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Expropriation Risk and Natural Resource Extraction: A Matter of Capital Intensity

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Preface

This thesis represents the culmination of a six year long journey through the jungle of 326.9 ECTS credits worth of business and economic theory, leading to the degree of Master of Philosophy in Economics. As I enter the final stage of the writing process, I acknowledge that the past five months of journal article reading, data collection, trials and errors would have been a lot more frustrating and depressing without the support of certain people.

First of all, I would like to thank my supervisor Florian Diekert for introducing me to the literature on which this thesis builds, but especially for the amount of time and effort[1] he has put down in motivating, encouraging, correcting, discussing and disagreeing with me. To cite the man himself: "You should be happy you got me as a supervisor early in my career, while I'm still enthusiastic." (Diekert, April 2013). I also want to thank my co-supervisor Jo Thori Lind for guiding me through the maze of panel data econometrics.

Thanks to Thom Åbyholm[2], Shingie Chisoro and Mirjam Unger for fruitful discussions and for creating a great working environment at the ESOP Scholarship office. Thanks to Bjørn G. Johansen for constructive criticism, Pål Ulvedal and Morten Grindaker for helpful comments, and to everyone that have shared meals with me at overcrowded tables in the cafeteria.

Thanks to the Centre[3] for the study of Equality, Social Organization and Performance for granting me the ESOP Scholarship and the accompanying office space and free coffee.[4] Finally, I would like to thank Professor Helge Hveem at the Department of Political Science, University of Oslo, for arranging my access to the mineral data from IntierraRMG.

Eivind Hammersmark Olsen
Oslo, May 2013

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[1] More than can be expected, I assure you.

[2] A special thanks to Thom for always notifying me about lunch and dinner times.

[3] Sic.

[4] Also, thanks to the inventor of coffee, God.

Summary

Recent years have seen a revival of expropriations in the resource sector, which was long believed to be a phenomenon of the 1970s when oil prices surged. This thesis investigates the effect of expropriation risk on the extraction decisions by mineral producers. Expropriation risk likely has different effects on extraction depending on the capital intensity of the resource, because of two effects that work in opposite directions: (i) expropriation risk tends to depress investments, which leads to lower capital–reserve ratios, ultimately giving higher marginal costs and slower extraction; (ii) expropriation risk induces mine owners to extract faster, because it decreases the expected value of the unexploited resource stock. I label these opposing effects the *ex ante* and *ex post* effects, respectively, reflecting that the two effects are results of decisions made before and after investment. The *ex ante* effect is arguably stronger the more capital-intensive the resource is, so the direction of the total effect is theoretically ambiguous, making it an empirical matter to determine how extraction rates are affected by expropriation risk.

The topic of this thesis is related to the literature on the resource curse, in which the quality of institutions have been pointed out as one of the key factors. Rent seeking has been proposed as an important mechanism through which the curse works, and the effect of expropriation risk on investment and extraction decisions is another possible mechanism—countries that are unable to efficiently exploit their natural resources will underperform relative to their endowments.

An increasing number of theoretical papers on expropriation risk and resource extraction have introduced investments in capital into the framework. However, while the theoretical literature on the subject is vast, the empirical evidence is wanting. Most empirical papers are concentrated mainly on deforestation and environmental issues related to this. Others have compared deforestation to oil production, the latter of which is relatively more capital-intensive, showing positive and negative effects of expropriation risk on extraction, respectively. I argue that in order to investigate whether capital intensity determines the effect of expropriation risk, we need to examine resources that are similar in most regards, but differ in terms of capital in-

tensity. Non-fluent minerals, specifically iron and coal, seem to satisfy this requirement.

In a theoretical section I provide some intuition for how expropriation risk is thought to distort investment and extraction decisions, and discuss implications of reserves being endogenous to this risk. The impact on different types of investments is also discussed, and I argue that there is likely a difference in short run and long run effects of expropriation risk. Because investments take time to materialize, and institutions tend to be persistent, the *ex ante* effect should be more pronounced between countries than within countries.

The empirical analysis is done in two steps, using time-series data from 1,579 iron and coal mines in 46 countries, and a variable describing expropriation risk. The first and preliminary step is to compare average investment–output ratios of iron and two types of coal. I find that (i) bituminous coal is more capital-intensive than other types of coal, (ii) iron is more capital-intensive than non-bituminous coal, and (iii) there are indications of iron also being more capital-intensive than bituminous coal. Second, this information is applied in an econometric model which separates the effect of expropriation risk on the three minerals.

Results from a pooled OLS regression show that extraction rates of all three minerals respond negatively to expropriation risk, but that the effect is stronger for bituminous coal and iron, the latter showing the strongest effect. This is consistent with what we would expect from the relative capital intensities of the minerals. The effects are quite large: A one standard deviation increase in the expropriation risk index is expected to give 44 %, 37 % and 24 % decreases in iron, bituminous coal and non-bituminous coal extraction rates, respectively. This emphasizes the importance of good property rights institutions in countries with large natural resource endowments. The results from the OLS regression withstand a number of robustness tests, although the difference in effects between iron and bituminous coal seems less robust. Random and fixed effects regressions are also applied, the latter initially giving significant, but puzzling results, which turn out to be driven by Chinese mines. Generally, however, within-country variations in expropriation risk may be too small for a fixed effects estimation to make sense.

My findings provide support to previous empirical investigations, that the response of extraction rates to expropriation risk is decreasing in capital intensity. However, my models have low explanatory power, indicating that there is a lot of variation explained by omitted variables. This motivates a discussion of some extensions of my analysis, and alternative approaches to the same problem.

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1 | Introduction

> "Nationalize the iron briquette sector, there is nothing to discuss."
>
> *Hugo Chavez*

The above quote is from a televised speech regarding the nationalization of the Venezuelan iron and steel sector in 2009 (Reuters, 2009). During his fourteen years as president of Venezuela, Hugo Chavez expropriated some 1,100 companies, a number of them in the natural resource sector (Goldhaber, 2013). Though long believed to be mainly a phenomenon of the 70s, in recent years countries like Russia (2006, 2007), Bolivia (2006), China (2006), Algeria (2006) and Argentina (2012) have also seen expropriations in the resource sector (Christensen, 2011; Romero & Minder, 2012; van Benthem & Stroebel, 2010); still, there is little empirical evidence of how risk of expropriation affects the exploitation of natural resources.

This thesis aims to explain—and provide empirical evidence for—the behavior of mining companies who face expropriation risk. More specifically, I examine how mineral extraction rates differ between different levels of expropriation risk. Conventional resource economics theory holds that higher expropriation risk leads to more rapid production; intuitively, mine owners have incentives to extract as much as possible before the resource is seized by the authorities.[1] This can more formally be derived from Hotelling's (1931) famous paper on optimal non-renewable resource extraction, in which the discount rate generally represents uncertainty about the future. He argues that an increase in the discount rate will result in extraction being shifted towards the present, and the resource being depleted at an earlier time. More explicit support for this view is found in e.g. Long (1975), and implicit support is found in most of the literature on the optimal extraction of natural resources (e.g. Perman, Ma, Common, Maddison, & McGilvray, 2011).

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[1] Note that 'mine owner' in this thesis refers to both (i) legal owners of a resource deposit and (ii) companies with contractual leasing rights to resource deposits that are owned by the state.

However, although the simplest Hotelling-type models give useful insight into some of the dynamics of resource extraction under uncertainty, they arguably do not tell the whole story. More specifically, they do not sufficiently take into account the fact that most non-renewable resources are highly capital-intensive, with large investments in exploration and capital equipment needed before extraction can begin (see e.g. Campbell, 1980). Furthermore, expropriation risk has been shown to significantly depress investment (Asiedu, Jin, & Nandwa, 2009; Knack & Keefer, 1995). Production likely depends positively on investments in mining capital, so the effect of expropriation risk on resource extraction is theoretically ambiguous.

Bohn and Deacon (2000) attempt to empirically disambiguate these effects for oil and deforestation, and provide evidence for the effect of expropriation risk being negative for oil and positive for deforestation, attributing it to the fact that oil is a lot more capital-intensive. They tell a convincing story, and their empirical results are not easily dismissed; however, the evidence for the less capital-intensive resource is not as compelling. For example, deforestation in developing countries is mostly linked to land clearing and firewood for households rather than industrial forestry. My claim is therefore that the positive relationship between expropriation risk and deforestation may have other causes than low capital intensity. That is to say, I believe in the theory behind the results in Bohn and Deacon (2000), but I argue that there is room for more empirical evidence.

In this thesis I will provide further empirical support of Bohn and Deacon's theory, by using data on iron and coal production.[2] The discussion will revolve around two distinct features of resource extraction under expropriation risk, which I call the *ex ante* and *ex post* effects. The former is the investment depressing effect of expropriation risk, while the latter is the "rushing" effect an increase in expropriation risk has on extraction from existing mines. The main idea is that if the resource is sufficiently capital-intensive, the *ex ante* effect will dominate the *ex post* effect, causing extraction to be slower under risk of expropriation.

The empirical analysis compares the effects of expropriation risk on iron, bituminous coal and non-bituminous coal. I use mine-level data on investments relative to average production value to show that iron is more capital-intensive than coal in general, and that bituminous coal is more capital-intensive than non-bituminous coal, which is consistent with what other papers have found (Creamer, Dobrovolsky, Borenstein, & Bernstein, 1960; Topp, Soames, Parham, & Bloch, 2008). This information is used to specify an econometric model where the effects on these three minerals are singled out.

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[2] Extraction and production refer to the same thing, and are used interchangeably in this thesis.

Pooled OLS regressions confirm the theoretical predictions; extraction rates of all minerals are affected negatively by expropriation risk, but more so for the more capital-intensive minerals iron and bituminous coal. A one standard deviation increase in the expropriation risk index is expected to give 44 %, 37 % and 24 % decreases in iron, bituminous coal and non-bituminous coal extraction rates, respectively, so the estimated effects are large. This implies that expropriation risk has a substantial economic impact through its effect on natural resource exploitation.

The thesis is structured as follows. Chapter 2 gives an overview of the theoretical intuition on which this thesis builds. It presents the conventional theory of resource extraction under uncertainty in more detail, gives an insight into opposing views, and presents arguments for why there is need for more empirical evidence. In the same section I also explain in more detail the *ex ante* and *ex post* effects. The data used in the empirical analysis is described in section 3, along with a discussion of the index of expropriation risk used in the regressions. Chapter 4 describes my empirical strategy, which involves making distinctions between minerals with respect to capital intensity, and explaining how this is information is coupled with expropriation risk in the econometric model. Chapter 5 presents the empirical results, along with a discussion of the findings and proposals for further research, and finally chapter 6 concludes.[3]

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[3] The investment–output comparisons in section 4.1.2 and the empirical analysis in chapter 5 are done in Stata 12 MP.

2 Theory

This chapter is intended to give some insight in the theory of resource extraction under uncertainty, how it has been tested empirically, as well as how the link from theory to empirics can be improved on. Section 2.1 gives some motivation for why the matter at hand is interesting, relates it to the resource curse literature, and discusses possible implications and economic consequences of the effect of expropriation risk on resource extraction. Section 2.2 provides a quick overview of the traditional theory, while section 2.3 discusses how economists have attempted incorporate capital investments into the models. The need for more empirical evidence of these theories is discussed in section 2.4, and section 2.5 discusses the *ex ante* and *ex post* effects in more detail.

2.1 Motivational Background

The specific focus in this thesis can in some sense be seen as a sidestep from the main-stream literature on the so called 'Resource Curse', a term for the apparent negative relationship between resource endowment and economic performance (see e.g. Sachs & Warner, 1995; Boschini, Pettersson, & Roine, 2007; Mehlum, Moene, & Torvik, 2006a, 2006b; Brunnschweiler & Bulte, 2008; van der Ploeg, 2011). The main body of this literature is concerned with why and under which circumstances resource rich countries seem to perform worse than other countries in terms of growth and GDP levels. Mehlum et al. (2006a, 2006b) for example, argue that the presence of a resource curse depends on the initial quality of institutions. If a country's institutions are good enough, the resource curse is turned to a resource blessing. Their focus is specifically on the end results of the impact of institutions on growth through resource abundance, and propose rent seeking as the underlying mechanism.

