta}\right)^{\frac{1}{2}} \frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}} > 0 \quad (5.13)$$

$$\frac{\partial y}{\partial c} = \frac{1}{c}\left(\frac{2c\eta}{\theta}\right)^{\frac{1}{2}} \frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}} < 0 \quad (5.14)$$

$$\frac{\partial \tilde{y}}{\partial \theta} = \frac{1}{\theta}\left(\frac{2c\eta}{\theta}\right)^{\frac{1}{2}} \frac{\tilde{R}_{12}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}} < 0 \quad (5.15)$$

$$\frac{\partial \tilde{y}}{\partial c} = -\frac{1}{c}\left(\frac{2c\eta}{\theta}\right)^{\frac{1}{2}} \frac{\tilde{R}_{12}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}} > 0 \quad (5.16)$$

We see that the larger the share ownership of the decisive individual, the larger the firm's output and the smaller the other firm's output. The reason is that a larger share of profits makes the owner care more about profits, relative to pollution and effort, and will produce more everything else being equal. Firm 2 knows this, and cuts back on its own production. Thus, firm 1 is crowding out firm 2. This is because y and $\tilde{y}$ are strategic substitutes, and is a known result.

Finally, using (5.7) and (5.11) we have:

$$\frac{\partial x}{\partial \theta} = x\left(\frac{1}{4\theta} + \frac{1}{2y}\frac{\partial y}{\partial \theta}\right) = \frac{x}{4\theta}\left(1 - \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) > 0 \quad (5.17)$$

$$\frac{\partial x}{\partial c} = x\left(\frac{1}{4c} + \frac{1}{2y}\frac{\partial y}{\partial c}\right) = \frac{x}{4\theta}\left(1 + \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) \quad (5.18)$$

where the latter equality follows from (5.11), and (5.13) and (5.14), respectively.

Similarly, by differentiating (5.8), we obtain:

$$\frac{\partial s}{\partial \theta} = \frac{s}{4\theta}\left(1 - \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) \quad (5.19)$$

$$\frac{\partial s}{\partial c} = \frac{s}{4\theta}\left(1 + \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) \quad (5.20)$$

Finally, we obtain the derivatives of the pollution intensity

$$\frac{\partial x/y}{\partial \theta} = \frac{x}{y}\left(\frac{1}{4\theta} - \frac{1}{2y}\frac{\partial y}{\partial \theta}\right) = \frac{x}{4\theta y}\left(1 + \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) \quad (5.21)$$

$$\frac{\partial x/y}{\partial c} = \frac{x}{y}\left(\frac{1}{4c} - \frac{1}{2y}\frac{\partial y}{\partial c}\right) = \frac{x}{4\theta y}\left(1 - \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) > 0 \qquad (5.22)$$

We now state the properties of the Nash equilibrium production, pollution, and pollution intensity:

Proposition 1
In Nash equilibrium, the larger the share of the decision maker of firm 1, the larger firm 1 production and pollution, and the smaller the production and pollution of firm 2. Furthermore, if the revenue elasticity is smaller than unity, i.e. if $-R_{11}y/R_1 < 1$, *then the pollution intensity is smaller as the share of the decision maker is larger.*
Proof: The results follow from (5.13), (5.15) and (5.17), and by substituting the inequality $-R_{11}y/R_1 < 1$ into (5.21). QED

Thus, if the revenue elasticity is smaller than unity, firms where the decision maker has a larger share of profits will appear to have cleaner production, in the sense that its pollution intensity is smaller.

5.3.4 Shareholder voting

We now turn to the choice of the shareholders, who elect the representative (CEO) of the firm. The representative then acts as in the previous section. Each shareholder has the number of votes equal to her number of shares, and we seek to find the Condorcet winner, i.e. the representative who cannot lose against any alternative candidate in a binary election. This Condorcet winner will be the individual preferred by the median in the *voting distribution* (which will not coincide with the median shareholder, because voting rights are proportional to ownership). The space of alternatives is one dimensional (the candidates differ only in one dimension: their shares of the firm), and we need only to verify that preferences over candidate identity are single peaked. [12] Shareholders in firm 2 act in the same way.

[12] See Yalçin and Renström (2003) in the context of voting over representatives among shareholders.

5.3.4.1 Preferences over candidates

We denote the production, pollution, and effort choices taken (in Nash equilibrium) by a hypothetical decision maker, with θ, as $y(\theta)$, $x(\theta)$, and $s(\theta)$, respectively. Also, the decision of firm 2 is affected by the identity of the decision maker in firm 1 (due to strategic interaction): $\tilde{y} = \tilde{y}(\theta)$. [13]

Indirect utility of a shareholder with ownership θ^i is:

$$V(\theta,\theta^i) = \theta^i \left(R(y(\theta),\tilde{y}(\theta)) - cy(\theta)^2 x(\theta)^{-1} s(\theta)^{-1} \right) - x(\theta)^2 \tag{5.23}$$

The first-order variation with respect to θ is

$$\frac{\partial V(\theta,\theta^i)}{\partial \theta} = \theta^i \left(R_2 \frac{\partial \tilde{y}(\theta)}{\partial \theta} + cy(\theta)^2 x(\theta)^{-2} s(\theta)^{-1} \frac{\partial x(\theta)}{\partial \theta} + cy(\theta)^2 x(\theta)^{-1} s(\theta)^{-2} \frac{\partial s(\theta)}{\partial \theta} \right) - 2x(\theta) \frac{\partial x(\theta)}{\partial \theta} \tag{5.24}$$

The first term (the term involving R_2) is the strategic commitment effect. R_2 is negative (revenue is falling if firm 2 increases its production, as the price is falling), and $\frac{\partial \tilde{y}(\theta)}{\partial \theta}$ is negative (as a decision maker with a larger share chooses larger production, y, for every level of $\tilde{y}$, implying that firm 2 finds it optimal to reduce its production, $\tilde{y}$). Thus, the first term is positive, implying that any shareholder tends to prefer a decision maker with larger share. The second term is the increase in profits due to pollution (note that $\frac{\partial x(\theta)}{\partial \theta} > 0$). This may or may not be outweighed by the negative effect of the pollution externality (the last term). The third term is the effect on profits by inducing more effort of the CEO (this effect is positive). Thus we can see already now that there is a tendency to delegate to a decision maker with a larger share, θ.

Using (5.5) and (5.6), the first-order variation (5.24) may be rewritten as (see Appendix A):

$$\frac{\partial V(\theta,\theta^i)}{\partial \theta} = \theta^i R_2 \frac{\partial \tilde{y}(\theta)}{\partial \theta} + \frac{\theta^i - \theta}{\theta} 2x(\theta) \frac{\partial x(\theta)}{\partial \theta} + \frac{\theta^i}{\theta} 2\eta^2 s(\theta) \frac{\partial s(\theta)}{\partial \theta} \tag{5.25}$$

We can now see that if $\theta=\theta^i$ the pollution effect term will cancel, because the individual shareholder exactly agrees with the pollution decision of the CEO. If $\theta^i <$

[13] Firm 2's pollution is also affected, but irrelevant to shareholders of firm 1 because of our assumption of local externalities.

θ, the decision maker is over-polluting and the individual shareholder would tend to prefer a decision maker with lower θ. If $\theta^i > \theta$, the individual shareholder would tend to prefer a decision maker with higher θ, to accommodate under-pollution.

Substituting for the partial derivatives of *x* and *s*, by using (5.17) and (5.19) we obtain: (see Appendix A):

$$\frac{\partial V(\theta,\theta^i)}{\partial \theta} = \theta^i R_2 \frac{\partial \tilde{y}(\theta)}{\partial \theta} + \frac{\theta^i - \theta}{\theta}\frac{x(\theta)^2}{2\theta}\left(1 - \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) + \frac{\theta^i}{\theta}\frac{\eta^2 s(\theta)^2}{2\theta}\left(1 - \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) \quad (5.26)$$

Since (5.5) and (5.6) imply $s=x/\eta$ we have

$$\frac{\partial V(\theta,\theta^i)}{\partial \theta} = \theta^i R_2 \frac{\partial \tilde{y}(\theta)}{\partial \theta} + \frac{2\theta^i - \theta}{\theta}\frac{x(\theta)^2}{2\theta}\left(1 - \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) \quad (5.27)$$

The term in parenthesis is always positive. For any $\theta < 2\theta^i$ the first-order variation is positive, implying utility is increasing in θ. This implies that the optimal θ is at least twice the level of θ^i (i.e. $\theta \geq 2\theta^i$). Thus, any individual shareholder prefers a decision maker of at least twice the share of her own. Equation (5.27) either gives an interior solution, which is the global maximum (see Appendix A), or a corner solution $\bar{\theta}$. In both cases, preferences are single peaked.

5.3.4.2 Shareholder-Voting Equilibrium

We concluded in the previous section that a shareholder prefers a decision maker of at least twice the share of her own. This in turn implies that any individual with a share $\theta^i = \bar{\theta}/2$ or greater will be at a corner solution wishing to delegate to the largest shareholder. Thus, the largest shareholder gets the vote of at least the group of shareholders holding $\bar{\theta}/2$ or more. If this group is in the majority, then the largest shareholder is the Condorcet winner. This, of course, depends on the distribution of shares. We shall derive a class of distributions sufficient for this to be the case. The class of distributions has the property that the density function does not decline too rapidly in theta (i.e. the distribution function is not too concave). Trivially, uniform distribution belongs to this class, as its distribution function is linear.

The distribution. First, the shares sum to one

$$1 = \int_{\underline{\theta}}^{\bar{\theta}} \theta f(\theta) d\theta \tag{5.28}$$

The median in the voting distribution, θ^m , is given by

$$\tfrac{1}{2} = \int_{\underline{\theta}}^{\theta^m} \theta f(\theta) d\theta \tag{5.29}$$

The decision maker with the maximum share ownership, $\bar{\theta}$, is preferred by the median in the voting distribution if $2\theta^m \geq \bar{\theta}$, i.e. if

$$\int_{\underline{\theta}}^{2\theta^m} \theta f(\theta) d\theta \geq \int_{\underline{\theta}}^{\bar{\theta}} \theta f(\theta) d\theta = 2\int_{\underline{\theta}}^{\theta^m} \theta f(\theta) d\theta \tag{5.30}$$

where the last equality follows from (5.28) and (5.29)

Let

$$\phi(n) \equiv \int_{\underline{\theta}}^{n} \theta f(\theta) d\theta \tag{5.31}$$

Then (5.30) always holds if $\phi(2n) \geq 2\phi(n)$ for any $n \geq \underline{\theta}$., i.e. if $\phi(n)$ is a convex function in *n*.

$$\frac{\partial^2 \varphi(n)}{\partial n^2} = f(n) + n\frac{\partial f(n)}{\partial n} \geq 0 \tag{5.32}$$

Thus, if

$$-\frac{\partial f(\theta)}{\partial \theta}\frac{\theta}{f(\theta)} \leq 1 \tag{5.33}$$

then the Condorcet winner is the representative with the largest share ownership.

We now have

Proposition 2

For any distribution of shares satisfying $-\frac{\partial f(\theta)}{\partial \theta}\frac{\theta}{f(\theta)} \leq 1$ (*i.e. the distribution function, F, is not too concave*), *the representative majority elected under shareholder voting is the one with the largest share ownership. Then the larger the share owned by the largest shareholder, the larger is the firm's production and* *absolute pollution level, and if in addition*$-R_{11}y/R_1 < 1$, *this makes the pollution intensity x/y smaller*.

The result shows the possibility that firms where the larger shareholder holds a larger share will have lower pollution intensity (in a shareholder voting equilibrium), i.e. the firm appears to have cleaner production. We shall test this result in the remaining of the chapter.

5.4 Data and Methodology

5.4.1 Sample and Data collection

Samples are drawn from publicly-traded U.S. firms that are required to report their toxic emissions in the Toxic Release Inventory (TRI) programme of the U.S. EPA. Only industrial facilities with ten or more full-time employees that release any listed toxic substance in excess of 25000 pounds and use at least 10000 pounds of any of the EPA's listed chemicals via any of four different media (air, water, land, or underground injection) are required to report the type and amount of emissions to the EPA. The TRI database has been well used for research on measurement of environmental performance (e.g., King and Lenox, 2002; Klassen and Whybark, 1999; Russo and Harrison, 2005; Berron et al, 2009, 2010).

The pollution emissions data initially originates from the U.S. EPA's TRI database at facility level. We weight on-site emission data of each chemical across air, water and land with responding Human Toxicity Potential value and then aggregate by the parent firm. Share ownership distribution data are available from the Thomson One Banker database. Financial data used as control variables are from Compustat database. This database includes expenses on research and development (hereafter referred to as XRD), total assets and separate assets in business segments which are used to calculate the firm pollution intensity (hereafter referred to as FIPI), and gross/net assets value of plants and properties and equipments (the ratio hereafter referred to as AGEasset), and debt ratio. The employment data used for calculating regulatory stringency comes from the U.S. Census Bureau and the total emissions of the state are from EPA's TRI. Moreover, the measurements of all variables are elaborated in section 5.4.2 and section 5.4.3. Precise definitions and sources are presented in Table 5.3 and Table 5.4

Our study aims to investigate the role of share ownership distribution on the level of pollutants emissions in firms. Particular focus is given to firms in which non-renewable resources are used as inputs for production. Hence, our samples are selected from the following industries: Primary Metal (SIC-code33), Metal Mining (SIC-code10) and Petroleum Refining and related Industries (SIC-code 29).

We initially identified 116 firms with data for the period 1997-2005. After subtracting companies with missing values for some of these variables, cross-referencing to the Compustat database for information on firm size, debt ratio and age of assets, and matching with both the TRI database for emission of firms and the Thomson One Banker database for information on share ownership, we were left with a 94-firm data set covering 1997-2005 and obtained 623 observations in total. To control for the potential influence of outliers, we truncated the sample by removing observations in firm no.24 named MAXXAM INC for all years and firm no.43 named TEXTRON INC in 2004 and 2005.

Moreover, our data structure of full sample can be found in Table 5.5B. The panel is extremely unbalanced, with the number of observations ranging from a minimum of 55 in year 2005 to a maximum of 89 in 1998. The usage of an unbalanced panel allows to both entry and exit, which partially mitigates potential selection and survivor bias.

5.4.2 Measurement of pollution emissions

In early studies, annual pollution emissions are simply summed up as a measurement for pollution (e.g. Cohen et al., 1997; Dooley and Fryxell, 1999; Eskeland and Harrison, 1997; Feldman et al., 1997; Khanna and Anton, 2002; Konar and Cohen, 2001; Rubin, 1999). However, it is hard to examine chemical exposure to harm for either the human or the ecosystem. Horvath et al. (1995) argue that simply summing annual pollution emissions of all TRI data is a poor proxy for its aggregate potential harm to human health or the environment. That is because the toxicity of TRI chemicals varies over more than six orders of magnitude. More importantly, weighted emissions approaches are more rigorous to weight toxic emissions in terms of relative harm, incorporating different toxicities in multi-media (i.e. air, water, land), and accounting for the chemicals' transport as well as exposure routes.

Various weighting methods are explored by researchers (see Table 5.2). According to Toffel and Marshall (2004) who compare and evaluates these methods, we choose the Human Toxicity Potential (HTP) scheme. There are four reasons for preferring HTP to other alternatives. First, although RQ has been applied by many studies (e.g. King & Lenox, 2000, 2002; Russo & Harrison, 2005), Toffel and Marshall (2004) find it problematic since being divided into five discrete values reduces its precision as a measure of relative harm. Moreover, it simply has one value per toxicity chemical but does not account for various release media. Consequently, it is hard to determine the relative harm of a particular chemical impact to the ecosystem or human health. Likewise, TRACI is abandoned as having the same drawbacks with RQ. Second, IRCHS is less appropriate as it seems designed for regulatory scrutiny and might be useful for prioritizing compliance management, rather than a weighting factor for gauging the relative impact to the environment. Third, EI99 and EDIP cover less than 10% of current TRI chemicals. Narrow coverage, to some extent, might make our estimation results biased. Finally, HTP factor is constructed by Hertwich et al. (2001) measuring toxicity in terms of benzene equivalence (for carcinogens) or toluence equivalence (for noncarcinogens). This method assigns each chemical a separate value for different media of release. It is more closely associated with actual risks to human health and environmental quality. Moreover, HTP results are highly correlated with those obtained with more sophisticated weighting methods such as RESI (r =.73) and the "ecoindicator99" (r =.92) (Toffel &Marshall, 2004).

In this paper, we improve on Berrone et al. (2010) by using the updated HTP factor of Hertwich et al. (2006) who introduce new calculations for emissions to air, water, agricultural and non-agricultural soil at two different soil depths. They also account for the oxidation products SO2 and NOx which are more dangerous than the primary pollutants. The formula for weighted pollution score for each facility is:

$$wp_{jt} = \sum_{M}\sum_{C} E_{MCt} \times f_{MC}$$

where E_{MCt} is the emissions of chemical C to medium M (air, water, surface of agricultural soil, rootzone of agricultural soil) in year t by facility j; and f_{MC} is the weighting factor (HTP value) corresponding to chemical C emitted to medium M. Note that in accordance with prior research (King & Lenox, 2000, 2002, 2004) and Berrone (2009, 2010), we only consider chemicals both that were consistently reported on over the period of our data analysis and that were included in the HTP list (see Appendix B and Appendix C)[14].

First, we weighted each chemical with responding HTP factors with respect to different mediums and sum them up. Second, we aggregated the results across chemicals at facility level. Third, the total emissions of facilities were aggregated by parent company. Moreover, as the HTP method provides cancer and non-cancer values, we calculated two different variables respectively. Both variables were log-transformed to tone down the unduly influential effect of a few observations with extreme emissions values. Then we standardized and averaged two variables to obtain weighted pollution level in firms. In the end, we improve on Berrone's (2010) measure not only by accounting for the effect of firm size (Hart and Ahuja, 1996) but also by incorporating price deflator. We finally create our dependent variable **PE** by

[14] Since TRI does not distinguish the emissions to land or underground between agricultural and non-agricultural soil, we calculate all emissions to land and underground as surface of agricultural soil and rootzone of agricultural soil respectively.

dividing the weighted emissions (WP) over deflated sales for firm i at time t which is formulated as $wp_{it} / (sales_{it} / price'deflator_{t})$, namely pollution per unit of sales.

5.4.3 Measurements of independent variables

As 5.3.4.2 stated, the decisive maker majority elected under shareholder voting is the one with the largest share ownership. To test our hypothesis, our key variable therefore is the percentage of shares outstanding held by the largest shareholder (**LSH**).

Following prior empirical study, our control variables include regulation stringency in firm-level, firm’s industry pollution intensity, and financial leverage, research and development expenses. Meanwhile, age of assets would be used for alternative measurement for R&D expenses. To assure the reliability of firm’s industry pollution intensity, industry dummies are used for alternative proxy.

Following prior empirical study, our control variables include regulation stringency in firm-level, firm’s industry pollution intensity, and financial leverage, research and development expenses. Meanwhile, age of assets would be used for alternative measurement for R&D expenses. To assure the reliability of firm’s industry pollution intensity, industry dummies are used for alternative proxy.

Environmental regulation is very common to use in the analysis of factors influencing pollution emissions (e.g. Meyer, 1995; King and Lenox, 2002, Berrone et al., 2010). Environmental regulatory stringency (***RS***) varies across states and imposes stringent or lax penalties for pollution. Previous empirical studies suggest that penalties and scrutiny are strong deterring factors for environmental pollutions. For example, Karpoff et al. (2005) provide evidence that legal penalties rather than reputation loss are most important in deterring environmental violations.

In terms of measurement for firm’s regulatory stringency, a previous proxy is obtained by calculating the inverse of the log of state toxic emissions divided by total employees (Meyer, 1995). Nevertheless, given facilities of a firm are perhaps located in different states, King and Lenox (2002) improve on Meyer's method and calculate the weighted average of the regulatory stringency for all the states where a firm has all facilities operating.

However, the method used in King and Lenox (2002) is suitable for the firm in which all facilities are required to be investigated whereas our sample concentrates on the facilities only engaging in industries with SIC10 and SIC29 and SIC33. For example, in 1999, Alcoa Inc. had 72 facilities in the U.S. and reported their toxicity release data to EPA's TRI programme. These facilities are located in different states and engaging many industries such as primary metal industry (SIC33), fabricated metal products industry (SIC34), transportation equipment industry (SIC37) and electric, gas and sanitary services (SIC49). Rather than investigating all industries firms are engaging in, our study only consider three industries, i.e. the metal mining industry (SIC10), the petroleum refining and related industry (SIC29), and the primary metal industry (SIC33). As for Alcoa Inc., only 36 facilities satisfy our data selection.

Following Kassinis and Vafeas (2002) and Berrone et al. (2009, 2010), our proxy for regulation and scrutiny is expected to be more intense in the states where the company is headquartered and where it has major operations since decision-makers come into closer contact with the community. It is approximated as total on- and off-site toxic releases of the state to which firm's headquarters belonged, divided by total employees, transformed into logarithm, and inverted. Total toxicity emissions for states are obtained from EPA's TRI programme. The amount of total employment for each state comes from the U.S. Census Bureau. It is thus assumed that lower toxic emissions in the state in which a firm has headquarters is associated with higher level of regulatory stringency facing the firm, and a higher value for this variable.

In addition to the environmental regulation factor, firm characteristics are also included, namely, debt ratio (**DEBT** for short) and age of assets (**AGEasset** for short) and R&D expenses (**XRD** for short). Debt ratio is measured as the ratio of debt over common/ordinary equity. **AGEasset** is approximated by the ratio between net and gross assets of the firm's plants and properties and equipment (**PPE** for short) (Konar and Cohen, 2000). Lower value means older age of PPE. Arguably, firms with older plant and equipment are likely to pollute more. However, the definition of **AGEasset** is ambiguous since continuous investment could offset the value of depreciation which reflects age of PPE. For this reason, we create an alternative measure for age of assets, R&D expenses by using price deflator to obtain a real value and transformed into logarithms. Higher value of R&D expenses is expected to lead to lower pollution emissions.