The literature on natural resource *extraction* and expropriation risk describes a second mechanism through which resource-rich economies can differ in terms of development; namely, whether resources are exploited efficiently or inefficiently. That is, this literature is not concerned with differentiating between abundance and scarcity of natural resources, but attempts to explain the dynamics of extraction under risk. In section 2.3 and 2.5 I present reasons for why expropriation risk might lead resources to be extracted too fast or too slow, depending on capital intensity. This may have implications for research on related subjects. For example, if extraction is too slow, the measure of abundance used in most of the resource curse literature—natural resource exports to GDP—will tend to underestimate the true resource abundance; that is, true resource abundance will not be accurately reflected in the value of exports, because extraction is inefficiently slow.[1] Other authors argue that natural resource exports to GDP is a measure of resource dependence, rather than abundance. Brunnschweiler and Bulte (2008), for example, propose to use a measure of known or probable reserves instead; however, this may also be misleading, because this measure of reserves is likely to be endogenous to expropriation risk (consult section 2.5.2).

Several economic consequences of sub-optimal extraction rates can be hypothesized. For example, a country with high expropriation risk and large endowments of resources that are capital-intensive, but economically viable under normal circumstances, may never be able to exploit that resource at a substantial rate until property rights become more secure. Moreover, if property rights are more insecure in the resource sector than anywhere else (see e.g. Poelhekke & Van der Ploeg, 2010), there is likely to be a misallocation of capital, labor and other production inputs, implying that the economy as a whole will be inefficient. In countries where the resource sector is large relative to the rest of the economy, the inefficiencies may be substantial. If there is expropriation risk in all sectors, investments in the resource sector might not be lower than anywhere else, but the resource rents are likely to give inefficiently high consumption (Konrad, Olsen, & Schöb, 1994), resulting in intergenerational inequity (Hartwick, 1977).

2.2 Theoretical Background

A great number of modern economic models for exhaustible resources build on the early work by Hotelling (1931), a paper that was somewhat unrecognized by his contemporaries, but received renewed interest in the 1970s. His main result was that, under very simplifying assumptions, the time and price path of resource extraction will be determined by the discount rate, in his paper equal to the interest rate. Socially efficient extraction requires that the growth rate of the resource price be equal to the discount rate in all periods. More specifically, he showed that optimal extraction will be strictly decreasing over

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[1] This is assuming that the resource sector is more sensitive to expropriation risk than the general economy.

time. If the discount rate should exceed price growth, extraction will be shifted towards the present—selling the resource and putting the money in the bank is more profitable than leaving the resource in the ground and waiting for higher prices.

We can distinguish between the private or subjective discount rate and society's discount rate. Society's discount rate might include the interest rate plus a preference for intergenerational (in-)equity. A high discount rate may thus reflect a heavier weighting of the current generation than future generations in the social planner's problem. The private discount rate can be thought of as the risk-free interest rate plus any risk premium investors might require. Expropriation risk will likely increase this risk premium, giving a higher discount rate. Thus in the event of an increase in expropriation risk, it can be derived from Hotelling (1931) that higher extraction rates and faster depletion will result. If individual firms operate with subjective discount rates, higher than society's discount rate, resources will be depleted inefficiently fast.

These ideas are more explicitly dealt with in Long (1975), in which nationalization with or without compensation is the source of uncertainty. He investigates several different scenarios, with differing assumptions about the discount rate and profit function. One of these scenarios is a situation where neither the actual occurrence nor the timing of a potential nationalization is known with certainty. Long shows that, assuming no compensation for expropriated property, and compared to a case with no risk: (i) extraction in the first period is higher, (ii) resource depletion is faster, (iii) extraction in the last period of both the certainty and the uncertainty case is equal, (iv) the two extraction paths intersect somewhere between the first and the last period of extraction.

Konrad et al. (1994) provide further support for this view, but introduce a notion of alternative investment opportunities, which they call 'Swiss bank accounts'. They look at a case in which a dictator owns the resource, and insecurity is related to the risk of a coup. If the resource sector is more insecure than the rest of the economy, we are in the Long (1975) case. Interestingly, if all investment opportunities in the economy are equally insecure, resource extraction will be according to the optimal Hotelling-rule. The efficiency result ultimately depends on whether the Swiss bank account of the dictator remains in her hands after the coup; however, even in the case where resource extraction is socially efficient, the total investment share of GDP is too low, and the consumption share is too high, so the economy as a whole is inefficient.

2.3 Mineral Extraction and Investments

The models in the papers presented in section 2.2 are based on a number of simplifying assumptions, and do not treat an important feature of many exhaustible resources: they require large investments, often up-front, to be extracted. Expropriation risk has been shown to have a detrimental effect on economy-wide investment (Knack & Keefer, 1995; Asiedu et al., 2009; Acemoglu & Johnson, 2005), and this is likely to be true also for the resource sector, perhaps even more so. If there are no investments, there can be no production, or this production is at best highly inefficient and primitive, and extraction will be low relative to reserves.[2] Even if exploration has been done successfully, and deposits of a resource are well known, exploitation of this resource requires someone to be willing to risk their capital to start production.

The idea that capital intensity is important for the dynamics of resource extraction is not new. Campbell (1980) looks at how capacity constraints and capital investments affect the optimal time-path of extraction, but does not explicitly deal with uncertainty. He concludes that with capital investments—all up-front—optimal extraction is constant over most of the lifetime of a mine, contrary to the decreasing path in Hotelling (1931). Olsen (1987) extends the models of Long (1975) and Campbell, and shows that in a model with capacity investments, higher uncertainty does not in general result in the extraction being shifted towards the present. If the resource stock is sufficiently large, both investments and extraction will be lower than in the risk-free case (see also Farzin, 1984). It is interesting to note that Olsen shows that it may be optimal to spread out investments over the lifetime of a mine, depending on the level and nature of uncertainty. A similar and related conclusion is reached in Lasserre (1982), in which the speed of extraction responds negatively to an increase in the discount rate if the economy is scarce in capital, relative to the natural resource endowment. Peterson (1978) argues that higher discount rates will tend to decrease extraction in the long run, because it discourages investments in exploration.

2.4 Current Empirical Evidence

The empirical evidence on natural resource use under risk of expropriation is very scarce, and is mostly related to deforestation. Deacon (1999) shows that

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[2] A term for this type of production is artisanal or small-scale mining, which relies mainly on labor input, and is common in many developing countries. This type of mining is outside the scope of this thesis, as production data is nearly impossible to get hold of.

deforestation rates are generally higher when expropriation risk is high, and Barbier, Damania, and Leonard (2005) demonstrate a similar relationship between level of corruption and deforestation. Ferreira and Vincent (2010) point out that there is a difference between deforestation and industrial timber harvesting, and show that commercial logging is decreasing in governance quality only if governance is strong to begin with; however, if governance is weak, improvements in governance increases timber harvests.

As far as I am aware, Bohn and Deacon (2000) are the first to empirically test whether capital intensity determines how expropriation risk affects extraction rates. They argue that the effect of expropriation risk (they call it ownership risk) is theoretically ambiguous and that it depends on the capital intensity of the resource.[3] Their rationale is that although expropriation risk tends to speed up extraction from existing mineral operations, it also decreases the expected net present value of investments. The depressing effect on investments leads to below optimal capital–reserve ratios, which raises extraction costs, implying slower extraction.

They test their theoretical predictions on oil investment, oil production and deforestation, and find that expropriation risk has a negative effect on the first two, but a positive effect on deforestation. The oil investment model shows that investments in drilling for exploration and production is decreasing in expropriation risk.[4] In the oil production model, the strength of the investment depressing effect is put up against the production rushing effect, giving the total effect of expropriation risk on oil production rates. Reserves are implicitly assumed to be exogenous to expropriation risk in the latter model, which may be a strong assumption (see section 2.5.2).

Although their results are very convincing, I claim that the case of less capital-intensive resources is not as compelling, for which I propose two reasons: Firstly, deforestation in developing countries is more often than not a result of the clearing of land area for cultivation or for firewood in households (Deacon & Mueller, 2004; Chomitz, 2007), which, to be fair, Bohn and Deacon are careful to point out. Therefore, forestry in these countries is not likely to be adequately captured by a model of inter-temporal optimization. Expropriation risk has been shown to be strongly negatively correlated with the level of development (see e.g. Acemoglu & Johnson, 2005), so Bohn and Deacon's result may be a reflection of deforestation being more rapid when it is driven by the need for farming area, rather than the conscious decision of a forestry

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[3] Note that the ownership risk index in Bohn and Deacon (2000) represents a somewhat broader measure of risk than the index in this thesis.

[4] Section 2.5.3 discusses how different types of investments can have different effect on extraction. Bohn and Deacon (2000) mention this, but are not able to empirically distinguish between different investments.

company. Notice that if agricultural land and forests are equally exposed to political expropriation risk, there is no obvious reason for why such risk would increase deforestation. Secondly, we might imagine that regulation of forests is more difficult in developing countries, e.g. because of corruption or a weak central government. In other words, countries with bad institutions, where expropriation risk is likely to be higher than average, might have difficulties with assigning property rights to forests. If so, the problem is one of *defining* property rights rather than *enforcing* them. In this case, forests are an unregulated common access resource, for which theory implies that extraction will be socially inefficiently high, even without the issue of expropriation risk.

At this stage I want to make clear that I agree with the theoretical predictions in Bohn and Deacon (2000); however, I believe that there is room for some improvement in the empirical testing of the theory. I have in this section given arguments for why forests are not an appropriate representative of a non-capital-intensive resource in this analysis, so one natural approach is to find other resources more suitable for empirical testing. Specifically, we could examine fairly similar non-renewable resources that are extracted from point sources, and for which capital intensity is likely to be one of the main differences. Most non-fluent minerals fit in this category, and although most of them are fairly capital-intensive, we should expect to find some variation in this respect. Section 4.1 shows how iron and different ranks of coal can be ordered in terms of capital intensity. As far as I am aware, this thesis is the first attempt to provide empirical evidence of the effect of expropriation risk on resource extraction by using cross-section data on non-fluent minerals.

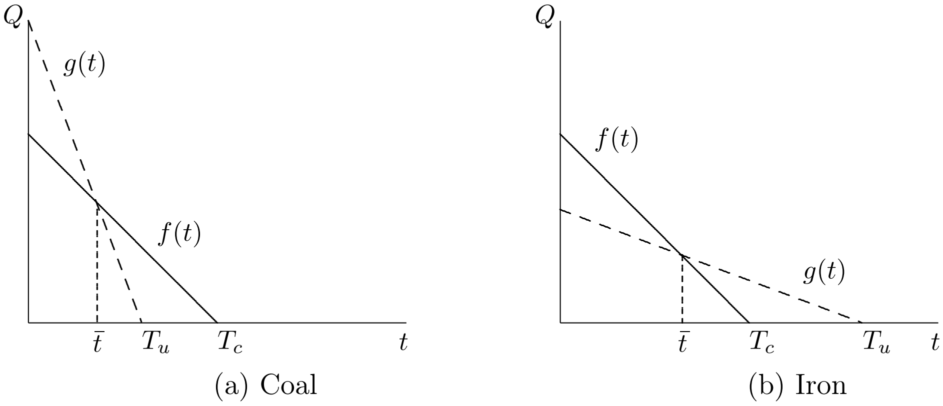
2.5 *Ex Ante* and *Ex Post* Effects

This section and following subsections is meant to explain in more detail the intuition behind the two opposing effects of expropriation risk on resource extraction. But before I do so, I find it appropriate and convenient to assign names to these effects. I will in the rest of this thesis refer to the investment depressing effect as the *ex ante* effect, and the “rushing” effect as the *ex post* effect. These terms are adopted from latin, and literally mean “before the event” and “after the event”, respectively. The “event” will in this case refer to the sinking of capital for mineral production. Note that my only original contribution here is that I have given names to the two effects to make their discussion more tractable, and to make it clearer that expropriation risk, in theory, has different effects before and after the investment decision. The underlying theory should be attributed to others, notably Olsen (1987); Farzin (1984); Lasserre (1982); Bohn and Deacon (2000).

It seems worthwhile to discuss in more detail what the *ex ante* and *ex post* effects represent, as well as how well we can hope to measure them. Within a given country, an unexpected increase in expropriation risk will induce owners of a resource to adjust their plans of production, taking into account that the probability of losing the rights to the resource some time in the future has increased. A rational response for a profit maximizing investor is to make sure that as much as possible of the minerals are converted to financial assets before expropriation occurs.[5] But if the increase in risk also depresses investments in resource extraction, this will tend to decrease extraction rates over time. These are the *ex post* and *ex ante* effects, respectively. The strength of the *ex ante* effect depends on how important physical capital is for production, but the *ex post* effect should be fairly invariant to capital-intensity. There is also likely an empirical difference between effects in the short run and the long run, because investments take time to materialize.