Finally, the influence of firms' industry pollution intensity and industry characteristics are considered. As for pollution intensity of firms, following Berrone et al. (2009), it accounts for the firm's industry composition and its dirtiness and the proportion of each business sector where the firm operates. We collect data from the Compustat Business Segment database and identified each sector's SIC code for firms. Categorized by two-digit SIC code, we then give a score to each segment regarding 'dirtiness' by ranking industries from the most to the least polluting sector according to the total amount of toxic emissions at industries level, which is established by *EPA's annual TRI (toxicity release inventory) national analysis*. Furthermore, incorporating the economic importance of each sector which is measured by $\frac{A_j}{A_T}$, we weight the pollution ranking score by the fraction of responding sector's assets over total assets of the firm. Then they are summed up at firm level. The measure is formulated as

$$FIPI = \sum_{j=1}^{n} R_j \times \frac{A_j}{A_T}$$

Where R_j is the pollution rank position of segment j, A_j is the total identifiable assets of segment j, A_T is the total assets of the company, and n is the total number of segments of the firm. Meanwhile, we create **Industry Dummy** variables as an alternative measure of firms' industry pollution intensity, by setting **IndustryD1**=1, if the firm belongs to the metal mining industry, otherwise it equals 0; **IndustryD2**=1 if the firm belongs to the petroleum refining and related industry, otherwise equals 0. To avoid the collinearity problem that the dummy variables trap may cause, **IndustryD3** is omitted. Our measure aims to identify the effect of industry upon pollution of firms, meanwhile, to examine the feasibility of FIPI.

5.5 Estimation Methods

Since our dataset has observations of multiple firms over different years, the use of time series cross-sectional data (also known as panel or longitudinal data) analysis techniques is appropriate to examine our hypotheses as to whether pollution emissions are statistically influenced by inequality of share ownership distribution. The equation of regression is as follows:

$$PE_{it} = \alpha + \beta_1 LSH_{it} + \beta_2 FIPI_{it} + \beta_3 RS_{it} + \beta_4 DEBT_{it} + \beta_5 XRD_{it} + u_{it} \quad (5.34)$$

where i represents each firm and t represents each time period (with $t = 1, 2 \cdots T$); PE_{it} is pollution emissions for firm i during period t; independent variables include largest shareholder's share ownership (LSH_{it}), the firm industry pollution intensity ($FIPI_{it}$), regulatory stringency (RS_{it}), debt ratio ($DEBT_{it}$) and expenditure on research and development (XRD_{it}). u_{it} is the error term.

Our estimation might suffer from potential self-selection bias. As stated above, the particular focus of observations is given to firms in certain industries in which non-renewable resources are the main input of productions. This sort of bias can be thought of as a form of omitted variable bias (Heckman, 1979). In addition, misspecification of models gives rise to heteroskedasticity. To mitigate these problems, Feasible Generalized Least Squares is appropriate whereby a within transformation is performed (i.e. each firm's observations are expressed in deviations from their firm-specific means). Meanwhile, we performed FGLS regression analysis for panel data with White's (1981) correction which solves some heteroscedasticity problems.

For the purpose of comparison and control of the robustness of the outcomes of empirical analysis, one more regression is made using panel-corrected standard error (PCSE) estimator with exactly the same error structure as the FGLS-model: firm level heteroskedasticity. The main reason for doing this is that the FGLS standard error estimates may be unacceptably optimistic. Beck and Katz (1995) attribute this overconfidence to time-series cross-section data where the error process has a large number of parameters since the FGLS assumes the error process is known but not estimated. This oversight causes estimates of the standard errors of the estimated coefficients to understate their true variability (Freedman and Peters, 1984), although there are no analytic results indicating whether this underestimate affects the performance of FGLS for panel data. Nevertheless, using Monte Carlo analysis, Beck and Katz (1995) show that PCSE estimates of sampling variability are very accurate, even in the presence of complicated panel error structures. They suggest that PCSE is superior to the more complicated GLS approach to the analysis of panel data.

Besides, we also performed regressions using Fixed Effects model and Random Effects model but F tests fail to reject the hypothesis that all the coefficients in both models are different than zero, suggesting that they are problematic and not appropriate for our sample.

5.6 Empirical Results

5.6.1 Descriptive statistics

The preliminary statistics are reported in Table 5.5A. The average level of pollution emissions per unit of sales into logarithm is -4.82022, ranging from -20.2044 to 13.66278. This wide range suggests that firms choose diverse pollution emissions levels although these firms possess similar industry characteristics such as non-renewable resources as principal input for production. The proportion of share ownership the largest shareholder holds ranges from 0.46% to 74.89%. The maximum value of a firm's industry pollution intensity is 25.0112 and the minimum is 0. The average value of regulatory stringency is 0.33 with the range between 0.04668 and 1.339952. The average debt to equity ratio is 0.90. These firms' expense in R&D is 17.51 on average (in log with base 10). The value of age asset ranges from 0.15 to 1.

Table 5.6 presents the Pearson correlation matrix between the variables estimated in the regression analyses. From Table 5.6, we may observe that share ownership distribution measured by the fraction of shares the largest shareholder holds is negatively associated with pollution emissions at with $p < 0.10$. Moreover, it is clear to see that all control variables have a strong linear relationship with the dependent variable (i.e. pollution emissions). In addition, we confirm that the variable of R&D expenses is related to its alternative measure, age of assets, at significance level of 10%.

5.6.2 Results

Table 5.7 presents estimates of equation (1). Column (1) and (2) reports Feasible Generalized Least Squares estimates. Column (1) shows that the effect of the largest shareholder's share ownership on pollution is highly significant. The estimated elasticity is -0.12, i.e. on average, across firms an increase in largest shareholder's share ownership by 10% leads to a decrease in pollution by 1.2%. In column (2), we replace XRD_{it} with $AGEasset_{it}$ to avoid misspecification due to a great number of missing values in XRD_{it}. The significance and coefficient of share ownership are unchanged suggesting that the main results are not biased due to missing values.

In column (3) and (4), we present the estimates obtained by Ordinary Least Squares with panel-corrected standard errors (PCSE). It yields coherent results with the FGLS estimates. The share ownership variables are significant and all have the sign expected on the basis of our model. In particular, column (3) provides strong results with a higher coefficient and is significant at 1% level. The point estimate (-7.803) indicates that the elasticity of pollution with respect to share ownership evaluated at sample means is -0.194, suggesting that a 10% rise in share ownership is associated with a 1.94% decrease in pollution.

Meanwhile, following previous environmental studies (Aragon-Correa, 1998; Berrone et al., 2009), *Wald Chi2* tests are conducted to examine the explanatory value of our independent variables. Results of these tests indicated that the increments in variance explained among different control models were all significant. *Wald Chi2* statistics are given in Table 5.7 confirming that the impact of share ownership distribution is statistically crucial to pollution emissions level in all cases other than due to random chance. Moreover, we also calculate the variance inflation factor (VIF) after each regression in pooled OLS to detect whether results were subject to multicollinearity. Remarkably lower VIF values indicate that our estimations are free of any significant multicollinearity bias.

Comparing column (1) through column (4), debt ratio has no relevance in explaining the pollution under the control of $AGEasset_{it}$ and with an opposite sign to the regressions controlling for XRD_{it}. In addition, $AGEasset_{it}$ is correlated with pollution at1% significance level. In contrast, it has weak influence on pollution but with expected sign when using PCSE. From all these estimations of Table 5.7, we confirm that the largest shareholder's share ownership has a negative and highly significant effect on pollution emissions which is consistent with our hypothesis.

5.6.3 Discussions

Our empirical evidence is broadly consistent with my theory hypothesis that share ownership controlled by the decisive shareholder (i.e. largest shareholder) positively affects pollution abatement. More importantly, this result implies that the firms with the more right-skewed ownership distribution are more likely to reduce pollution emissions when the pollution emissions decision is taken through shareholders. This result is counter to Roemer (1993), who shows the poorer the median voter is relative to the average, then economic democratization will make his/her share higher, thereby the more production and the more of the externality the firm produces.

Moreover, in accord with our findings, pollution emissions, to some extent, are related to specific industry pollution intensity of firms. Contrary to previous research by Berrone et al. (2010), who find that industry pollution position intensity does not impact environmental performance, we find evidence that it has a positive and significant effect on pollution emissions. This may be due to the fact that our observations are based on industries with similar characteristics; for example, they all use non-renewable resources as inputs of production.

We confirm the significantly negative relationship between regulatory stringency and pollution emissions which is consistent with Berrone et al. (2010). It suggests that stringent regulation would bring better environmental quality while lax regulation would lead to more pollution, which is also supported by previous studies (see e.g. Earnhart, 2004; King and Lenox, 2002).

We also find evidence that pollution emissions would be lower as a firm expends more on R&D, suggesting that technology can help to reduce pollution. As Frosch and Gallopoulos (1989) argued, as firms' further reductions in pollution become progressively more difficult, more significant changes in processes or even entirely new production technologies are needed. This result is also supported by Walley and Whitehead (1994), who suggest that as the firm moves closer to 'zero pollution', emission reductions will become more technology- and capital- intensive.

In addition, we find no evidence that older plants or equipment tend to pollute more. Nelson and Tietenberg and Donihue (1993) reach a similar conclusion that increased age of plants does not have a significant impact on emissions. Dasgupta et al. (2000) also find no evidence that plants with newer equipment have better environmental performance. The unsatisfied result, to some extent, is attributed to ambiguous definition of AGEassets. As stated in section 5.4.3, age of assets is measured as the ratio of net asset value over gross asset value of PPE. Although it accounts for depreciation of assets over time, new investment or new assets are continuously involved. Therefore, this measure is not reliable to be an accurate proxy to reflect the age of PPE.

Some of our results are difficult to explain. Surprisingly, in contrast to Berrone et al. (2010) and Konar and Cohen (2000), age of assets shows significant and positive sign. Since AGEasset is measured such that larger values indicate newer assets which tend to have newer PPE with more innovative technologies in pollution control or abatement, we expect it to be negatively correlated with pollution emissions levels. While our results show that newer plants are more likely to release toxicity, as elaborated above, measurement bias renders the estimates unreliable. Meanwhile, DEBT indicates significantly positive impact to pollution emissions after controlling for R&D expenses while insignificantly negative effect is shown in the regressions including age of assets.

Our research results are also rich in policy implications. It is important for policy makers and regulators to understand how the largest shareholder affects pollution abatement decisions and how the concentrated share ownership structure in the US is associated with incentives for firms to reduce pollution emissions.

5.7 Sensitivity Analysis

Since this negative relationship between share ownership distribution and pollution challenges Roemer's theoretical work, and also since sample selection may influence the coefficient estimates, this section thoroughly tests the robustness of these results. It estimates a number of variations of the model estimated in Table 5.7, testing whether the negative relationship between share ownership and pollution persists across different variable definitions, and model specifications.

First, we test the robustness of our results to different definitions of control variables. Industry dummy variables are taken as alternative measurement for firm industry pollution intensity. Column (1) and Column (2) in Table 5.8A1 separately report the re-estimations with FGLS controlling for XRD or AGEassets suggesting that alternative measurement of variables have left our main results largely unchanged. Surprisingly, using PCSE estimator, the largest shareholder's ownership is not correlated with pollution when controlling for AGEasset.

Furthermore, in accord with Barslund (2007), we check the robustness by including or excluding one or more controls in our preferred specification. We add time dummies based on a variables set of Table 5.7. The results are presented in column (3) and (4) of Table 5.8A1 and Table 5.8A2. Time dummies are jointly insignificant for both estimation methods. Once again, we confirm that the relationship between the largest shareholder's ownership and pollution remains significant and negative. The sign and coefficients of control variables are qualitatively similar to our main results regardless of FGLS estimator and PCSE estimator.

We also estimate a set of regressions where the dependent variable (pollution emission) is regressed on core variable (share ownership distribution) and all possible combinations of other control variables. The results are represented in Table 5.8B1 and Table 5.8B2 respectively. For each regression, the coefficient of share ownership distribution indicates strongly significant and negative sign. The results of the robustness checks confirm our initial assessment. In particular the variable of share ownership remains significant and negative across different specifications.

5.8 Conclusions

This study investigates the relationship between pollution emissions and the distribution of share ownership. Theoretically, we show that firms tend to delegate pollution decisions to the largest shareholder. The more share ownership the largest shareholder has, the more pollution would be cleaned up. We have presented panel data estimates of this relationship using data on 93 U.S. publicly traded firms covering the period 1997-2005 and concentrated on three industries, i.e. the metal mining industry, the petroleum refining industry and the primary metal industry. The technique of feasible generalized least squares (FGLS) for panel data is applied to correct the heteroskedasticity across firms and to account for firms' heterogeneity. After controlling for the effects of firm-specific factors on firm-level pollution, our estimations reveal that share ownership distribution matters for the firm's pollution emissions and the effect is statistically significant. Strong evidence is found that the more share ownership the largest shareholder holds, the less pollution the firm produces.

This paper makes several contributions. First, it provides a theoretical model to analyze the negative relationship between right-skewed share ownership distribution and pollution emissions which contrasts with prior research by Roemer (1993). Second, robust empirical evidence is provided to confirm the role of share ownership distribution in pollution decisions when pollution decisions are taken through shareholder voting. Third, this research may have implications for U.S. economic reformers or regulators who are striving to improve corporate governance and environmental protection.

Future research should attempt to identify the effect of firm performance on pollution emissions. Combined with the endogeneity problem of pollution, we would further examine the relationship between share ownership distribution and pollution emissions.

Table 5.1 Summary of relevant empirical studies

Authors	LHS	RHS	controls	result	sample	method	adjusted R^2
Telle (2006)	Return on sales	Pollution	fim sub-industry pollution, capital, employees	positive	85 plants Norway Year1990-2001	panel data model (RE)	0.12
Cormier et al	Market valuation	Pollution	Monetary working capital Inventories Fixed assets Debts Preferred stock Price/earnings ratio	negative	74 firms	OLS	0.2
(1993)				negative*	(Canada) Year1986-1988	reweighted least squares	0.45
Derwall et al. (2005)	Portfolio performance	eco-efficiency	Return difference between portofolios	positive*	450 firms (U.S.) Year1995-2003	multifactor regression	0.87
Filbeck and Gorman	Return	compliance	Rank dummy in Regulatory Market value of equity	negative*	24 firms	t test	.
(2004)				positive	(U.S.) Year1996-1998	OLS	0.04
Konar and Cohen	tobin's q-1	Pollution	Replacement cost of tangible assets Advertising expenditures R&D growth in revenues Market share Growth revenues Age of assets	negative***	321 firms	OLS	0.47

(2001)	ln(q)	lawsuits	Capital expenditure/depreciation Import penetration		(U.S.) Year1989		0.46
Kassinis and Vafeas (2002)	environmental lawsuit dummy	board size board composition directorships insider ownership	envrionmenal preferences congresional voting record regulatory stringency log (sales) return on assets	positive** postive*** negative* positive*	209 fims (U.S.) Year1994-1998	logit regression	.
Berrone et al. (2010)	environmental performance	family firm dummy family CEO status dummy	total sales, ROA, price-book ratio board size institutional ownerhsip regulatory stringency industry pollution intensity age	positive* positive	194 firms U.S. Year1998-2002	OLS	0.27 0.34
King and Lenox (2002)	pollution	firm size R&D intensity debt ratio regulatory stringency		positive*** negative*** positive*** positive***	614 firms U.S. Year 1987-1990	Pearson correlation	.
Nelson et al. (1993)	pollution	age capital utilization output	the perfentage of a firm's steam generating capacity located in a (SO_2) nonattainment	unrelated unrelated unrelated	44 utilities U.S. Year1991-1996	3SLS	.

			area				
		regulation		negative			
Wu	violation	competitive pressure		negative**	1964 facilities	multinomial probit	
(2009)	on air emission	investor pressure		positive**	U.S.		
		regulatory pressure		positive	Year 2005		
		costs risks and barriers		negative			
		CEO environemntal values		positive			
		publicly traded		positive			
		small facility		positive			
	overcompliance	competitive pressure		poitive			
	on water pollution	investor pressure		negative			
		regulatory pressure		positive			
		costs risks and barriers		negative			
		CEO environemntal values		positive***			
		publicly traded		positive			
		small facility		negative			
Earnhart	biological oxygen demand	KDHE/EPA lagged penalty	seasons dummy	positive***	40 facilities	panel data models	0.5
(2004)	wastewater pollution	cumulative EPA inspections	nonreporting of emissions	negative	U.S.	(FE and RE)	
		cumulative KDHE inspections	population	negative***	Year1990-1998		
		Annual EPA enforcement	sales taxes	negative***			
		Annual KDHE enforcement	monthly effluent limit	negative			
		predicted EPA inspection	permit expiration	positive***			
		predicted KDHE	final limit type	negative			

		inspection				
			nonreporting of effluent limit			
			IV--lagged EPA inspection			
			IV--lagged KDHE inspection			
Konar and Cohen	abnormal returns	disclosure of TRI emissions	.	negative***	192 U.S. firms	event study
(1997)	change in rank of emissions	rank of abnormal returns	.	negative***	top 40 firms Year1989	.

*significant at the 10% level
**significant at the 5% level
*** significant at the 1% level

Table 5.2 Abbreviations of typical weighting methods

HTP	Human Toxicity Potential
IRCHS	Indiana Relative Chemical Hazard Score for Environment
RSEI	Risk-screening Environmental Indicators
EI99	EcoIndicator99
EDIP	Environmental Design of industrial products
TRACI	Tool for the reduction and assessment of chemical impacts
RQ	comprehensive environmental response, compensation, and liability act reportable quantity

Table 5.3 Description of variables

Variables	Description of Variables
PE	pollution emissions in pounds per unit of sales; pollution emission (in pounds) is weighted by on-site emissions by HTP factor and aggregate the pollution of facilities by parent firms and deflated by sales (in US dollars)
LSH	Percentage of shares owned by largest shareholder
FIPI	Firm Industry pollution intensity, all business sectors' industry rank multiplied by the proportion of responding sector's assets
RS	Regulatory stringency approximated by the total emissions of state the firms' headoffice belonged to divide by total employments of the state
DEBT	Debt ratio of debt over common equity
XRD	Log of Research & Development expenses divided by price deflator
AGEasset	age of assets measured as net assets over gross assets of plants properties and equipments
Firm Size	real value of total sales; obtained by using sales divided by price deflator
IndustryD1, IndustryD2	If the firm engaging in metal mining industry with SIC code = 10, the value equals 1, otherwise 0. If the firm engaging in petroleum refining industry with SIC code = 29, the value equals 1, otherwise 0.

Table 5.4 Data Sources

Variables	sources
PE	Toxicity Release Inventory program of U.S. EPA www.epa.gov/tri/tridata/current_data/index.html
LSH	Thomson One Banker
LA5	Thomson One Banker
LA20	Thomson One Banker
LAH	Thomson One Banker
FIPI	Industry pollution ranking from TRI Business segments financial information from COMPUSTAT
RS	Pollution data from TRI Employment from U.S. Census Bureau www.census.gov/econ/susb/historical_data.html
DEBT	COMPUSTAT
XRD	COMPUSTAT
AGEasset	COMPUSTAT
Firm Size	Total sales from COMPUSTAT Price deflator from ERS(Economic Research Service)

Table 5.5A Summary Statistics

Variable	Observations/firms	Mean	SD	Minimum	Maximum	Median
PE(Log)	752 (n=102)	-4.82022	5.315607	-20.2044	13.66278	-5.16517
LSH	733 (n=101)	0.119453	0.095946	0.0046	0.7489	0.0979
FIPI	618(n=98)	14.52486	6.342527	0	25.0112	14.41236
RS	703(n=95)	0.328804	0.145352	0.046698	1.339952	0.2818295
DEBT	751(n=102)	0.900006	3.221656	-32.4641	29.43789	0.4982781
XRD(log)	394(n=55)	17.51116	2.210904	12.73189	22.82657	17.084
AGEasset	744(n=102)	0.540755	0.15024	0.150579	1	0.5141255

Table 5.5B Sample description

year	number of observations	Percent	Cumulative
1997	77	12.46	12.46
1998	89	14.40	26.86
1999	75	12.14	39.00
2000	73	11.81	50.81
2001	65	10.52	61.33
2002	66	10.68	72.01
2003	61	9.87	81.88
2004	57	9.22	91.10
2005	55	8.90	100.00
total	618	100.00	

Table 5.6 Correlations Matrix

	1	2	3	4	5	6	7
1 PE	1.00						
2 LSH	-0.06	1.00					
3 FIPI	0.32*	0.08	1.00				
4 RS	-0.20*	-0.03	-0.20*	1.00			
5 DEBT	-0.11*	0.02	-0.15*	0.02	1.00		
6 XRD	-0.24*	-0.35*	-0.47*	0.13*	0.1797*	1.00	
7AGEasset	0.13*	0.14*	0.36*	-0.16*	0.13*	0.08	1.00

Note: a. Pearson correlations above 0.08 or below -0.08 are significant at the 10% level or better. b. * denotes P-value <0.01

Table 5.7 FGLS and PCSE regressions of pollution emissions on share ownership distribution

Variables	FGLS (1)	FGLS (2)	PCSE (3)	PCSE (4)
Main effects				
LSH	-4.767**	-4.806***	-7.803***	-4.226*
	(-2.26)	(-4.00)	(-2.96)	(-1.89)
Controls				
FIPI	0.056**	0.155***	0.178***	0.246***
	(2.14)	(8.02)	-4.01	-6.03
RS	-1.928***	-4.732***	-2.019**	-5.228***
	(-2.73)	(-6.87)	(-2.04)	(-4.75)
DEBT	0.205***	-0.053	0.197**	-0.083
	(2.79)	(-1.12)	-2.34	(-1.08)
XRD	-0.422***		-0.349***	
	(-5.98)		(-3.41)	
AGEasset		2.273***		-0.00392
		(3.22)		(0.00)
_cons	1.42	-6.124***	-1.093	-6.238***
	(0.98)	(-15.47)	(-0.53)	(-6.97)
Observations	316	584	316	584
Wald chi2 (5)	80.4***	195.41***	67.19***	88.97***

Note: a) *p <0.10, **p<0.05, ***p<0.01; b) two-tailed tests for all tests and coefficients; c) t value are in parentheses. Model (1) and model (2) are estimated using Feasible Generalized Least Squares (FGLS) estimator. Model (3) and model (4) are estimated using Ordinary Least Squares with Panel-Corrected Standard Errors (PCSE).