Section 2.5.1 discusses the implications of expropriation risk if reserves are held fixed, while section 2.5.2 briefly discusses what might happen if measures of resource stocks are endogenous to risk. Section 2.5.3 describes different types of investments, and section 2.5.4 discusses how the lagged effect of investments imply a difference between long run and short run effects.

2.5.1 Extraction with Fixed Reserves



(a) Coal

(b) Iron

Figure 2.1: Extraction paths under with and without risk

Notes: Q denotes extraction, and t denotes time. Solid lines, $f(t)$, and dashed lines, $g(t)$, represent the extraction paths without and without risk, respectively. T_c and T_u are the terminal periods in each respective case.

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[5] This implicitly assumes that financial assets are more secure than the resource, or that only the latter is targeted. See Konrad et al. (1994).

To make things more concrete, and to relate this section to the empirical part of this thesis, I use coal and iron to represent non capital-intensive and capital-intensive resources, respectively.[6] Figure 2.1a and 2.1b show the possible effect on the extraction path for coal and iron, respectively, of an increase in expropriation risk. Q denotes extracted amount, and t is time. Conventional theory (notably Long, 1975), corresponding to 2.1a, suggests the extraction path $f(t)$ without risk, and $g(t)$ when risk is introduced. The extraction path is steeper with expropriation risk, and the terminal period comes sooner ($T_u < T_c$); however, expropriation risk is also expected to depress investment, which makes production from a given resource stock less efficient and more costly, leading to slower extraction (see Perman et al., 2011, pp. 526–527). The steepness of the curve will likely depend on the importance of capital in production. I claim that since iron is more capital-intensive than coal, we can expect the extraction path for coal under risk to be steeper than that for iron. The reason is that investments in production equipment is relatively more important for iron productivity. In fact, if iron is sufficiently capital-intensive, we might see a pattern similar to that in figure 2.1b, where the extraction path is flatter with risk. Alternatively, we might find that both coal and iron have flatter extraction paths under risk than without risk, but that iron extraction is relatively flatter.

Notice that for the case in figure 2.1a, theory predicts that extraction under risk should be higher until some time $\bar{t}$, and then lower, compared to the certainty case. This implies that when comparing production data from two mines, in which one operates under risk and the other under no risk, we might observe both higher and lower extraction in the risky mine, depending on the value of t, i.e. at what time in a mine's life we make the observation. This is one reason why we should use extraction relative to known reserves, rather than extraction in absolute terms, when testing the theory empirically. Assuming $0 < g'(t) < f'(t) \; \forall \; t \in [0, T]$, as well as a fixed initial resource stock, $\int_0^{T_c} f(t)\,\mathrm{d}t = \int_0^{T_u} g(t)\,\mathrm{d}t$, it can be shown that the ratio of extraction to reserves, defined as $f(t)/F(t)$ will always be smaller than $g(t)/G(t)$, where where $F(t) = \int_t^{T_c} f(t)\,\mathrm{d}t$ and $G(t) = \int_t^{T_u} g(t)\,\mathrm{d}t$ give the remaining resource at time t. In the linear case, the proof is trivial. For a proof of the general case, consult section D.1 in the appendix. This result implies that the extraction *rate* is strictly increasing in expropriation risk for coal, and strictly decreasing in expropriation risk for iron.

The two graphs in figure 2.1 illustrate the basic theory on which the empirical analysis is built. The variable of interest is the extraction *rate*, which

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[6] Note that the actual effects on coal and iron could very well be in the same direction, because they are both relatively capital-intensive. See section 4.1 for an evaluation of the relative capital intensities of coal and iron.

changes over time with both production and reserves. However, I only have data on the most recently reported measure of reserves (see section 3.1.1), so the extraction rate in my analysis will only fluctuate with production, relative to a fixed reserve measure. For cross-mine comparisons to make sense, I need to show that this extraction rate variable will behave in the same way as one where reserves decrease with extraction.

Consider figure 2.1b for iron. Let t' be the time at which my reserves data is measured, which corresponds to 2011 for almost all mines in the sample (confer section 3). Extraction $f(t)$ and $g(t)$ varies over time, but is observed only for $t \leq t'$, and $F(t')$ and $G(t')$ are constant. It is easy to see that if

$$\frac{f(t')}{F(t')} > \frac{g(t')}{G(t')}$$

which has been proved[7] for all $t' \in [0, T]$, then

$$\frac{f(t)}{F(t')} > \frac{g(t)}{G(t')} \qquad \forall\, t \leq t' \leq T$$

because

$$\begin{aligned} f'(t) < g'(t) < 0 \qquad & \forall\, t \\ G(t') > F(t') \qquad & \forall\, t' > 0 \end{aligned}$$

This result does not necessarily hold for $t > t'$, but as long production is measured at or before the time reserves are measured, my empirical approach is consistent with theory. Note that we expect this approach to lead to an overestimation of early extraction rates, especially so for the steeper of the two curves, which implies that the effect of expropriation risk might also be overestimated. However, this should affect only the magnitude of the effect, not its direction.

This intention of this section is to clarify how extraction rates are expected to vary between mines in countries with different expropriation risk. Within a given country there is likely a difference between short run and long run effects, but it is outside the scope of this thesis to go into details of the dynamics at

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[7] The proof in appendix D.1 is for the non-capital-intensive case, but the same proof obviously also holds for the capital-intensive case.

work. Simply put, the empirical analysis will focus on how extraction rates are affected by expropriation risk, based on the following three conjectures:[8]

Conjecture 1: Expropriation risk affects natural resource extraction rates negatively through the *ex ante* effect and positively through the *ex post* effect;

Conjecture 2: The *ex ante* effect is increasing in capital intensity of resources, while the *ex post* is invariant to capital intensity;

Conjecture 3: The higher the capital intensity, the less positive—or more negative—is the *total* effect of expropriation risk on extraction rates.

2.5.2 Extraction with Endogenous Reserves

The area under the graphs in figure 2.1a and 2.1b give the initial economically viable stock of the resource, all of which is assumed to be discovered and known in the first period. This resource stock was assumed to be invariant to expropriation risk, i.e. $\int_0^{T_c} f(t)\,\mathrm{d}t = \int_0^{T_u} g(t)\,\mathrm{d}t$, which corresponds to an implicit assumption in the oil production model of Bohn and Deacon (2000). There are, however, several reasons why the assumption of exogenous reserves may not hold. Firstly, measures of reserves do not generally reflect the physical size of the resource, but rather that part of the resource that can be extracted with a profit. A decrease in investment also decreases the economically viable part of the resource stock, because marginal production costs increase, making less of the physical stock profitably extractable. Secondly, assuming that continuous exploration is required to discover more of a resource, the decrease in investments that accompanies expropriation risk will also decrease known physical reserves compared to the certainty case. Thirdly, the reserves variable used in the empirical analysis is mostly based on company reporting (see section 3.1). Companies that find themselves threatened by expropriation may have an incentive to underreport their reserves in order to mitigate the risk.[9] Thus if expropriation risk increases, there are at least three reasons why the measure of reserves may decrease, so reserves are not necessarily exogenous.[10]

To clarify the implications of endogenous reserves, a stylized example of

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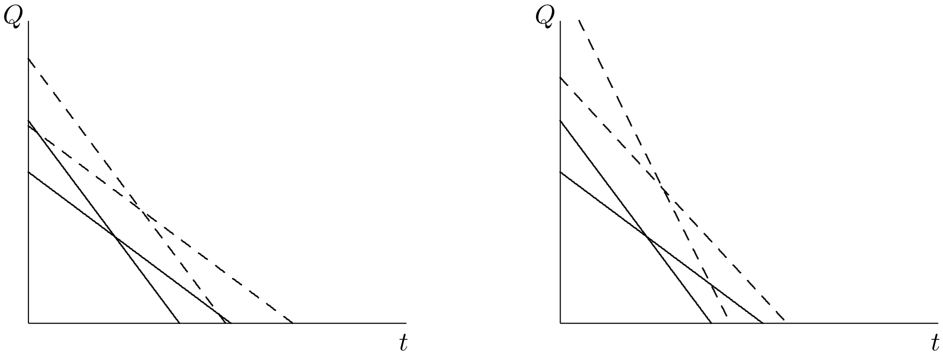
[8] These conjectures are based on the theory in Bohn and Deacon (2000), as is the rest of the discussion in this section.

[9] Durnev and Fauver (2011) and Durnev and Guriev (2011) show that expropriation risk reduces company transparency.

[10] Reserves may be endogenous also with respect to the price of the resource.

extraction paths with and without expropriation risk is given in figure 2.2.[11] Let A and B be two identical coal companies with the same initial extraction path, assumed to be linear for simplicity, given by the less steep solid line in figure 2.2a.[12] Suppose they are both faced with the option of investing in a project that will increase productivity, which in turn will increase the part of known resources that is economically profitable to extract. Without any risk of expropriation this project has a positive expected present value for both firms. An increase in reserves would shift out the extraction path, shown by the dashed lines in figure 2.2a, and the additional reserves is equal to the increase in the area under the graph. Before the investment decision is made however, company A becomes exposed to expropriation risk, while B remains protected from this risk. Suppose that this makes the project unprofitable for company A, because the risk has significantly increased the expected present value of future returns. The result is that only company B invests in the project, giving an outward shift in the extraction curve, to the flatter of the two dashed lines.



(a) Non capital-intensive (b) Capital-intensive

Figure 2.2: Extraction paths with endogenous reserves

Notes: Q denotes extraction, and t denotes time. Solid lines are the extraction paths before investment, the steeper of which represents the *ex post* effect of expropriation risk, dashed lines represent extraction paths after investment. The *ex ante* effect can be thought of as the difference between the steepest solid line and the steepest dashed line.

The *ex ante* effect on company A can be illustrated by the fact that they now *do not* invest in the project, giving lower extraction in each period and lower reserves than if the investment had been made. The *ex post* effect increases the slope of the extraction path, to the solid steeper line in figure

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[11] This graphical analysis is quite informal, and is made only to illustrate an idea. A more rigorous mathematical analysis might have been appropriate, but since this thesis is mainly empirical, I have not done this.

[12] The lines in the figure are unlabeled to make the illustrations clearer. The text indicates which lines relate to which mine.

2.2a. Compare this curve to the dashed line parallel to it: If there were no effect of risk on investment, extraction would have been higher in every period, so risk depresses extraction through investment. Notice, however, that the extraction *rate* would actually be lower without the *ex ante* effect, i.e if the investment were made. To see why, compare the ratio of current extraction to remaining reserves at any time t: The outward shift increases reserves relatively more than extraction, so the ratio goes down. The reason is that, in this particular case, the increase in reserves is accompanied by an increase in the terminal period, so that extraction is more spread out over time.

However, Perman et al. (2011) show that if productivity increases (or marginal cost decreases), the time until exhaustion will decrease, and the extraction path will generally be steeper. That is to say, in the absence of expropriation risk, the increase in productivity both expands reserves and tilts the extraction path, the latter of which is what I stated in section 2.5.1. Thus the effect on the extraction rate is ambiguous, and will likely depend on capital intensity. There was ambiguity also in the case with fixed reserves; however, endogenous reserves is a second source of ambiguity.

A possible response of extraction of a more capital-intensive resource to an increase in risk is shown in figure 2.2b. Note that the relevant curves for comparison of mines is the steepest of the solid lines and the flatter of the dashed lines. In the figure, the extraction path is steeper in the risky mine, but since reserves have increased in the non-risky mine, the total effect on extraction rates is theoretically ambiguous.

The discussion in this section is intended to trigger some reflection over how endogenous reserves may cause some complications for empirical work, but a more formal theoretical study is required in order to thoroughly assess the effects of such an assumption.[13] Note that, although this section implies some of the dynamics involved, this is not the focus of the empirical analysis. For simplicity I will in the rest of the thesis assume that the reserves measure is exogenous to expropriation risk.

2.5.3 Different Types of Investments

There are three main categories of mining investments: investments in exploration, start-up investments for production and investments for further expanding production in existing mines. Exploratory investments may be related to undiscovered deposits, as well as undiscovered reserves within or

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[13] Venables (2011) presents a model with endogenous field openings, which could perhaps be extended to include expropriation risk.

nearby operating deposits.[14] Investments in exploration will intuitively be increasing over time, and different between countries or mines with unequal degrees of depletion—the most easily discoverable reserves are found first (Bohn & Deacon, 2000). Start-up investments involve for example construction of specialized infrastructure (railways, pipes etc.), structures (e.g. mine shafts) and purchase of mining machinery (e.g. drilling and earth moving machines) (Ferreira & Vincent, 2010). If minerals are processed within mines, investments may also include mills and machinery for mineral processing. Expansionary investments may be similar to start-up investments, but occur only after a mine has been put into operation. These investments may be necessary to gain access to new parts of a deposit, or aimed at improving productivity. The data set used in the estimations does not adequately distinguish between different types of investments, and all three categories are likely to be found in the investment variable (confer section 4.1).