Table 5.8A1 Sensitivity analysis using FGLS

	FGLS (1)	FGLS (2)	FGLS (3)	FGLS (4)
LSH	-4.528***	-2.694***	-5.844589***	-7.225891***
	(-2.38)	(-2.79)	(-2.71)	(-5.8)
RS	-2.803***	-3.790***	-1.955244***	-4.776612***
	(-7.94)	(-7.24)	(-2.51)	(-6.72)
DEBT	0.242***	-0.094**	.2031751***	-.0506997
	(3.7)	(-2.16)	(2.7)	(-1.03)
XRD	-0.414***		-.3978383***	
	(-7.59)		(-5.32)	
FIPI			.0648591**	
			(2.33)	
Industry Dummy	0.928**	-0.273***		
	(2.45)	(-1.21)		
AGEassets		4.846***		3.264543***
		(10.39)		(4.88)
Year Dummy			Yes	Yes
_cons	2.284**	-6.107***	1.063451	-5.857931***
	(2.3)	(-23.71)	(0.7)	(-13.15)
Observations	372	678	316	584
Wald chi2 (5)	116.2***	231.83***	74.74***	311.76***

Note: a) Dependent variable: the ratio of pollution emissions over firm values. b) Estimates based on Feasible Generalized Least Squares. We also performed regression based on PCSE estimator showing similar outcome which is available in request. c) Significance level: *p<0.10, **p<0.05, ***p<0.01. d) t value are in parentheses.

Table 5.8A2 Sensitivity analysis using PCSE

	PCSE (1)	PCSE (2)	PCSE (3)	PCSE (4)
LSH	-7.40677***	-0.21587	-8.744623***	-5.596846**
	(-3.04)	(-0.12)	(-3.27)	(-2.49)
RS	-2.94767***	-4.82989***	-2.265469**	-5.558374***
	(-3.14)	(-5.21)	(-2.28)	(-5.09)
DEBT	0.186049**	-0.15583*	.2019357**	-.0917728
	(2.08)	(-1.82)	(2.41)	(-1.19)
XRD	-0.4635***		-.3497638***	
	(-5.49)		(-3.41)	
FPI			.1764789***	0.236831***
			(3.96)	(5.84)
Industry1	omitted	10.89722***		
		(7.55)		
Industry2	-0.34831	omitted		
	(-0.62)			
Industry3	omitted	0.951522**		
		(2.19)		
AGEassets		4.127293***		0.7580011
		(3.5)		(0.49)
Year Dummy			Yes.	Yes.
_cons	3.626328**	-6.69569***	-.2670759	-6.49031***
	(2.44)	(-8.38)	(-0.12)	(-7.20)
Observations	372	678	316	584
R-squared	0.1098	0.2645	0.1840	0.1642
Wald chi2 (5)	52.71***	92.83***	71.99***	102.17***

Note: a) Dependent variable: the ratio of pollution emissions over firm values. b) Estimates based on Feasible Generalized Least Squares. We also performed regression based on PCSE estimator showing similar outcome which is available in request. c) Significance level: *p<0.10, **p<0.05, ***p<0.01. d) t value are in parentheses.

Table 5.8B1 Sensitivity analysis using FGLS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
LSH	-4.769***	-3.075***	-4.522**	-3.904***	-2.802***	-5.171***	-3.755***	-3.309***	-4.544**	-4.859***
	(-5.46)	(-3.11)	(-2.34)	(-3.23)	(-3.10)	(-2.79)	(-3.13)	(-3.66)	(-2.11)	(-3.91)
RS		-5.055***	-2.436***	-5.161***	-4.798***	-2.780***	-5.085***	-4.694***	-2.047***	-4.833***
		(-9.57)	(-5.82)	(-7.55)	(-9.42)	(-8.95)	(-7.52)	(-9.21)	(-2.90)	(-6.93)
DEBT		-0.097**				0.210***	-0.029	-0.110**		
		(-2.49)				(3.27)	(-0.64)	(-2.51)		
XRD			-0.352***			-0.400***			-0.392***	
			(-6.56)			(-7.53)			(-5.60)	
FIPI				0.174***			0.169***		0.054**	0.163***
				(10.57)			(10.4)		(2.09)	(8.32)
AGEasset					4.284***			4.628***		2.026***
					(11.9)			(12)		(2.89)
_cons	-4.300***	-2.803***	1.382	-5.115***	-5.182***	2.128**	-5.063***	-5.249***	1.141	-6.115***
	(-38.65)	(-14.51)	(1.42)	(-16.79)	(-18.50)	(2.18)	(-17.30)	(-19.52)	(0.79)	(-15.18)
Observations	733	686	372	591	679	372	591	678	316	584

Note: a) Dependent variable: the ratio of pollution emissions over firm values.

b) Estimates based on Feasible Generalized Least Squares. We also performed regression based on PCSE estimator showing similar outcome which is available in request.

c) Significance level: *p<0.10, **p<0.05, ***p<0.01 d) t value are in parentheses.

Table 5.8B2 Sensitivity analysis using PCSE

	PCSE	PCSE	PCSE	PCSE	PCSE	PCSE	PCSE	PCSE	PCSE	PCSE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
LSH	-3.47359**	-2.44069	-6.46646**	-4.15016**	-3.13152*	-7.26465***	-3.97812*	-3.09705*	-7.80339***	-4.22587*
	(-2.07)	(-1.31)	(-2.53)	(-1.94)	(-1.63)	(-3.02)	(-1.84)	(-1.61)	(-2.96)	(-1.89)
RS		-6.89812***	-3.19346***	-5.44374***	-6.43602***	-2.94365***	-5.45056***	-6.25628***	-2.01858**	-5.22847***
		(-6.52)	(-3.43)	(-5.04)	(-5.80)	(-3.14)	(-5.06)	(-5.75)	(-2.04)	(-4.75)
DEBT		-0.15393				0.191577**	-0.08988	-0.17854**	0.196603**	-0.08304
		(-1.90)				(2.14)	(-1.23)	(-2.17)	(2.34)	(-1.08)
XRD			-0.41893***			-0.47039***			-0.34868***	
			(-5.07)			(-5.63)			(-3.41)	
AGEasset					3.52667***			4.078722***		-0.00392***
					-2.84			-3.19		(-0.00)
FIPI				0.23881***			0.23067***		0.178189***	0.245704
				(7.29)			(7.01)		(4.01)	(6.03)
_cons	-4.32948***	-2.27849***	2.96035**	-6.12252***	-4.38946***	3.672741**	-5.9358***	-4.58026***	-1.09343	-6.2385***
	(-14.04)	(-4.42)	(1.98)	(-9.42)	(-4.82)	(2.47)	(-8.92)	(-5.04)	(-0.53)	(-6.97)
Observations	733	686	372	591	679	372	591	678	316	584

Note: a) Dependent variable: the ratio of pollution emissions over firm values. b) Estimates based on Feasible Generalized Least Squares. We also performed regression based on PCSE estimator showing similar outcome which is available in request. c) Significance level: *p<0.10, **p<0.05, ***p<0.01 d) t value are in parentheses.

Appendix A

First, (11) and (12) can be written as:

$$R_1(y,\tilde{y}) = 2^{\frac{3}{2}}\left(\frac{c\eta}{\theta}\right)^{\frac{1}{2}} \tag{A1}$$

$$\tilde{R}_1(\tilde{y},y) = 2^{\frac{3}{2}}\left(\frac{\tilde{c}\,\eta}{\tilde{\theta}}\right)^{\frac{1}{2}} \tag{A2}$$

Differentiating through (A1)-(A2) gives:

$$R_{11}dy + R_{12}d\tilde{y} = \left(\frac{2c\eta}{\theta}\right)^{\frac{1}{2}}\left(\frac{dc}{c} - \frac{d\theta}{\theta}\right) \tag{A3}$$

$$\tilde{R}_{12}dy + \tilde{R}_{11}d\tilde{y} = \left(\frac{2\tilde{c}\,\eta}{\tilde{\theta}}\right)^{\frac{1}{2}}\left(\frac{d\tilde{c}}{\tilde{c}} - \frac{d\tilde{\theta}}{\tilde{\theta}}\right) \tag{A4}$$

Next, solving for the partial derivatives, we obtain (13)-(16).

The first-order variation of individual *i*'s indirect utility with respect to θ, equation (24) can be rewritten as follows:

$$\frac{\partial V(\theta,\theta^i)}{\partial\theta} = \theta^i\left(R_2\frac{\partial\tilde{y}(\theta)}{\partial\theta} + cy(\theta)^2x(\theta)^{-2}s(\theta)^{-1}\frac{\partial x(\theta)}{\partial\theta} + cy(\theta)^2x(\theta)^{-1}s(\theta)^{-2}\frac{\partial s(\theta)}{\partial\theta}\right) - 2x(\theta)\frac{\partial x(\theta)}{\partial\theta}$$

$$= \theta^iR_2\frac{\partial\tilde{y}(\theta)}{\partial\theta} + \left(\frac{\theta^i}{\theta}\theta cy(\theta)^2x(\theta)^{-2}s(\theta)^{-1} - 2x(\theta)\right)\frac{\partial x(\theta)}{\partial\theta} + \frac{\theta^i}{\theta}\theta cy(\theta)^2x(\theta)^{-1}s(\theta)^{-2}\frac{\partial s(\theta)}{\partial\theta}$$

$$= \theta^iR_2\frac{\partial\tilde{y}(\theta)}{\partial\theta} + \frac{\theta^i-\theta}{\theta}2x(\theta)\frac{\partial x(\theta)}{\partial\theta} + \frac{\theta^i}{\theta}2\eta^2s(\theta)\frac{\partial s(\theta)}{\partial\theta} \tag{A6}$$

where the last line is obtained by using (5) and (6).

Equation (27) is

$$\frac{\partial V(\theta,\theta^i)}{\partial\theta} = \frac{\theta^i}{\theta}A + \frac{2\theta^i-\theta}{\theta}B \tag{A7}$$

where

$$A \equiv R_2\theta\frac{\partial\tilde{y}(\theta)}{\partial\theta} > 0 \tag{A8}$$

$$B \equiv \frac{x(\theta)^2}{2\theta}\left(1 - \frac{R_1}{y}\frac{\tilde{R}_{11}}{R_{11}\tilde{R}_{11} - R_{12}\tilde{R}_{12}}\right) > 0 \tag{A9}$$

(suppose (27) is zero for $\theta = \theta^*$, then (27) gives

$$\theta^* = \left(2 + \frac{A}{B}\right)\theta^i \qquad \text{(A10)}$$

Thus there exists an interior solution for any individual where

$$\bar{\theta} \geq \left(2 + \frac{A}{B}\right)\theta^i > 0 \qquad \text{(A11)}$$

To see that (A10) is the global maximum, rewrite (A10) as

$$A = \frac{\theta^* - 2\theta^i}{\theta^i} B \qquad \text{(A12)}$$

and use (A12) to substitute for A in (A7) to obtain

$$\frac{\partial V(\theta, \theta^i)}{\partial \theta} = \frac{\theta^* - \theta}{\theta} B \qquad \text{(A13)}$$

which is positive (negative) when $\theta^* > \theta$ ($\theta^* < \theta$), i.e. utility is increasing in θ for $\theta < \theta^*$ and declining in θ for $\theta > \theta^*$.

Appendix B

Non-cancer human toxicity potential in toluene equivalents for emissions to different compartments

CAS#/Compound ID	air	water	land	underground
630206	56	5	56	4.4
71556	30	28	30	3.3
79345	2.8	2.5	2.8	1.1
79005	4.9	14	5.1	15
75343	3.9	4	3.9	0.24
75354	9.5	24	9.5	4.7
75683	1	0.0086	0.97	4.5E-05
57147	1900	170	160	20
95943	8900	19000	8300	5600
120821	9.6	78	10	19
95636	11	330	11	44
106934	1500	1300	1500	180
95501	8.2	10	8.2	6.1
107062	4.2	4.8	4.2	0.54
540590	8.6	14	8.6	1.6
78875	220	260	220	200
528290	840	230	220	130
106990	5.5	19	5.5	1.4
541731	6	7.4	6	1.6
542756	13	48	13	0.91
108452	58	8.7	7.1	2
106467	2.2	1.3	2.2	2.7
100254	170	210	160	42
123911	0.051	0.056	0.051	0.042
106898	640	240	560	25
109693	0.61	0.86	0.61	2
63252	0.041	0.42	0.043	0.059
80057	7.9	0.38	0.58	3.1
58902	29	56	11	5.7
57117314	2E+08	1E+09	1E+08	4.4E+08
1746016	9E+11	4.9E+11	8.8E+11	6.3E+12
93765	63	4.8	4.8	12
95954	6.5	7	3.9	1.5
88062	13	0.21	7.9	1.5
88891	6100	710	970	2300
118967	510	3	44	170
94757	45	1.1	2.2	6.2
120832	51	0.15	25	1.2

105679	1.2	0.87	0.69	0.04
51285	94	7.8	32	45
121142	100	0.92	33	41
576261	98	450	290	780
606202	200	0.94	37	91
126998	12	29	12	23
95578	21	56	12	0.4
75296	11	14	11	34
109864	6.1	20	6.2	0.59
88744	860	360	340	45
79469	5.8	15	6.2	6.3
88722	4.6	1.4	4.2	2.9
90437	0.26	0.72	0.22	0.091
99081	38	47	40	93
101779	2.8	0.048	0.015	0.095
534521	1700	56	500	94
100027	21	6	21	3.4
71751412	4000	31	0.33	110
83329	0.45	2.6	0.5	1.9
30560191	140	26	11	0.11
75070	9.3	5.1	8.4	0.051
67641	0.079	0.076	0.073	0.0013
75058	30	15	27	0.53
98862	2.5	0.63	1.5	0.076
107028	4700	5800	4600	170
79061	2000	25	3.9	4
79107	62	0.22	9.6	0.42
107131	38	19	36	1.7
116063	620	750	660	300
309002	720000	2600000	940000	2200000
107186	4.3	1	2.1	0.046
107051	88	45	88	6.8
96184	43	54	43	24
319846	59	110	25	11
7429905	12000	9.3	8.3	3.1
7664417	7.5	0.032	1.8	0.0015
101053	1400	58	1.7	4.4
62533	91	57	52	3.8
120127	0.18	0.0081	0.72	3.1
7440360	7400	1500	1500	1400
12674112	3000	200000	96	71
7440382	84000	20000	83000	130000
1912249	17	0.015	3.3	19
86500	260	6.4	9.8	61

7440393	370	48	38	25
114261	62	8.9	4.1	7.4
17804352	6.6	0.41	0.35	2.5
25057890	780	1500	1100	62
71432	8.1	6.1	8.1	3.6
108383	0.41	0.5	0.41	0.046
95476	0.54	0.6	0.54	0.042
106423	0.53	0.59	0.53	0.048
108985	8200	19000	9200	70000
92875	100	5.3	3.1	5
65850	0.02	0.0024	0.0096	0.00076
100447	21	1.9	20	3
7440417	24000	540	950	1100
319857	1500	2000	550	360
82657043	97	260	23	270
92524	0.98	3.4	0.88	0.15
111444	2.7	4.3	2.9	2.9
117817	33	9	0.3	4.8
56359	2300	9500	830	870
75274	280	210	270	69
75252	200	210	200	65
1689845	31	11	1.8	1.3
71363	0.71	0.17	0.4	0.011
85687	2.9	0.082	0.0031	0.076
94826	76	6.9	0.41	0.84
7440439	2E+06	140000	1900000	3.7E+07
2425061	220	180	5	6
133062	0.23	0.0036	0.14	0.078
10605217	42	14	12	18
1563662	180	52	160	8
75150	1.4	2	1.4	0.82
630080	0.27	0	0	0
56235	2300	2300	2300	350
75445	300000	82	230000	400
110805	1.3	0.082	0.28	0.026
75694	9.6	9.1	9.6	0.61
75718	4.6	3.8	4.6	0.44
57749	100000	240000	120000	160000
470906	360	180	82	34
76131	5.9	5.6	5.9	1
79118	190	1.7	3.3	1.4
108907	0.95	5.3	0.96	1.4
124481	140	120	140	45
75456	1.4	0.011	1.4	1.3

75003	0.071	0.073	0.07	0.00053
67663	14	16	14	1.4
1897456	15	0.59	1.4	1.7
101213	3.5	1.1	0.41	0.37
2921882	220	640	21	36
7440473	2400	260	530	620
156592	15	21	15	5.6
10061015	14	51	14	0.36
7440484	31000	65	95	85
7440508	11000	6600	3600	1500
56724	1900	970	43	70
98828	0.41	0.38	0.41	0.036
21725462	270	57	41	21
110827	0.039	0.18	0.04	0.047
108941	0.016	0.0081	0.014	0.00033
60515	1600	570	420	210
52315078	780	170	320	1400
66215278	86	38	33	9.8
50293	35000	66000	35000	43000
62737	350	160	300	0.082
52918635	50	1.2	0.031	8.5
8065483	8100	780	510	540
333415	1300	980	660	100
74953	79	84	79	1.2
1918009	19	4.3	2.4	1.4
25321226	9.2	9.7	2.4	1.6
120365	73	30	2.6	2
115322	3100	6700	2200	68
60571	130000	480000	150000	160000
111422	310	1.7	1.2	0.52
84662	0.39	0.31	0.22	0.05
131113	0.023	0.0017	0.0041	0.0004
124403	41	10	33	0.062
121697	12	4.8	12	20
84742	11	1.8	4.9	6.3
88857	910	720	670	150
117840	26000	160000	8200	1500000
122394	14	14	2.8	0.96
298044	13000	4300	250	400
330541	380	120	110	280
115297	15	23	15	28
72208	14000	44000	18000	18000
13194484	15000	14000	9500	840
141786	0.092	0.024	0.086	0.0013

140885	1.6	0.71	1.5	0.033
759944	2	2.3	1.9	0.51
60297	0.23	0.37	0.23	0.0072
97632	0.66	1.5	0.67	12
100414	0.27	0.35	0.27	0.018
107211	0.25	0.0042	0.02	0.00065
75218	340	170	330	54
96457	4600	400	290	130
122145	480	120	18	38
55389	3000	14000	2000	180
900958	1100	590	52	370
206440	22	7.9	17	39
86737	3.2	17	2	3.2
133073	5.4	0.024	0.094	0.51
50000	16	0.29	4.2	0.11
64186	0.064	0.0018	0.016	0.00013
110009	45	41	45	1.3
58899	2900	5400	2400	1000
1071836	19	140	15	6.5
76448	250	1800	520	2000
1024573	8800	340000	11000	20000
87683	4300	30000	4300	4100
118741	21000	33000	21000	20000
77474	130	120	94	130
67721	5500	4900	5100	2900
110543	0.81	7.1	0.81	7.7
108101	1.4	0.35	1.3	0.027
302012	390	140	140	0.46
74908	1700	1600	1700	72
7647010	24	0.12	0.1	1.9E-16
7664393	7.1	0	0	0
778364	0.031	9	0.031	2.2E-12
123319	7.5	0.0015	0.014	0.11
36734197	15	0.49	0.52	2
78831	0.26	0.044	0.16	0.0018
78591	0.032	0.16	0.067	0.016
67630	0.018	0.0042	0.0087	0.00059
143500	14000	150000	9000	9100
7439921	580000	42000	540000	1.6E+07
330552	290	210	91	76
121755	24	7.2	0.3	2.7
108316	22	4.1E-06	2E-07	3.9E-06
7439965	3100	3.5	3.4	2.1
108394	13	0.77	4.1	0.78

99650	4300	62000	970	9000
7085190	420	14	8.8	5.6
7439976	1E+07	1.3E+07	1.4E+07	1.4E+07
67561	0.099	0.016	0.053	0.00041
16752775	24	21	15	1.9
94746	1100	62	18	7.4
72435	71	1.6	4.6	65
79209	0.081	0.02	0.075	0.00092
96333	0.8	0.33	0.75	0.013
74839	1600	900	1600	9.2
74873	57	33	57	0.2
78933	0.05	0.013	0.04	0.00047
80626	0.53	0.93	0.53	0.045
298000	2000	1900	1100	85
1634044	0.081	0.17	0.082	0.029
126987	460	690	540	6300
75092	7	4.4	7	0.19
22967926	190000	120000	190000	210000
51218452	4.6	0.95	0.72	0.77
21087649	8	9	8	2.4
7786347	1100	51	4.2	9
2385855	23000	260000	17000	18000
7439987	12000	3600	14000	20000
91203	18	22	18	31
7440020	3200	26	24	18
7697372	4.2	0	0	0
98953	24	110	34	40
10102440	4.3	0.014	0.0095	7E-17
55630	3.2	0.33	0.072	0.093
90040	180	23	84	64
95487	15	0.49	3.1	0.25
23135220	20	0.69	0.44	0.22
301122	1000	170	31	0.22
10028156	4.4	0	0	0
56382	100	31	0.79	6
11097691	2E+06	5900000	1800000	4100000
106478	12	4.5	2.1	0.63
106445	16	0.05	0.69	0.032
608935	7700	12000	7600	6200
82688	1300	1400	1000	950
87865	32	0.13	7.6	21
52645531	28	48	0.47	16
108952	0.36	0.0027	0.075	0.0028
7664382	31	0	0	0