Whether we can expect to find expansionary investments over the lifetime of a mine likely depends on both uncertainty and geology. A once and for all start-up investment in mining capital might be optimal under full certainty, and if geological conditions permit it. Spreading out investments over time might be the better choice if uncertainty is generally high, including expropriation risk, and if deposits have properties demanding regular expansion investments (Olsen, 1987).

2.5.4 Long and Short Run Effects

The *ex post* effect is quite intuitive and easy to understand, and is likely observable in the short run. Isolating this effect, we should expect that extraction happens faster in mines that are exposed to risk, and also that extraction increases over time within mines when risk increases. Explaining and testing the *ex ante* effect is more cumbersome, and it might vary depending the nature of the investment. Investments take time to materialize, which implies that any *ex ante* effect of an increase in risk is not visible right away. This further implies that the observed between-mine and within-mine effects might not be the same.

Notice that the simple theory in section 2.5.1 is basically an exercise in comparative statics for the extraction path with and without risk. It does not say anything about the transition from zero to positive expropriation risk. In empirical studies, one must take into account that investments are likely to have a lagged effect on extraction. This is probably especially true for investments in exploration—it may take years from the start of exploration before any production takes place. If expropriation risk increased to such

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[14] Further exploration of known deposits could also be thought of as expansions.

a level that all exploratory activity stopped, but all other investments were unaffected, we wouldn't expect the *ex ante* effect to be visible in the short run, because exploratory activity has no effect on extraction from deposits that are already known. The effects of start-up investments should also appear with a lag, but less so than for exploration, since the former in some sense represents a later step in the process of opening mining operations at a new site. Expansionary investments may have a lag similar to that of start-up investments, but the effect might not be as pronounced, because existing capital equipment could still be employed in production, though less efficiently.

Political institutions tend to be persistent (Acemoglu, Johnson, & Robinson, 2001), which implies that between country variation in expropriation risk should be larger than within-country variation. This, along with the discussion in the preceding paragraph, implies that long run effects of risk are more likely to be found in cross-country or cross-mine analysis. That is to say, if the time-period under investigation is fairly short, *ex ante* effects might not be visible over time within the same mine, only between mines. Figure 2.3 illustrates this idea for for country-level extraction, where LR, MR and HR denotes low risk, medium risk and high risk countries, respectively. The lines in the figure represent what we can expect to observe in the data. The solid upward sloping lines are the within-country effects of expropriation risk on extraction; however, because risk in is higher in the high risk country, on average, extraction is also lower on average than in the medium risk and low risk countries. This conjecture has implications for how the empirical analysis is done, for example regarding the choice between the OLS and the fixed effect estimator. In figure 2.3, the dashed line represents the slope that the OLS estimator might produce, which is a weighted average of the between- and within-effects.

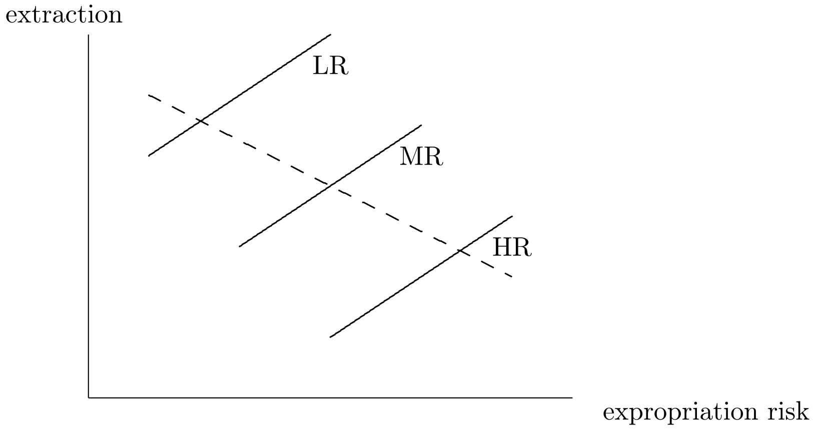

Figure 2.3: Within and between effects

3 Data

The empirical analysis in this thesis is based on data on mineral production, reserves and investments in individual mines, as well as a cross-country index that quantifies the level of expropriation risk. Section 3.1 presents the mineral data, specifically how production and reserves are defined and reported, and describes the final sample used in regressions, while section 3.2 presents the expropriation risk index used as the main explanatory variable of interest.

3.1 Mineral Data

In this thesis, only iron and different ranks of coal are considered, because it makes the analysis more convenient.[1] The reason is that with most other minerals of economic importance, for example gold, silver and copper, production normally involves a metallurgical process of separating different metals from the same ore. The distribution of these minerals in the actual output may be quite random, because metal concentration can vary widely within the same ore. Iron and coal mining however, seems to be more of a "what you dig is what you get"-process. Since the purpose of this thesis is to examine the *behavior* of mining companies, I find it more convenient to not include in the analysis minerals for which actual output is fairly random—what is interesting is how expropriation risk affects mining effort, not the actual output. This could still be achieved for these minerals by using ore production instead of metal output. This is not feasible, however, because the dataset does not distinguish between missing and zero values of this variable. Also, data on grades and concentrations of different metals within the ores in each production year is missing for a great number of observations, so consistent valuation of this ore output would be cumbersome. Note that this randomness wouldn't be expected to bias the results, but it would increase the variance of the error term in the regression.

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[1] Coal rank is a measure of the level of organic metamorphism, that is, how much heat and pressure the coal deposit has been exposed to. See http://geology.com/rocks/coal.shtml.

Diamonds are not considered in this thesis because production value is difficult to derive, owing to the fact that the price of diamonds largely depends on their quality. Section 4.1 describes how project investments and mean production value is used to classify iron and coal in terms of capital intensity, and the data on diamonds is not suitable for this method.

Data on iron and coal mining operations is collected from the IntierraRMG Raw Materials Database (RMD) (IntierraRMG, 2013).[2] IntierraRMG is a resource intelligence agency that provides monthly updated data on the resource sector. The RMD includes a wide array of variables on minerals, including production, reserves, investment, geology, mining technology and mineral grade. The data is mainly based on company reporting, alternatively on official country statistics. In cases where company reporting is insufficient or absent, IntierraRMG provide their own estimates. The valuation of output is based on iron and coal prices retrieved from the US Geological Survey and US Energy Information Administration, respectively (see table A.4 in the appendix).

3.1.1 Production and Reserves Data

The production data is measured in million metric tonnes, and runs from 1984–2012 for iron and 2000–2012 for coal. However, because observations for 2012 involves a lot of missing values due to a lack of reporting, I have chosen to limit the time period to 2011. Production of iron and coal is defined as gross weight of salable concentrate and run-of-mine coal output, respectively.[3] For iron, gross weight of actual ore production is also available, though with a shorter time-series, and with no distinction between missing and zero values. Most of the production data is reported by the mining companies. Where this is not available, IntierraRMG have estimated the production data, when feasible, e.g. based on information about mine capacity. Whether or not to include estimated data in the regressions is a question of what we believe about the reliability of these estimates, on which there is not much to go on from the description of the dataset. However, because the share of estimated data seems to be very low and evenly distributed between countries, there should not be large issues with including these observations.[4]

Reserves are defined as the economically viable part of measured or indicated resources, and are the sum of proven and probable ore reserves. The measure of reserves will generally depend on current prices and expectations

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[2] I want to thank Professor Helge Hveem at the Department of Political Science, University of Oslo, for arranging access to these data, through an agreement with IntierraRMG.

[3] Run-of-mine output refers to the production of crude coal. I refer to World Coal Institute (2005) for further details about the coal mining process.

[4] Although the dataset indicates observations for which production is estimated, the proprietary dataset software is limited with regards to exporting this information.

of future prices, as well as expropriation risk (see section 2.5.2). In order for cross-mine comparisons to make sense, production must be made relative to the size of reserves. This is a limiting factor on the sample, because reserves data is only reported for slightly more than half of the coal mines, and less than half of the iron mines. Data on reserves are inconveniently only available for the most recent estimate, which means that while production varies from year to year, reserves are held fixed.[5] Theory predicts that this might lead to an overestimation of extraction rates for early periods (see section 2.5.1.), but the qualitative results should be consistent with an analysis with varying reserves.

3.1.2 The Sample

Table 3.1 shows how the mines in the sample are distributed between countries. China is the most heavily represented country in the coal sector, with 44 % of non-bituminous coal mines and 22 % of bituminous coal mines, followed by Russia, India and the United States. Almost one third of the iron mines in the sample are in India, with Russia, Australia, the United states and Brazil collectively with another third. Note that the because countries with poor institutions likely also have poor reporting, mines in less developed countries may be underrepresented in the sample. Summary statistics on country-level production, reserves and average production rates are given in A.2 in appendix A, and the distribution of mine-years by country is shown in table A.1.

Any exclusions of observations from the final sample are made because of missing data. For observations where data on production or reserves is not available, the dependent variable $ln(production/reserves)$ is undefined. The time series on iron production is limited by the the expropriation risk variable, which only goes back to 1995.[6] Finally, because bituminous, sub-bituminous, anthracite and lignite coal have different prices, *lprice* is missing for mines where coal rank is not reported, so these mines are also excluded. The final sample contains 16,215 observations of 1,579 mines in 46 countries, with an average time-period of a little over 10 years.

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[5] I could attempt to deal with this by 'backtracking' reserves, adding production in period t to reserves in period $t-1$, so as to get a reserves variable that declines with production. This would however generally yield inconsistent values of the new variable, because of missing production data.

[6] This is very unfortunate, because there is likely a number of interesting events that could affect property rights measures in the years 1984–1994.

Table 3.1: Distribution of mines in the sample

	Non-bitum. coal		Bitum. coal		Iron	
	Freq.	Pct.	Freq.	Pct.	Freq.	Pct.
Algeria					3	1.73
Argentina	1	0.24				
Australia	10	2.43	85	8.54	19	10.98
Austria					1	0.58
Bangladesh			1	0.10		
Botswana			1	0.10		
Brazil			1	0.10	13	7.51
Canada	8	1.95	15	1.51	4	2.31
Chile					5	2.89
China	182	44.28	219	22.01	1	0.58
Colombia			8	0.80		
Czech Rep.	6	1.46	4	0.40		
Egypt			1	0.10	1	0.58
Germany	1	0.24				
Greece	5	1.22				
Hungary	4	0.97				
India	19	4.62	169	16.98	52	30.06
Indonesia	17	4.14	12	1.21		
Iran					8	4.62
Kazakhstan	1	0.24	5	0.50	2	1.16
Liberia					1	0.58
Mauritania					2	1.16
Mexico	1	0.24	1	0.10	6	3.47
Mongolia	3	0.73	3	0.30		
Mozambique			1	0.10		
New Zealand	5	1.22	2	0.20	2	1.16
Niger			1	0.10		
Norway			3	0.30	3	1.73
Peru					1	0.58
Philippines	1	0.24				
Poland	5	1.22	37	3.72		
Romania	11	2.68				
Russia	64	15.57	183	18.39	17	9.83
Serbia	2	0.49				
South Africa	6	1.46	43	4.32	5	2.89
Swaziland	1	0.24				
Sweden					2	1.16
Thailand	1	0.24				
Tunisia					1	0.58
Turkey	9	2.19	4	0.40	6	3.47
UK	1	0.24	7	0.70		
USA	37	9.00	111	11.16	9	5.20
Ukraine	10	2.43	74	7.44	6	3.47
Uzbekistan			1	0.10		
Venezuela			2	0.20	3	1.73
Zimbabwe			1	0.10		
Total	411	100.00	995	100.00	173	100.00

Source: IntierraRMG RMD

3.2 Expropriation Risk Index

In order to examine the effect of expropriation risk on mineral extraction, the relevant sources of this risk must be defined and a variable measuring it must be obtained. There are many sources of ownership risk, notably violent conflict, including guerrilla warfare, revolutions, political instability and the type and quality of a country's institutions. Bohn and Deacon (2000) define ownership risk broadly, and construct an index from instability events and regime changes, but the index does not explicitly account for formal property rights institutions. Instead they assume that regime type is a proxy for these formal institutions.