14816183	78	61	64	6.4
85449	5.9	4.3E-05	0.00084	0.077
23103982	19	0.12	1.6	8.1
106503	1.4	0.027	0.031	0.047
23950585	11	9	4.4	2.3
1918167	36	1.6	0.61	1.1
115071	0.022	0.037	0.022	0.012
75569	29	18	28	0.8
13457186	140	40	5.9	17
129000	11	0.24	14	42
110861	74	8	47	0.9
78488	24000	97000	19000	370
78922	0.57	0.14	0.23	0.008
7782492	8100	1600	1900	2900
7440224	1600	460	1400	1800
93721	6.6	2	3.5	2.3
122349	100	11	12	26
100425	0.085	0.34	0.086	0.2
96093	30	5.4	6.5	0.72
2025884	6	0.00064	0.00051	0.0073
75650	2.2	2.2	1.9	0.62
127184	57	43	57	39
7440280	1E+07	2700000	1.4E+07	2.1E+07
137268	50	1.3	3.9	3.4
7440315	39	0.024	39	67
57018049	22	19	6.9	4.6
108883	1	0.88	1	0.096
8001352	2300	2800	2300	4600
156605	0.66	2.4	0.67	0.64
10061026	11	50	11	0.35
2303175	250	710	200	33
24017478	670	300	180	120
52686	170	6.6	3.9	3.7
79016	0.64	10	0.68	9.2
121448	11	1.1	4.9	0.043
1582098	110	8.6	79	150
639587	1300	580	83	480
7440622	1200	710	970	1200
108054	1.5	0.75	1.4	0.015
593602	23	50	23	13
75014	69	3800	72	370
1330207	0.27	0.31	0.27	0.034
7440666	190	14	18	22
12122677	6.6	1.8	0.67	0.87

Appendix C

Cancer human toxicity potential values for emissions to different compartments, in benzene-to-air equivalents

CAS#/Compound ID	air	water	land	underground
630206	3.2	0.28	3.1	0.25
79345	9.1	6.4	8.9	2.7
79005	2.2	2.4	2.2	1.4
75343	0.23	0.23	0.23	0.014
75354	0.69	3	0.69	0.4
57147	7.2	0.54	0.53	0.064
67562394	690000	3600000	550000	1800000
120821	0.0045	0.18	0.0063	0.041
106934	6.3	12	6.4	1.8
107062	2.4	2.8	2.4	0.32
78875	1.1	1.4	1.1	1.3
106990	0.54	4.9	0.54	0.14
541731	0.6	0.83	0.59	0.17
542756	0.3	0.27	0.29	0.0058
106467	1.4	0.72	1.4	1.4
123911	0.086	0.093	0.086	0.069
207089	1000	15000	1100	1300
106898	1.1	0.45	0.94	0.05
100005	3	2.9	3	1.6
63252	0.0035	0.036	0.0037	0.0051
57117314	8500000	40000000	3800000	17000000
1746016	1.2E+09	7E+08	1.2E+09	9E+09
51207319	1600000	7000000	670000	1600000
88062	2.5	0.043	1.6	0.3
118967	0.56	0.0032	0.048	0.18
94757	0.61	0.015	0.03	0.084
95807	62	1.5	5.4	22
121142	4.5	0.041	1.5	1.8
606202	10	0.046	1.8	4.5
91598	3.6	3.4	2.1	0.27
123739	3.3	1.8	3.1	0.015
79469	22	57	24	24
90437	0.00072	0.002	0.00062	0.00026
91941	9.6	0.0027	2.9	21
101779	22	0.44	0.14	0.88
92671	560	13	3.3	13
30560191	0.16	0.03	0.013	0.00013

75070	0.017	0.0068	0.015	0.000041
60355	0.91	0.019	0.048	0.0037
79061	130	1.6	0.26	0.26
107131	3.9	1.6	3.7	0.15
309002	2500	9200	3300	7900
107051	0.038	0.02	0.038	0.0029
96184	130	160	130	74
319846	87	170	38	16
62533	0.011	0.0068	0.0061	0.00044
7440382	2600	640	2700	4300
1912249	9.7	0.0086	1.9	11
151564	340	810	460	15
114261	0.066	0.0095	0.0043	0.0079
17804352	0.1	0.0062	0.0053	0.038
71432	1	0.76	1	0.44
92875	11000	570	340	540
56553	54	0.45	22	91
50328	6400	9.4	200	30000
205992	130	370	110	240
91225	12	3	5.9	0.47
98077	240	0.019	0.69	6.1
100447	0.89	0.079	0.85	0.13
7440417	22	6.1E-47	0.045	0.02
319857	98	130	36	23
82657043	3.9	11	0.95	11
108601	0.085	0.29	0.095	0.17
111444	16	26	18	18
117817	0.13	0.035	0.0012	0.02
75274	52	39	51	13
75252	1.1	1.2	1.1	0.38
1689845	4.6	1.6	0.27	0.19
7440439	28	1.3E-49	0.81	0.81
2425061	4.8	3.9	0.11	0.13
133062	0.0051	0.000078	0.003	0.0017
86748	0.018	0.2	0.00034	0.00022
10605217	0.13	0.043	0.037	0.055
56235	280	270	280	43
120809	0.14	0.0025	0.0019	0.0026
57749	250	640	310	420
124481	19	17	18	6.2
67663	1.6	1.6	1.6	0.1
107302	12	0.0022	12	0.81
1897456	0.049	0.002	0.0046	0.0058
7440473	130	3.2E-46	0.5	0.26

218019	5.1	0.78	1.2	21
10061015	0.74	0.63	0.74	0.0063
21725462	32	6.9	4.9	2.6
52315078	1.9	0.41	0.76	3.3
66215278	0.11	0.05	0.042	0.013
72548	350	2300	340	370
72559	240	340	250	320
50293	210	410	220	270
62737	1	0.66	0.91	0.00026
53703	300	1700	300	3800
25321226	1.4	1.5	0.38	0.25
115322	82	180	59	1.8
60571	7500	27000	8600	9400
64675	1.6	0.022	0.67	0.27
77781	190	0.22	34	4.7
330541	1.1	0.34	0.31	0.76
13194484	3.1	2.9	1.9	0.17
140885	0.078	0.034	0.074	0.0016
75218	11	5.6	10	1.7
96457	1.2	0.1	0.075	0.035
133073	0.14	0.0006	0.0024	0.013
50000	0.02	0.00035	0.0055	0.00014
58899	55	120	50	22
1071836	0.008	0.058	0.0065	0.0028
76448	38	270	78	290
1024573	45	1800	56	100
70648269	5.2E+08	4.6E+08	510000000	520000000
87683	50	74	49	47
118741	2300	3400	2200	2100
67721	270	230	250	140
302012	22	2.5	5.2	0.009
123319	1.2	0.00025	0.0023	0.018
193395	280	5700	350	5100
36734197	1.9	0.062	0.066	0.25
78591	0.0011	0.0027	0.0014	0.00028
143500	6200	84000	5000	5100
7439921	28	2	26	780
330552	7.5	5.4	2.4	2
121755	0.05	0.016	0.00065	0.0059
74873	0.67	0.4	0.67	0.0023
60344	1.8	2.9	2	0.34
74884	110	55	110	3.3
1634044	0.000011	0.0029	0.000055	0.00057
75092	0.2	0.14	0.2	0.006

51218452	0.46	0.094	0.071	0.076
2385855	5900	68000	4300	4800
122667	33	3.4	0.046	0.26
7440020	2.8	9E-48	0.0011	0.00029
55630	15	1.5	0.33	0.42
86306	0.019	0.12	0.02	0.009
90040	0.13	0.11	0.13	0.2
95534	0.12	0.11	0.12	0.36
106478	0.23	0.083	0.038	0.012
82688	76	77	57	53
87865	1.2	0.005	0.3	0.82
52645531	1	1.7	0.017	0.6
23950585	0.96	0.75	0.37	0.19
75569	0.26	0.42	0.26	0.042
106490	0.38	1.9	1.3	5.1
78488	12	50	9.9	0.19
94597	0.31	1.8	0.35	0.23
122349	4.5	0.48	0.51	1.1
96093	0.59	0.11	0.13	0.014
127184	0.92	0.79	0.92	0.73
62566	2.3	0.019	0.014	0.006
8001352	50	60	50	100
10061026	0.56	0.56	0.56	0.0058
2303175	17	48	13	2.2
79016	0.055	0.15	0.055	0.15
1582098	0.46	0.036	0.33	0.61
593602	0.36	0.8	0.36	0.2
75014	1.9	4.6	1.9	0.88

Notes:
1. Source: Hertwich E.G. and S.F. Mateles and W.S. Pease and T.E. McKone (2006). An update of the human toxicity potential with special consideration of conventional air pollutions. Working papers no.1/2006. Norwegian University of Science and Technology (NTNU) Industrial Ecology Programme (IndEcol).
2. CAS#/Compound ID = The chemical abstract service number of the chemical or chemical compound category.
3. We only consider chemicals (indicated by CAS number or compound ID) both that were consistently reported on over period of TRI program and that were included in the Hertwich et al. (2006)'s HTP list.

Chapter 6

Conclusions

6.1 Summary of main findings

As for the imperfect competition, profit maximization is no longer well-defined firm objective. The preferences of the owners are often inconsistent with the firm objectives when a firm realizes that it can affect its price. The reason is that an individual with a share different from the population average wish to manipulate prices to alter wages versus profits. This thesis formulates three theoretical models that capture the effects of share ownership distribution on production and pollution intensity when firm decisions are taken through shareholder voting. These models' hypotheses are tested by the panel data. The theoretical propositions and empirical findings are summarized as follows.

6.1.1 Share ownership distribution and non-renewable resources extraction rate

In chapter 3, different from Stiglitz (1976), we formulate a simple open-economy model with resource extraction where individuals differ in share ownership of the resource firm. The extraction decision is assumed to be made by the median in the voting distribution as the median's policy proposal cannot lose against an alternative proposal in a binary election. We take as our shareholder voting equilibrium the extraction rate (i.e. the extraction rate preferred by the median in the voting distribution). The shares owned by the largest shareholder are taken as a proxy for the share of the median in the voting distribution given voting rights becomes naturally left-skewed (as the distribution of voting rights is not the same as the distribution of share ownership).

We demonstrate that at each level of resource use, an individual shareholder with a share greater (smaller) than one over the population size prefers a smaller (greater) decline in extraction if substitution elasticity is smaller than unity. The result is reversed for higher substitution elasticity. The individual prefers an extraction rate coinciding with the first best if either the individual holds a share equal to one over the population size or if production function is Cobb-Douglas (unitary substitution elasticity). Our hypothesis is that if there is low substitution elasticity, the extraction rate is smaller if the largest shareholder holds a larger share, and that a higher rate of extraction in one period gives a lower decline in the use of non-renewable resources in the next.

We then test the impact of the share ownership owned by the largest shareholder on the extraction rate based on 20 US oil firms which are listed on Standard &Poor’s and the New York Stock Exchange covering the periods 1993-2007. Moreover, we create a proxy for extraction rate in firm-level so that resolve the unavailability of firm’s reserves data which is a common difficulty for researcher in relevant literature. To mitigate the endogeneity of regressors and the heterogeneity across firms, first-difference Generalized Method of Moments (GMM) estimator is used. According to the criteria of Bond et al. (2003), the first-difference GMM model suggests the instruments are weak. System GMM is used consisting of the original equation and the first-differenced one. In particular, system GMM estimator has lower bias and higher efficiency than all other estimator when the sample is smaller.

Our empirical result indicates that the extraction rate of non-renewable resources is smaller when the largest shareholder holds larger share ownership after controlling the effects of the lagged extraction rate, debt ratio and firm size and macroeconomic shocks (i.e. time dummy). The result is consistent with our theoretical hypothesis. Moreover, a non-linear relationship between them is captured suggesting that extraction rate decreases in the largest shareholder’s share ownership at an increasingly change rate. In addition, we find that larger firms are more likely to choose lower extraction rate. Higher debt would lead to greater extraction rate.

Finally, we use alternative measurements of control variables and alternative estimation method, i.e. within groups IV to test the robustness of the results. The signs and coefficients of the share ownership and debt ratio are qualitatively similar to our main results. However, firm size indicates irrelevant to the extraction rate when the measurement is changed (i.e. firm value is replaced by total assets).

6.1.2 Share ownership distribution and extraction rate of petroleum in oil fields

Different from Pesaran (1990) and Favero (1992) who develop the production modeling for oil fields of UKCS, we would improve on accompanying strategic interactions between resources extracting firms and incentives to strategically delegate among shareholders. Chapter 4 examines the impacts of the share ownership owned by the largest licensee and the largest shareholder of the responsive multinational firm on extraction rate of petroleum.

The sample consists of 44 oil fields in UKCS over 1997-2001. Our econometric analysis is conducted with the aid of two specific standard panel data models: fixed-effects model and random-effects model. According to the Hausman test, the random-effects model dominates the fixed-effects model. Meanwhile, we correct the panel-specific autocorrelation and panel-level heteroskedastic error problems by clustering at the panel level.

The results show that the share ownership of the largest licensee and the largest shareholder of its multinational company are important determinants of the extraction rate of the oil field. We find evidence that share ownership owned by the operator (i.e. the largest shareholder of the oil field is the operator) has a positive effect on oil extraction rate at 5% significant level. The largest shareholder from the operator's multinational company shows a strong relationship with the extraction rate of the oil field at 0.1% significant level. In particular, when the multinational firm's largest shareholder increases 1 per cent of ownership, extraction rate would increases by 0.3%. Moreover, pay thickness has negative impact on the extraction rate, suggesting that the oil field extract less when pay thickness is greater. Remaining reserves are positively correlated with extraction rate.

In the end, we conduct a robustness test through sample selection and model specification and alternative estimation methods. First, the result changes little by excluding the influential point (i.e. outlier). Second, we test for non-linearities by adding quadratic and cubic terms of the key variables (i.e. share ownership of the largest licensee and the largest shareholder). We do not capture the effects of quadratic or cubic relationship between share ownership and extraction rate. Third, to compare the robustness of random-effects model, Feasible Generalized Least Squares estimator (FGLS) and OLS with Panel-Corrected Standard Errors (PCSE) are used. The results are again qualitatively similar to our main results.

6.1.3 Share ownership distribution and pollution emissions

In chapter 5, different from Roemer (1993), a duopoly model is constructed which can capture strategic interaction among firms. It adds an incentive of strategically delegating to a CEO with different preferences, in order to affect the equilibrium of the game between the firms.

We demonstrate that individual shareholder with a share θ^i prefers a decision maker of at least twice the share of her own. This in turn implies that any individual with a share $\theta^i = \bar{\theta}/2$ or greater, will be at a corner solution wishing to delegate to the largest shareholder. Thus, if the distribution of shares satisfying $-\frac{\partial f(\theta)}{\partial \theta}\frac{\theta}{f(\theta)} \leq 1$ (i.e. the distribution function is not too concave), the largest shareholder gets the vote of at least the group of shareholders holding $\bar{\theta}$ /2 or more. The representative majority elected under shareholder voting is the one with the largest share ownership, and then the largest shareholder is the Condorcet winner.

In a Nash equilibrium, the larger the share of the decision maker of firm 1, the larger firm 1 production and pollution, and the smaller the production and pollution of firm 2. Furthermore, if the revenue elasticity is smaller than unity, i.e. if $-R_{11}y/R_1 < 1$, then the pollution intensity is smaller as the share of the decision maker is larger. Therefore, the hypothesis is that firms where the larger shareholder holds a larger share will have lower pollution intensity in a shareholder voting equilibrium.

In terms of our empirical study, we test above hypothesis based on 93 U.S. publicly traded firms covering the periods 1997-2005 for three industries: the metal mining industry, the petroleum refining industry and the primary metal industry. We improve on the measurement of pollution intensity taking into account weighted pollution emissions and deflated sales of the firms. To compare the robustness of our results, we use two estimation methods Feasible General Least Squares (FGLS) and Panel-Corrected Standard Error (PCSE). The heteroscedasticity problems in panel level are corrected.

The result indicates that there is a negative relationship between the pollution intensity and share ownership by the largest shareholder after controlling for the effects of regulatory stringency, firm industry pollution intensity and age of assets and expenditure in research and development. The result is consistent with the theoretical hypothesis. The estimate suggests that a 10% rise in share ownership is associated with a 1.94% decrease in pollution. Moreover, we find that industry pollution intensity has a positive impact on pollution intensity. Pollution intensity is larger when regulation of state is lax. We also find that pollution intensity is lower as a firm expends more on research and development.

In the end, we test the robustness of our results using alternative measurements and different model specifications. The coefficients and significance of variables are qualitatively similar to our main results. We confirm the evidence that the larger share ownership the decisive shareholder has, the lower the pollution intensity of the firm.

To sum up, our research has demonstrated that share ownership distribution matters for resources extraction and pollution control theoretically and empirically. A government or a regulator can reform with respect to sustainability and environmental protection by regulating share ownership structure. For instance, governments need to take ownership structure into account when privatizing a non-renewable resource company. However, our theoretical hypothesis and empirical studies might not fit China or other emerging economics due to different legal ownership structure in which government or regulator play an important role rather than decisive shareholder.

6.2 Major contributions

Our analysis differs from the other economic studies in the field in a number of respects and main points are summarized in the following table 6.2:

- **Application of median voter theory to resources firms' decisions**

Different from the prior literature in optimal extraction path of non-renewable resource, we construct a resource model taking into account the preferences of the individual who have a share different from the population average. Since the extraction rate preferred by median voter cannot loose against an alternative proposal by other candidates in a binary election, we take shareholder voting equilibrium as the extraction rate. Voting distribution is naturally left-skewed which increases as the largest shareholding becomes larger. Hence, the largest shareholder is the proxy for median voter (i.e. decisive shareholder). Contrary to Stiglitz (1976), the extraction path will not coincide with the first-best, unless the decisive shareholder holds a share exactly equal to one over population size.

- **Duopoly model with shareholder voting for pollution decisions**

Different from the previous study in pollution decisions, we formulate a duopoly model with shareholder voting taking into account strategic interactions between two resource firms. We demonstrate that firms wish to delegate to the largest shareholder. Moreover, in Nash equilibrium, the larger share the decisive shareholder has, the lower pollution intensity is preferred. This conclusion is contrary to Roemer (1993) who analyze the role of share ownership distribution in pollutants level without considering strategic interactions for more than one firm.

- **Empirical techniques with panel data models**

Few empirical evidences investigate the role of share ownership distribution in extraction and pollution decisions. We collect sample in time-series cross-section structure. As for the resource extraction model in chapter 3, system GMM and first-differenced GMM are used to mitigate the heteroscedastics and endogeneity due to the lagged extraction rate and other regressors. In particular, system GMM ensures the robustness of our results while the sample size is small. As for the resource extraction for oil fields in chapter 4, fixed effects model and random effects model are used to control the heterogeneity (i.e. unobservable specific factors across oil fields influencing the extraction rate) across oil fields. As for pollution decision model in chapter 5, FGLS and PCSE are conducted based on TRI data. This is different from the recent paper concerning firm pollution emissions by Berrone et al. (2010) who estimate their panel regressions applying average Ordinary Least Squares (OLS). Our estimators can better capture the heterogeneity among firms and heteroscedastics across panels.

- **Novel proxy for extraction rate and pollution intensity**

To resolve the unavailability and comparability matters in terms of firms' resource reserves which is a difficulty for many researchers in related literature, we take firm value as proxy. Therefore, annual extraction rate is measured by the ratio between the values of total production over firm value for each year. As for the measurement of pollution, we improve on pollution by using deflated firm sales and obtain absolute value in ratio.

Table 6.1 Contributions

Novelty	Results	Chapters
1. Applying median voter theory to non-renewable resources	The extraction rate of non-renewable resources is lower when decisive shareholder with larger share ownership	3
2.Constructing a duopoly model with shareholder voting taking into account strategic interaction	Firms wish to delegate to the largest shareholder voting. The larger share the largest shareholder has, the less is the pollution intensity.	5
3. Empirical study using panel data models are implemented.	Share ownership distribution has impact on extraction and pollution decisions of resource firms. Estimation methods include: GMM, FE, RE , FGLS , PCSE.	3,4,5
4. Variable measurements	$ExtractionRate = \frac{price_{oil} \times production_{oil} + price_{gas} \times production_{gas}}{FirmValue}$	3
	$PollutionIntensity = wp_{it} / (sales / PriceDefaltor)$	5

6.3 Limitations and Future Research

Although enormous effort has been made to study the effect of share ownership distribution in resource firms' extraction rate and pollution intensity, there are inevitably some limitations in this thesis.

Firstly, we are aware that the empirical results appear to be a paradox between chapter 3 and chapter 4. This inconsistency is mainly attributed to different decision models. In chapter 3, the extraction decision model is constructed for a resource firm while it does not fit the empirical study of chapter 4 for oil fields where there are many resource producers on the same place. Therefore, the most important issue for future research is that a theoretical model would be developed for chapter 4. We would capture a game between resource extracting firms (different firms on the same plateau). It will be strategic interaction between those firms and incentives to strategically delegate among shareholders.

Secondly, we restrict our focus to those firms listed U.S. market in chapter 3. Future research questions could be using data from other markets, developing a differential game model of resource extraction. Moreover, as for chapter 4, sample size is small due to the data availability of UKCS oil fields. To further investigate the role of share ownership distribution in extraction of oil fields of North Sea, we would collect more data from oil fields in Norwegian Sea area[15].

Finally, on the empirical side, the most important extension is to endogenize pollution emissions and firm performance. Combined with the endogeneity problem of pollution, we would further examine the relationship between share ownership distribution and pollution emissions. Meanwhile, we want to check these larger shareholders' identity aiming to study what critical incentives drive their decisions in extraction and pollution control.

[15] North Sea oil often refers to a larger geographic set including areas in UK and Norway.

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