This thesis is mainly concerned with ownership risk that is driven by a country's political and judicial institutions, for which there are two reasons. Firstly, the theories presented in section 2 are mostly based on the political aspect of risk, so my choice of variable is made to make the empirical analysis as consistent with theory as possible. Secondly, political institutions have a given geographical area of relevance, defined by a country's national borders, and are as such relevant for all mines within the same countries. Instability events such as conflicts and guerrilla warfare might be limited to a certain area of a country, or even cross national borders, which implies that these events will not affect all mines within a given country in the same way. Geospatial data on individual mines was not available until the April update of the RMD dataset, so such an approach was not feasible within the time frame of this thesis. Therefore, in this thesis ownership risk is taken to mean expropriation risk, making a variable describing the quality of national institutions a natural choice.

The empirical analysis employs the 'property rights' variable from the Index of Economic Freedom (IEF) (The Heritage Foundation, 2013).[7] The Heritage Foundation is a conservative think tank based in Washington D.C. that promotes economic freedom and limited government. The non-neutral nature of the organization might be a cause of concern for the reliability of the data they produce. Because of its agenda of showing that economic freedom is good for economic growth, one might suspect that the data is constructed so as to confirm these beliefs. An implication of this is that the index might be endogenous to economic growth or GDP levels, by construction. There is not much else to say than that this may be a weakness to my analysis, but that the IEF is the best available alternative for the purpose of this thesis.[8]

The Index of Economic Freedom covers 185 countries over the time-period

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[7] Further information can be found at http://www.heritage.org/index/property-rights.

[8] Ideally, I would have checked for robustness with other indices, but other datasets of the same type, such as the BERI and PRS ICRG indices, are very costly.

1995–2013. It is based on a weighted average of ten different sub-indicators, one of which is the ‘property rights’ variable. This variable runs from 0 to 100, where 0 represents no protection of property rights and 100 is maximum protection of property rights. The Heritage Foundation defines it as follows (“Property Rights”, n.d., para. 1):

> “The property rights component is an assessment of the ability of individuals to accumulate private property [...] It measures the degree to which a country’s laws protect private property rights and the degree to which its government enforces those laws. It also assesses the likelihood that private property will be expropriated and analyzes the independence of the judiciary, the existence of corruption within the judiciary, and the ability of individuals and businesses to enforce contracts.”

There are two sides of property rights implied by this definition: (i) the protection of private property from other private parties, and (ii) the protection of private property from government expropriation. Although discussions in this thesis are mostly concerned with the latter of the two, both relate to formal political institutions, and both are likely to influence extraction decisions.

In order to make the interpretation of the risk variable more consistent with the terminology in the rest of this thesis, I construct an *expropriation risk* variable, defined as 100−‘property rights’. Interpreting expropriation risk as the opposite of the protection of property rights should not be too controversial. Table 3.2 gives summary statistics for this variable, called *exprisk* for short, over all the observations in the sample. Notice that the between mine standard deviation is close to six times higher than the within-mine standard deviation.[9] This is consistent with institutions being persistent, as proposed in section 2.5.3, and has implications for model estimation and interpretation.

Table 3.2: Summary statistics for expropriation risk—*exprisk*

	Mean	Std. dev.	Min	Max	Observations
Overall	53.06	24.49	5	100	N = 16215
Between		24.14	7	90	n = 1579
Within		4.68	25.41	84.31	T = 10.27

Source: Heritage Foundation 2013 Index of Economic Freedom.

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[9] Table A.6 gives the average expropriation risk of countries in the sample.

4 | Empirical Strategy

The theory presented in section 2.5.1 and the corresponding conjectures 1–3 describe the theoretical framework on which the empirical analysis is built. This chapter provides a description and discussion of the methods used to incorporate this framework into an econometric analysis. The analysis is done in two steps: First determining which mineral is more capital-intensive, and then using this information to examine how the effects of expropriation risk change with capital intensity. The first step is given in section 4.1, where iron and coal are categorized in terms of capital intensity. Section 4.2 specifies the econometric model used in the second step and discusses some assumptions of the model, as well as the choice of estimator.

4.1 Determining Capital Intensities

In section 2.4 I presented some arguments for why the relationship between expropriation risk and deforestation found in Bohn and Deacon (2000) may be spurious. Specifically, because forests are a common access resource if unregulated, deforestation may be driven by other factors than expropriation risk. Hence one of the most important features of this thesis is that I compare non-exhaustible resources that are as similar as possible in all aspects other than capital intensity, specifically iron and coal. The mineral sector is capital-intensive in general (see e.g. Campbell, 1980), but there is also likely to be differences between minerals, because the technologies required for extraction differ. Section 4.1.1 presents the method with which I propose to categorize minerals with respect to capital intensity, and this method is then applied to the RMD dataset in section 4.1.2.

4.1.1 The Method

In order to classify minerals by capital intensity I use the 'project cost' variable from the Raw Materials Database (IntierraRMG, 2013). This variable includes "[t]he sum of mine, plant and local infrastructure investments. Costs of e.g.

harbour, railway, refinery etc. are not included." (IntierraRMG, 2004, p. 59). In other words, this variable seems to be an appropriate indicator of sunk cost for each mine. Dividing it by the mean value of output gives a mine specific indicator of capital intensity, measured in percent. Note that the motivation for doing this is to make it meaningful to compare mines of different sizes, as well as relating investments to the value of the extracted mineral. More common measures of capital intensity are capital–output ratios and capital–labor ratios; however, I do not have mine-level data on these variables, and collecting country-level data for all the countries in the sample would be too time consuming for the time frame of this thesis.

The relevance of this investment–output ratio as a proxy for capital intensity needs a discussion. These investments may be of both start-up, expansionary and exploratory nature. Although in some cases it reflects investments made at a preliminary stage of mine development, some mines have positive values for this variable way into the years of operation. This arguably reflects the cost of further expanding existing mines, i.e. "digging deeper", improving technology or simply increasing capacity. For large deposits, a project may only involve parts of the operation, i.e. the expansion of one of many mining sites. It may also reflect the construction of new mining sites within the same operation. This could be reflected in a small project cost relative to the value of overall output, thus underestimating the true capital intensity. It is difficult to determine observations for which this is the case. Assuming that the operations in most deposits are concentrated in a small geographical area, and that mining from a deposit is limited to one or two sites, the error shouldn't be very large, and at least not systematic.

The investment–output ratio will most likely reflect mostly expansionary investments, because for mines that are in the preliminary stages of operation, and no actual production has taken place, the investment–output ratio is undefined. Intuitively, when more of the reserves are extracted, investments must be made in order to make use of those parts of the deposit that are not as easily accessible. Hence the project cost variable can arguably be assumed to be an indicator of the typical size of investment required to keep the mine in operation at a normal level of production, which I believe can be assumed to be correlated with the typical start-up investment. The average of the investment–output ratio for all mines of a certain mineral should then reflect the typical size of investments for that mineral, relative to production value. This is exactly what theory says matters for mining companies: If mining of a mineral in general requires a large sunk cost investment relative to the value of the extracted mineral, expropriation risk will reduce the incentives to go through with that investment.

4.1.2 Investment–output Comparisons

Table 4.1 shows a comparison between iron and coal mines of mean project cost divided by average production value. Only observations for which the project cost takes a positive value are included, because the dataset does not distinguish between missing values and zero for this variable. The mean for iron is more than twice as large as the mean for coal, and significantly larger at the 10% level, when variances are assumed to be unequal.[1] This result indicates that iron mines in the sample on average have higher capital intensity than do coal mines. The standard deviation of the means is quite large for both minerals, which implies that projects may be of widely different types and magnitudes from one mine to the next. This is not unexpected, since there are a number of reasons for why project costs might differ between mines.

Table 4.1: Comparing the capital intensities of coal and iron

Mineral	N	Mean	Std.Err.	Std. Dev.	95% Conf. Interval
Coal	180	13.53	3.96	53.11	[5.72, 21.34]
Iron	46	29.31	11.45	77.63	[6.26, 52.37]
Combined	226	16.75	3.93	59.07	[9.00, 24.49]
diff = mean(coal) − mean(iron)					t = –1.3029
H_0: diff = 0			Satterthwaite's degrees of freedom = 56.2054		
H_1: diff < 0			H_1: diff ≠ 0		H_1: diff > 0
Pr(T < t) = 0.0990			Pr(|T| > |t|) = 0.1979		Pr(T > t) = 0.9010

Notes: Source: IntierraRMG RMD. Variable defined in section 4.1.1. Unequal variances assumed. Observations are limited to non-zero 'project cost', but not to regression sample.

The results thus far are encouraging, but we may be able to do even better, because a difference in capital intensity is possible not only between iron and coal, but also within different ranks of coal. Consequently, the difference in means between iron and coal should not be as pronounced for some coal ranks. For example, Topp et al. (2008) show that the iron sector of Australia has roughly the same capital–output ratio as the coal sector. Note, however, that most of Australia's coal production consists of bituminous coal: 75% of Australian coal mines in the sample produce bituminous coal, and production of bituminous coal is more than twice as high as non-bituminous coal. Furthermore, according to Creamer et al. (1960), bituminous coal had roughly two times the capital–output ratio of anthracite coal and other non-metals in 1953, in fact similar to most metals. The reason is apparently that the bituminous mining process generates insecure working conditions that will likely

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[1] Satterthwaite's degrees of freedom is a weighted average of the degrees of freedom for each group.

necessitate higher investments in equipment to prevent fatalities and other disasters (Stephan, 1998).

One might argue that the capital intensity for a specific mineral is not necessarily the same today as it was in 1953. For example, in countries where mineral stocks are close to the initial endowment, the amount of investment in physical capital required to extract one unit of mineral will intuitively be lower than in countries where mineral stocks are close to exhausted. Also, mineral-specific technical progress in mining can cause optimal capital–output ratios to change over time for some minerals, while it for others stays constant. Therefore, a mineral that used to be relatively non-capital-intensive may be found to have a high capital intensity today. However, if *relative* capital intensities have not changed too much over the past 60 years, we can expect that distinguishing between different coal ranks is worthwhile. Any difference in effects might be substantial, because almost half the mines in the dataset, and 70 % of the mines in the sample, are reported to be producing mainly bituminous coal (see table A.3 in appendix A).

In table 4.2 the sample mean project cost divided by mean production value is shown to be significantly higher for bituminous coal than for other coal ranks. The difference is both more pronounced and more significant compared to table 4.1—bituminous coal has more than three times the investment–output ratio of non-bituminous coal, on average. The difference is significant at the 5% level, with a p-value of 0.0237. Comparing the investment–output ratios of iron and non-bituminous coal mines in table 4.3 further confirms the predictions. By this measure, iron is roughly six times as capital-intensive as non-bituminous coal, and the difference is significant with a p-value of 0.0191. Hence both bituminous coal and iron are more capital-intensive than non-bituminous coal, but the difference is larger for iron. Table 4.4 shows that iron has almost twice the average investment–output ratio than bituminous coal, but the difference is only significant at the 15 % level. That is to say, the average difference is quite substantial, but the variation between mines is too large for confirming this statistically.

We conclude from the above discussion that iron and bituminous coal are a lot more capital-intensive than non-bituminous coal. We also strongly suspect that iron is more capital-intensive than bituminous coal, but more evidence would be needed to confirm this statistically. Relating this to conjecture 3 in section 2.5.1, we expect that the effect of expropriation risk on the extraction rate for iron is more strongly negative (or less positive) than for bituminous coal, and we expect both of these to exhibit a stronger negative (or less positive) effect than non-bituminous coal.

Table 4.2: Comparing the capital intensities of bituminous and non-bituminous coal

Mineral	N	Mean	Std.Err.	Std. Dev.	95% Conf. Interval
Non-bituminous	31	4.15	1.14	6.36	[1.82, 6.48]
Bituminous	123	13.09	4.32	47.94	[4.53, 21.65]
Combined	154	11.29	3.47	43.05	[4.44, 18.14]
diff = mean(nonbitum) − mean(bitum)					t = –2.0001
H_0: diff = 0			Satterthwaite's degrees of freedom = 136.904		
H_1: diff < 0			H_1: diff $\neq 0$		H_1: diff > 0
Pr(T $<$ t) = 0.0237			Pr(|T| $>$ |t|) = 0.0475		Pr(T $>$ t) = 0.9763

Notes: Source: IntierraRMG RMD. Variable defined in section 4.1.1. Unequal variances assumed. Observations are limited to non-zero 'project cost', but not to regression sample.

Table 4.3: Comparing the capital intensities of iron and non-bituminous coal

Mineral	N	Mean	Std.Err.	Std. Dev.	95% Conf. Interval
Non-bitum. coal	31	4.15	1.14	6.36	[1.82, 6.48]
Iron	46	24.20	9.33	63.29	[5.40, 43.00]
Combined	77	16.13	5.68	49.85	[4.81, 27.44]
diff = mean(nonbitum) − mean(iron)					t = –2.1330
H_0: diff = 0			Satterthwaite's degrees of freedom = 46.3416		
H_1: diff < 0			H_1: diff $\neq 0$		H_1: diff > 0
Pr(T $<$ t) = 0.0191			Pr(|T| $>$ |t|) = 0.0383		Pr(T $>$ t) = 0.9809

Notes: Source: IntierraRMG RMD. Variable defined in section 4.1.1. Unequal variances assumed. Observations are limited to non-zero 'project cost', but not to regression sample.

Table 4.4: Comparing the capital intensities of iron and bituminous coal

Mineral	N	Mean	Std.Err.	Std. Dev.	95% Conf. Interval
Bituminous coal	123	13.09	4.32	47.94	[4.53, 21.65]
Iron	46	24.20	9.33	63.29	[5.40, 43.00]
Combined	169	16.11	4.05	52.60	[8.13, 24.10]
diff = mean(bitum) − mean(iron)					t = –1.0803
H_0: diff = 0			Satterthwaite's degrees of freedom = 65.2767		
H_1: diff < 0			H_1: diff $\neq 0$		H_1: diff > 0
Pr(T $<$ t) = 0.1420			Pr(|T| $>$ |t|) = 0.2840		Pr(T $>$ t) = 0.8580

Notes: Source: IntierraRMG RMD. Variable defined in section 4.1.1. Unequal variances assumed. Observations are limited to non-zero 'project cost', but not to regression sample.

4.2 Regression Model

Based on conjectures 1–3 in section 2.5.1 and the investment–output comparisons in section 4.1.2, equation (1) describes the econometric model on which the empirical analysis is built. The dependent variable is $lprodrate_{it} \equiv ln(production_{it}/reserves_i)$, and explanatory variables of interest are $exprisk_{it}$, $exprisk_{it} \times ironi$ and $exprisk_{it} \times bituminous_i$. ε_{it} is a disturbance and u_i are unobserved mine-specific effects.[2]

$$\begin{aligned} ln(production_{it}/reserves_i) = \beta_0 + \beta_1 exprisk_{it} + \beta_2 exprisk_{it} \times iron_i + \\ \beta_3 exprisk_{it} \times bituminous_i + \boldsymbol{\delta}'\mathbf{z}_{it} + u_i + \varepsilon_{it} \end{aligned} \tag{1}$$

exprisk is the expropriation risk index described in section 3.2, while $exprisk \times iron$ and $exprisk \times bituminous$ are interactions between the expropriation risk index and dummies for iron and bituminous coal mines, respectively.[3] *iron* takes the value 1 for observations from iron mines, and 0 otherwise, and *bituminous* takes the value 1 for bituminous coal mines, otherwise 0. This implies that all coal mines that are not reported to produce mainly bituminous coal are part of the reference group.

The interaction variables make the effect of expropriation risk mineral dependent—i.e. capital intensity dependent—and are in the rest of this thesis are referred to as *expriskiron* and *expriskbitum*. $\boldsymbol{\delta}'$ is a coefficient vector, and $\mathbf{z}_{it}$ is the corresponding vector of variables that are thought to explain mineral production, but for which the coefficients are not interesting per se.[4] This vector includes, among others, a time trend in order to account for changes in technology and input prices, as well as the log of annual average commodity price. There are probably a number of other variables that may explain changes in extraction—notably technology and geological conditions—but the dataset provides limited information about such properties of individual mines, so they are not included. Following Bohn and Deacon (2000) I use the log of the production rate, because it seems to fit the data better.

$$\frac{\partial lprodrate}{\partial exprisk} = \beta_1 + \beta_2 iron + \beta_3 bituminous \tag{2}$$

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[2] See table A.5 in appendix A for a description of the variables and their sources.

[3] The dummies themselves are not included in fixed effects regressions, because they are constant within mine. In this context their coefficients are not interesting in themselves, so the dummies are included in $\mathbf{z}_{it}$.

[4] Vectors are here defined as column vectors, so $\boldsymbol{\delta}'$ is a row vector.

The partial effect of expropriation risk on *lprodrate* is given in equation (2). β_1 can be both positive and negative; it describes the effect of expropriation risk given that the mineral is non-bituminous coal, i.e. when $iron = bituminous = 0$. This effect depends on the relative magnitude of the *ex ante* and *ex post* effects for non-bituminous coal. β_2 should be negative, because iron is more capital-intensive than non-bituminous coal, on average. This implies that the *ex ante* effect should be stronger, decreasing the total effect of risk on extraction. $\beta_1 + \beta_2$ then gives the total effect of expropriation risk for iron. By the same argument, β_3 should also be negative, because bituminous coal is more capital-intensive than other coal ranks, on average. The total effect of expropriation risk on bituminous coal is then $\beta_1 + \beta_3$. Recall that the ranking with respect to capital intensity in section 4.1.2 was statistically inconclusive when comparing iron and bituminous coal, so the absolute value of β_2 relative to β_3 is ambiguous. Sections 4.2.1 and 4.2.2 in the following discuss some of the the assumptions of the regression model described by equation (1), and how these assumptions affect the choice of estimation method.

4.2.1 Unobserved Heterogeneity

One consequence of leaving out variables describing for example technology and geology is that it leads to issues related to unobserved heterogeneity, represented by u_i in equation 1. This heterogeneity introduces different problems depending on whether or not the unobserved effects are correlated with the regressor variables in the model, $\mathbf{x}_{it}$, i.e. depending on whether $cov(u_i, \mathbf{x}_{it}) = 0$ or not. If they are not correlated, the OLS estimator is still unbiased and consistent, but there is serial correlation in the disturbances. This can be alleviated by clustering the standard errors or applying the random effects estimator (see Wooldridge, 2010). The choice between the random effects and pooled OLS estimator depends on some additional assumptions, specifically about exogeneity of regressors, which is discussed in section 4.2.2.

Heterogeneity can arise both between countries and between mines, but there can be made a number of arguments for why we should assume mine-specific unobserved heterogeneity: Differences in geology of the deposit, hereunder concentration of the mineral in ores and average depth of deposits. Extraction technology may also differ, and is largely unobserved. Local infrastructure is another factor that is likely to be time-invariant, but cross-section variant. A likely suspect with which these heterogeneities might be correlated is the expropriation risk variable. The reason is that countries with high expropriation risk are also likely to be less developed, and thus employ less sophisticated technologies and bad infrastructure. Acemoglu and Johnson (2005), for example, show that property rights institutions do affect long run growth, opening up for correlation between measures of property rights and technology. This may, however, not be a big concern: Because of the multi-national nature of many mining companies, technologies are likely to be similar across countries, and fairly independent of development. Also, we may believe that the same companies will invest in local infrastructure to be able to transport extracted resources, as well as gaining goodwill of the authorities in a country or region.

A substantial part of the unobserved heterogeneity is likely to be attributable to the long-run effects of expropriation risk. That is to say, investments, and thus the amount of capital equipment in the resource sector will be low if risk has been persistently high for a long time, making extraction more costly and less rapid, on average. In econometric terminology this means that there are some unobserved mine-specific effects that are correlated with some of the regressors, *exprisk*, *expriskiron* and *expriskbitum*, but also the dependent variable, *lprodrate*. This may result in an omitted variables bias, suggesting that the fixed effects regressor is appropriate. But this also implies that be bias in the coefficients from a pooled OLS estimation arguably largely reflects what we have already predicted; that is, long run effects of expropriation risk should be more noticeable between mines in different countries. That is to say, the problem of unobserved correlated heterogeneity is not necessarily a problem at all, but a feature of the dynamics of the theoretical model that enables us to observe long run effects through OLS estimation.

Note that the causal factor that we are interested in is the expropriation risk, but the channels through which this affects extraction are the *ex ante* and *ex post* effects. The latter effect should be relatively directly observable within each mine, and the definition of this effect implies a direct impact of risk on extraction decisions. The response of extraction through the former effect is not direct, but goes through investment decisions, which over time determines the amount of capital equipment in production, resulting in the ultimate response of extraction. Consequently, the *ex ante* effect is not directly observable, but rather implied by the difference in coefficients between the OLS (or random effects) and fixed effects estimations. The conclusion is thus that we look to the OLS estimation for long run effects, including both the *ex ante* and the *ex post* effects, and the fixed effects estimation for the short run (*ex post*) effects.[5]

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[5] Note that if $cov(u_i, \mathbf{x}_{it}) = 0$, random effects is preferred over fixed effects because of its efficiency properties: Fixed effects regression leaves out all the between group variation, leading to higher variance. In this case, however, I choose to consider all three estimators because the fixed effects estimation is proposed to tell a different story than the random effects and OLS estimations.

4.2.2 Exogeneity of Explanatory Variables

The choice between the random effects and OLS estimators depends on what assumptions we make about the errors. Random effects estimation requires $E(\varepsilon_{it}|\mathbf{x}_{i1}, ..., \mathbf{x}_{iT}) = 0$ i.e. strict exogeneity, in which case both OLS and random effects are unbiased and consistent, but only the latter is efficient. If strict exogeneity does not hold, but $E(\varepsilon_{it}|\mathbf{x}_{it}) = 0$ (no contemporary correlation) does, we should use pooled OLS with clustered standard errors. The fixed effects estimator is consistent even if $cov(u_i, \mathbf{x}_{it}) \neq 0$, but does also require strict exogeneity.

The assumption of strictly exogenous regressors is quite strong, and there is a possibility that it might not hold in this case. For example, the expropriation risk index is by definition not an exogenous variable, because it has been constructed by researchers based on events and country-specific traits. We may, for example, suspect that political shocks in previous periods affect both expropriation risk and extraction rates in this period. Relaxing the strict exogeneity assumption still leaves pooled OLS applicable, but only if the unobserved heterogeneity is uncorrelated with the regressor variables. For the sake of completeness, the estimations in section 5 will include outputs from all three estimation methods.

Much of the literature on the resource curse is concerned with problems of endogeneity of explanatory variables with respect to the dependent variable. That is, x is expected to cause y, but we suspect that y may also cause x. This is also called the simultaneity problem, and can lead to biased estimates. For example, in Mehlum et al. (2006b) the regression of GDP growth on resource abundance and quality of institutions, the dependent variable is likely to be causal to the institutions variable. That is to say, we expect that as countries grow richer, they can also afford better institutions. The simultaneity problem can be remedied by employing an instrumental variable approach. However, when the variable we are trying to explain is extraction rate, i.e. production over reserves, it is not clear why there should be a simultaneity bias. We might believe that a country that is abundant in natural resources also suffers from low quality institutions (see Ross, 2001b, 2001a), but there is no obvious reason for why extraction relative to reserves at the mine-level should affect institutions. Hence I have chosen not to include an instrumental variable estimation.[6]

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[6] It should be noted that Bohn and Deacon (2000), the only empirical analysis on this topic that is fairly similar to mine, do not mention simultaneity problems in the main regressions.

5 | Empirical Analysis

The first and preliminary step of the empirical analysis was done in section 4.1.2, where iron, bituminous coal and non-bituminous coal were ranked in terms of capital intensity. This chapter presents the results from the econometric analysis. Section 5.1 presents the result from the main regressions, and discusses the magnitude and significance of the estimated effects. Section 5.2 gives the results from various tests of robustness, and section 5.3 shows what happens to the results when China is dropped from the sample. An alternative approach to capital intensity is empirically tested and shortly discussed in section 5.4, and finally section 5.5 discusses some possible extensions of the analysis.

5.1 Regression Results

Results from ordinary least squares, random effects and fixed effects regressions on equation (1) are shown in table 5.1. Dummies for iron and bituminous coal are included in the OLS and random effects regressions to account for the possibility that extraction rates might be inherently different between the three groups of minerals in the sample.[1] Standard errors are clustered on country-years because the expropriation risk index is common for all mines in the same country, which might give some correlation between the residuals of mines within a given country and year.[2] The following sections 5.1.1 and 5.1.2 discuss the results from the OLS and fixed effects regressions, respectively.

5.1.1 OLS Regression

From the OLS regression in table 5.1 we see that the coefficient estimates of the three expropriation variables are all significant and of the expected

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[1] Consult table A.5 in the appendix for a description of all variables used in the regressions.

[2] Alternatively, clustering standard errors by mines either increases or leaves unchanged the t-values.

sign. The results imply that a one unit increase in the risk index is expected to give an approximate decrease in extraction rate for non-bituminous coal mines of $0.00977 \times 100\ \% \approx 1\ \%$. For iron mines the same effect is about 1.8 %, and for bituminous coal it is close to 1.5 %.[3] This indicates that the *ex ante* effect is stronger than the *ex post* effect for all minerals, but more so for the more capital-intensive minerals iron and bituminous coal, consistent with conjectures 1–3 in section 2.5.1. As suggested by the suspected but statistically insignificant difference in capital intensities, iron extraction rates seem to respond more negatively than bituminous coal extraction rates. The effects are quite large: A one standard deviation increase in expropriation risk is associated with a 0.44 log-point—or approximately 44 %—decrease in extraction rate of iron, a 37 % decrease for bituminous coal, and a 24 % decrease for non-bituminous coal.[4] This implies that in countries where the resource sector is large relative to the rest of the economy, expropriation risk may have severe economic consequences through the resource extraction channel. A country with bad property rights institutions along with large endowments of a capital-intensive natural resource is likely to be performing below its economic potential. The model does not have very high explanatory power, with an adjusted R^2 of 0.077, most likely because there are a number of omitted variables, notably technology and geology. Note, however, that the main focus here is estimating the effects of expropriation risk, not attempting to explain as much variation in extraction rates as possible.

To make the effects of expropriation risk more concrete, consider Norway and Algeria. Both countries are minor producers of iron, but while Algeria scores of 70 on the risk index in 2011, Norway scores 10 in the same year. If Algeria had the property rights institutions of Norway, all other things equal, the OLS estimation in table 5.1 implies that the average extraction rate of iron would be 0.082 units higher, up from 0.042 to 0.122.[5] Be aware, however, that this does not imply that Norway's iron extraction path is optimal, or that the optimal paths for Norway and Algeria are the same. This will depend, for example, on a society's preferences for intergenerational equity.

Comparing the three regressions in table 5.1 we notice that the sign of the coefficients are the same sign and similar magnitude for all variables except

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[3] Note that the definition of extraction rate is mineral production in a given year divided by the size of reserves in 2011, and it should thus be interpreted with some care. For example, the extraction rate may take a value higher than 1, i.e. production may be higher than reserves, which is of course impossible in a physical sense. However, for convenience, I refer to this variable as the 'extraction rate'.

[4] One standard deviation is about 24.5, see table 3.2 in section 3.2

[5] Note that because of Jensen's inequality, $\widehat{ln(prodrate)} \leq ln(\widehat{prodrate})$. To get the correct predicted values, I apply the formula $\widehat{prodrate} = exp(\frac{\hat{\sigma}^2}{2} + \widehat{ln(prodrate)})$. The value of $\hat{\sigma}^2$ in the OLS regression in table 5.1 is 1.2899. See Hill, Griffiths, and Lim (2008, p. 95).

Table 5.1: Estimation of equation (1)

	Dependent variable is ln(production/reserves)		
	(1) OLS	(2) Random effects	(3) Fixed effects
exprisk	-0.00977***	0.00300	0.00896**
	(-10.24)	(1.07)	(2.19)
expriskiron	-0.00805***	-0.01016***	-0.01249***
	(-3.95)	(-2.74)	(-2.90)
expriskbitum	-0.00527***	-0.00566**	-0.00562*
	(-3.84)	(-2.22)	(-1.72)
iron	0.33475***	0.39996	
	(3.12)	(1.17)	
bituminous	0.30485***	0.25673	
	(3.27)	(1.11)	
lprice	-0.23082***	-0.05305	-0.00580
	(-8.58)	(-0.76)	(-0.08)
year	0.04919***	0.03661***	0.02968***
	(7.84)	(5.03)	(4.38)
constant	-101.02491***	-77.06812***	-63.39377***
	(-8.05)	(-5.31)	(-4.74)
N	16215	16215	16215
adj. R^2	0.077		0.065

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: t-statistics in parentheses are based on robust standard errors clustered on 562 country-years. *exprisk* is the expropriation risk index; *expriskiron* and *expriskbitum* are interactions between *exprisk* and dummies for iron and bituminous coal mines, respectively; *lprice* is the log of mineral price; and *year* is a time trend. The sample is limited only by missing values on production, reserves, prices and the expropriation risk variable. The regression includes 1579 mines in 46 countries, of which 173 are iron mines, 411 are non-bituminous coal mines and 995 are bituminous coal mines. Random and fixed effects regressions are at the mine-level. Note that reserves are fixed over time within mines.

exprisk, *lprice* and *year*. Any bias in the coefficients of *lprice* and *year* are not causes of concern in themselves, but the large change in the coefficient of *exprisk* from the OLS and random effects estimations to the fixed effects estimation is an indication that there is some unobserved heterogeneity which is correlated with *exprisk*. A Hausman-test comparing the estimates of the random and fixed effects regressions strongly rejects the null hypothesis of the coefficients being the same, with a p-value of less than 0.0000, so random effects and thus OLS estimation are likely to be inconsistent and biased. This is, however, more interesting than it is inconvenient—I have already implied in section 2.5.3 and 4.2.1 that cross-mine analysis should show stronger evidence of the *ex ante* effect than within-mine analysis, the reason being the time lag of investments and persistency of expropriation risk within countries. If most of the unobserved heterogeneity can be attributed to differences in average investment levels in the mining sector, we should expect mines in countries with low investments to have less production capital, and lower extraction rates on average. Hence, I believe that the results from the pooled OLS regression in table 5.1 give a good indication that there is a significant negative effect of expropriation risk on extraction rates, and that this effect increases in absolute value with capital intensity.

5.1.2 Fixed Effects Regression

While OLS should indicate the long run effects of expropriation risk, fixed effects estimation should be an indicator of short run effects, because it considers only within-mine variation. The results from the fixed effect regression in table 5.1 indicates that expropriation risk has a positive and significant effect on non-bituminous coal extraction rates of approximately 0.9 % per unit increase in the risk index. The interpretation is that within a specific mine, an increase in expropriation risk from one year to the next tends to speed up extraction, through the *ex post* effect. Iron extraction, however, is expected to respond negatively over time, by approximately $0.00896 - 0.0125 = -0.00354 \approx -0.35$ % per unit increase in expropriation risk. Using the notation in equation (1) in section 4.2, a t-test with the null and alternative hypotheses $H_0 : \beta_1 + \beta_2 \geq 0$ and $H_1 : \beta_1 + \beta_2 < 0$ has a t-value of -1.797, less than the left-tail critical t-value $t_{(0.05,555)} = -1.645$.[6] Thus we conclude that the within-mine effect of expropriation risk on iron extraction is significantly less than zero at the 5 % level. For bituminous coal the effect is less positive than for non-bituminous coal; the sum of the coefficients for *exprisk* and *expriskbitum* is significantly greater than zero, with a t-value of 1.71. The explanatory power for the fixed effect estimator is 0.065, lower than for the OLS regression.

The results from the fixed effects regression are actually somewhat puzzling. I have argued that the *ex ante* effect is not likely to be very visible within mines, so that the fixed effect estimates should reflect mainly the *ex post* effect, but the estimates indicate otherwise. One possible explanation is that because non-bituminous coal is not very capital-intensive, changing production by adjusting the number of workers is relatively easy. That is to say, extraction can quickly be increased (decreased) when there is an increase (decrease) in expropriation risk. For iron and bituminous coal, production might

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[6] The standard error is $se(\widehat{\beta}_1+\widehat{\beta}_2) = \sqrt{var(\widehat{\beta}_1) + var(\widehat{\beta}_2) + 2cov(\widehat{\beta}_1, \widehat{\beta}_2)}$. The respective (co-)variances can be found in the covariance matrix in table C.1 in the appendix.

be less sensitive to the number of workers, so quick adjustments of production might not be as easy. The coefficients for bituminous coal are smaller than that for non-bituminous coal, and significantly greater than zero, consistent with this explanation. By the same argument, we would expect a positive or no significant effect on iron extraction of a change in expropriation risk, but the sum of coefficients for *exprisk* and *expriskiron* is significantly negative. As we shall see in section 5.3, however, this no longer holds when Chinese mines are dropped from the sample.

I have chosen to emphasize the results from the fixed effects and OLS estimations, so I will only shortly comment on the random effects estimation. The coefficients from the random effects regression are slightly different than the OLS estimation, especially for *exprisk*, which is not significant at the 5 % level. A possible explanation is that the random effects estimator puts heavier weight on the within-mine variation more than does the OLS estimator. Since the within-effect of *exprisk* is positive and the OLS coefficient is negative, the insignificant coefficient in the random effects model may be a result of the positive and negative effects canceling out. The coefficients for *expriskiron* and *expriskbitum* are very similar in all three regressions, and I therefore believe that I am not making a serious mistake by not discussing the random effects estimation in more detail.

5.2 Robustness tests

Table 5.2 shows the results from some robustness tests on the OLS regression in table 5.1, the results from which are repeated in regression (1) in table 5.2. Firstly, we might suspect that a country's investment–GDP ratio could explain some of the variation in extraction rates, for example because higher investments give better production technology and thus higher extraction. If investment share is correlated with the expropriation risk index, the estimates in regression (1) might be biased. Adding the investment share of PPP converted GDP from Penn World Table (Heston & Summers, 2012) to the equation has virtually no effect on the expropriation risk coefficients or their t-values, and the variable itself is not significant. Next, consider interactions between the investment–GDP ratio and the iron and bituminous dummies; If a higher investment share has an effect on extraction, this might be especially evident for capital-intensive minerals. As expected, the interaction between iron and the investment–GDP ratio is positive and significant. An increase in the investment share by one percentage point is expected to increase iron extraction rates with approximately 2.9 %. Notice, however, that the coefficients of the expropriation risk variables remain significant, and are largely unchanged except for *expriskiron*, which decreases slightly in absolute value.

The last regression is based on the same variables as regression (3), but state owned mines are dropped from the sample. We would expect that privately owned and state owned mines behave differently in the face of expropriation risk; that is, if the source of expropriation risk is the government, or more generally a country's institutions, there is no obvious reason why state owned mines should respond to this risk at all. The results from regression (4) shows that the exclusion of state owned mines leaves the expropriation risk coefficients largely unchanged and highly significant. Introducing world region fixed effects has little effect on the expropriation–mineral interaction variables. The absolute value of *exprisk* is reduced, but it is still significant at the 10 % level, so the qualitative conclusions are unchanged.

Now consider some modifications of the countries in the sample. Table 5.3 shows how the estimates change when world regions are excluded one by one.[7] Dropping Asia from the regression—which involves excluding big producers like India and China—has virtually no effect on neither the size of the coefficients nor their significance, but the R^2 increases slightly. We reach the same conclusions by dropping Africa, Oceania, Europe and Latin America. However, when North America (Canada and USA) is dropped, expropriation risk interacted with the bituminous coal dummy is no longer significant. USA and Canada account for about 12 % of the sample mine-years for coal (table A.1), and both have very low expropriation risk (table A.6). Other large coal producers like Russia, China and India have substantially higher average expropriation risk. Thus the insignificant coefficient of *expriskbitum* might be a result of the loss of variation when excluding North America, and does not necessarily reduce the strength of the conclusions. All in all, the size and significance of the coefficients do not change very much between the regressions in tables 5.2 and 5.3, so the results of the baseline OLS regression in table 5.1 seem fairly robust to changes in the model and the sample.

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[7] World regions are as defined by the UN. See table A.1 for an overview of which regions the different countries belong to.

Table 5.2: Robustness tests

	Dependent variable is ln(production/reserves)				
	(1)	(2)	(3)	(4)	(5)
exprisk	-0.00977***	-0.01003***	-0.00993***	-0.00909***	-0.00312*
	(-10.24)	(-10.00)	(-9.57)	(-8.96)	(-1.90)
expriskiron	-0.00805***	-0.00772***	-0.00626***	-0.00681***	-0.00949***
	(-3.95)	(-3.56)	(-2.86)	(-3.06)	(-4.62)
expriskbitum	-0.00527***	-0.00547***	-0.00544***	-0.00582***	-0.00521***
	(-3.84)	(-3.99)	(-3.62)	(-4.41)	(-3.84)
iron	0.33475***	0.30196***	-0.46020	-0.68885**	0.44179***
	(3.12)	(2.78)	(-1.55)	(-2.26)	(4.02)
bituminous	0.30485***	0.31569***	0.40651***	0.84604***	0.31448***
	(3.27)	(3.38)	(3.21)	(6.07)	(3.49)
lprice	-0.23082***	-0.23076***	-0.23673***	-0.16007***	-0.24022***
	(-8.58)	(-8.87)	(-9.03)	(-5.58)	(-9.37)
year	0.04919***	0.05227***	0.04932***	0.04710***	0.04606***
	(7.84)	(7.66)	(6.73)	(6.29)	(8.38)
ki		-0.00151	-0.00150	-0.00205	
		(-0.44)	(-0.46)	(-0.59)	
ironki			0.02935***	0.03505***	
			(2.79)	(3.23)	
bitumki			-0.00336	-0.02117***	
			(-0.70)	(-4.36)	
constant	-101.02***	-107.14***	-101.20***	-96.98***	-95.08***
	(-8.05)	(-7.84)	(-6.89)	(-6.47)	(-8.64)
N	16215	14897	14897	11915	16215
adj. R^2	0.077	0.079	0.081	0.088	0.021

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
(1) Baseline OLS regression on full sample.
(2) OLS regression with investment–GDP ratio.
(3) OLS regression with investment–GDP ratio and interactions.
(4) Same as (3), but without state owned mines.
(5) World region fixed effects.
Notes: t-statistics in parentheses are based on robust standard errors clustered on country-years. Investment–GDP ratios, *ki*, were collected from Penn World Table 7.1 (Heston & Summers, 2012). *ironki* and *bitumki* are dummies for iron and bituminous coal interacted with the investment–GDP ratios. World regions are defined in table A.1.

Table 5.3: Second round of robustness tests—dropping world regions

	Dependent variable is ln(production/reserves)					
	(1) Asia	(2) Africa	(3) Oceania	(4) Europe	(5) North Am.	(6) Latin Am.
exprisk	-0.00909***	-0.00960***	-0.00821***	-0.01012***	-0.01225***	-0.00972***
	(-5.93)	(-10.26)	(-8.54)	(-10.00)	(-8.94)	(-10.19)
expriskiron	-0.00958***	-0.00660***	-0.00734***	-0.00737***	-0.00728***	-0.01071***
	(-4.00)	(-3.14)	(-3.48)	(-3.19)	(-2.73)	(-5.21)
expriskbitum	-0.00759***	-0.00559***	-0.00718***	-0.00407***	0.00053	-0.00535***
	(-3.25)	(-3.90)	(-4.83)	(-3.24)	(0.32)	(-3.84)
iron	0.14452	0.33273***	0.33005***	0.38551***	0.27607*	0.46520***
	(1.08)	(3.11)	(2.71)	(3.45)	(1.74)	(4.31)
bituminous	0.49714***	0.31522***	0.45259***	0.20565**	-0.08902	0.30945***
	(3.80)	(3.32)	(4.37)	(2.16)	(-0.76)	(3.30)
lprice	-0.27945***	-0.25034***	-0.24832***	-0.16668***	-0.23395***	-0.23950***
	(-3.84)	(-9.48)	(-9.10)	(-5.84)	(-8.67)	(-9.00)
year	0.03647***	0.05298***	0.05142***	0.04629***	0.05477***	0.04849***
	(4.49)	(8.78)	(7.94)	(6.00)	(8.55)	(7.47)
constant	-75.36***	-108.57***	-105.56***	-95.37***	-112.01***	-99.59***
	(-4.65)	(-8.99)	(-8.14)	(-6.18)	(-8.74)	(-7.66)
N	8517	15577	15032	11854	14298	15797
adj. R^2	0.108	0.081	0.065	0.081	0.051	0.080

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: t-statistics in parentheses are based on robust standard errors clustered on country-years. Names of the world regions are included above each regression to indicate which one is dropped from the sample.

5.3 Dropping China from the Sample

Table A.1 in the appendix shows that almost one third of the observations are from coal mines in China, so we might suspect that these observations are driving the results. Estimates from the OLS, random effects and fixed effects regressions on equation (1) when Chinese mines are dropped from the sample are shown in table 5.4. OLS estimation gives similar results to those in table 5.1, but for the random and fixed effects models, none of the expropriation risk variables are now significant at the 5 % level, except *exprisk* in the random effects estimation.

A fixed effect estimation of equation 1 on Chinese coal mines is shown in table C.2 in appendix C. Notice that the R^2 is almost 0.29, indicating that the fixed effects model has a lot more explanatory power for China than for the rest of the world. The coefficient of *exprisk* is positive and significant at the

10 % level, and negative but insignificant for *expriskbitum*. Random effects and OLS regressions yield insignificant results.

The detrimental effect on the fixed effects estimation of dropping China from the sample motivates a discussion of what might be going on. Expropriation risk in China increases from 70 to 80 in 2007, but the reason for this change is not clear, because the authors of the index do not give details on the rationale for changes in each case. Actually, China passed a law in 2007 designed to *increase* protection of private property (Kahn, 2007), so we would have expected expropriation risk to decrease in that year, not increase. Another puzzling fact is that most, if not all Chinese mines in the sample are owned by the state, at different levels of government (province, municipality, county and city), either directly or indirectly. Thus there is no obvious reason for why coal extraction should be higher when expropriation risk increases.

Table 5.4: Estimation of equation (1) without China

	Dependent variable is ln(production/reserves)		
	(1) OLS	(2) Random effects	(3) Fixed effects
exprisk	-0.01075***	-0.00545***	-0.00234
	(-8.32)	(-2.89)	(-1.28)
expriskiron	-0.00668***	0.00082	0.00139
	(-3.03)	(0.29)	(0.56)
expriskbitum	-0.00666***	-0.00000	0.00249
	(-3.10)	(-0.00)	(0.92)
iron	0.20216	-0.44837**	
	(1.59)	(-2.03)	
bituminous	0.28862**	-0.27608*	
	(2.34)	(-1.86)	
lprice	-0.18884***	0.05288	0.08413
	(-2.97)	(1.02)	(1.60)
year	0.03467***	0.01917***	0.01489***
	(4.72)	(4.98)	(3.69)
constant	-71.97292***	-41.77133***	-33.72382***
	(-4.91)	(-5.50)	(-4.24)
N	11718	11718	11718
adj. R^2	0.090		0.023

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: t-statistics in parentheses are based on robust standard errors clustered on 550 country-years. All mines in China were dropped from the estimations.

A part of the explanation for these results might be that production data from 2008–2011 is of questionable quality—almost all of the data in these years has been estimated by IntierraRMG rather than reported by the mining companies. This period approximately coincides with the period when expropriation risk is higher, and it is hard to determine how accurate the estimated data are. However, recall that the results from the fixed effects regression in table 5.1 were actually somewhat puzzling, because it seemed that the *ex ante* effect was unexpectedly present in the short run within mines. That is to say, the non-existing effects we get when China is dropped is not entirely unexpected, and might be an indication that the initial results were spurious. Regression on a fixed effects model for China in the years 2000–2007 (not shown), i.e. excluding the estimated production data, leaves expropriation risk insignificant at any reasonable level of significance.

China is an enormous country, arguably with substantial heterogeneity across regions, and it may thus be deserving of a dedicated study. From these results, however, it seems like the effect of expropriation risk on mineral extraction is in general difficult to capture by a fixed effects model: (i) The average within-country variation of expropriation risk is very small; (ii) long run effects are difficult to observe within mines; (iii) even though *ex post* effects can appear in the short run, coal and iron production might take time to adjust.

5.4 Revisited: Determining Capital Intensities

The main strategy for determining capital intensity, described in section 4.1, involves comparing average investment–output ratios. One advantage of this approach is its general nature—it can be applied to different minerals, enabling comparison of capital intensities. An alternative, not so general approach is to differentiate with respect to production methods for specific minerals. This section shortly discusses an attempt at this, which seems to give results consistent with those in section 5.1.1.

A publication from the World Coal Institute (2005) indicates that the room & pillar method of coal mining requires a lot less investment in machinery relative to production than does the longwall method.[8] The choice between the two methods is largely dictated by geology and other properties of the coal deposit, so they are not perfect substitutes. This implies that we would expect the investment depressing effect of expropriation risk to have a larger

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[8] The investment–output ratio approach in section 4.1.2 is not conclusive in this case, because there are too few observations of longwall and room & pillar mining with non-zero values on the 'project cost' variable.

negative impact on mining from deposits that require longwall mining.

Table 5.5 shows the results from an OLS regression on a sample that includes only mines that are reported to employ either the room & pillar or longwall method of coal mining. The effect of capital intensity is captured by creating a dummy for longwall mining and interacting it with the expropriation risk index. Expropriation risk has a small negative and insignificant coefficient, but the interaction variable *expriskl ongwall* is negative and significant at the 1 % level. This indicates that while expropriation risk has no apparent effect on coal extraction in mines that employ the less capital-intensive room & pillar method, it has a strong negative effect on coal extraction in mines that use the relatively more capital-intensive longwall method, consistent with the overall results from the OLS regressions in previous sections.

Table 5.5: Room & pillar and longwall mining

	ln(production/reserves)	
exprisk	-0.0026	(-0.73)
expri sklongwall	-0.0134^{***}	(-3.69)
longwall	0.5819^{***}	(5.62)
lprice	-0.3089^{***}	(-9.74)
year	0.0647^{***}	(8.07)
constant	-132.01^{***}	(-8.19)
N	6302	
adj. R^2	0.086	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: t-statistics in parentheses are based on robust standard errors clustered on 224 country-years.

5.5 Extensions and Further Research

The results from the empirical part of this thesis are definitely interesting in themselves, but they also give motivation for further research, for example because the models have low explanatory power. There are a number of direct extensions and modifications of the empirical analysis that could give more detailed insight into the mechanisms at work. This section provides a brief presentation of four possible extensions of the analysis in this thesis, as well as one more related to the paper by Bohn and Deacon (2000).

The first possible extension could be to examine whether environmental regulations of the mining sector affect extraction decisions. We might suspect that there is less political pressure for environmental issues in less developed countries, which also tend to have higher expropriation risk. The producers cost of regulations is likely to vary between minerals, because the waste from the mining process will vary. Coal, for example, has been shown to have a large detrimental effect on the environment (Rathore & Wright, 1993; Tiwary, 2001; Younger, 2004). If regulations on coal mining increases the marginal cost of extraction, theory predicts that extraction will be slower[9]. Isolating this effect, we would expect coal extraction to be more rapid in less developed and less regulated economies. Thus the effect of expropriation risk on extraction in the OLS regression in table 5.4 might be an underestimation, but this will of course depend on the correlation between expropriation risk and environmental regulation.

We could also imagine an extension by simply including more minerals in the analysis. Ideally, minerals would be ordered in terms of capital intensity, which would make us able to provide better evidence of the proposed causality. Moreover, some minerals are probably more exposed to expropriation than others. This thesis has examined coal and iron specifically, but mostly because of analytical convenience. Minerals like oil, gold and diamonds have through history been especially associated with conflict and expropriation (Harsch, 2007), so we may expect an analysis on these minerals to show even stronger effects. Notice also from figures B.1 and B.2, showing the distributions of coal and iron mines across countries, that neither of these minerals are found in great amounts in Africa or South America, two continents that historically have seen the lion's share of conflict over natural resources. Therefore, it might be interesting to do an analysis on minerals that are more common in these regions, in which many countries exhibit high levels of expropriation risk (see table A.6).

Another extension could involve categorizing mines by state, domestic and foreign ownership. Firstly, if expropriation risk comes from the authorities, we might expect state owned mines to be fairly unresponsive to risk. Secondly, we may believe that foreign companies are more frequently targeted than are domestically owned companies. Thirdly, one could examine the effects on state owned mines of risk from other sources than the government.

This thesis is concerned mainly with formal property rights institutions, as defined by the property rights variable from the Index of Economic Freedom (The Heritage Foundation, 2013). An obvious test of robustness would be to check whether we get the same results with other property rights indices. Moreover, we would expect that there are a number of other variables that also affect mineral extraction, notably armed conflict. One could for example combine mineral extraction data with the Georeferenced Event Dataset

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[9] This is the opposite effect of capital investments, which decreases the marginal cost of extraction and speeds up extraction. Confer section 2.5.1.

(GED) from the Uppsala Conflict Data Program[10] with GPS information on individual mines. This would allow for an investigation of effects of ownership risk that does not respect national borders or is very local. The UCDP dataset also has information about whether conflict is state-based, non-state or one-sided, effects of which could be suspected to vary depending on mine ownership.

Although the theory and empirical results in Bohn and Deacon (2000) are convincing, there may be other explanations for an observed negative effect of expropriation risk on extraction rates. One such explanation is given by Laurent-Lucchetti and Santugini (2012), who claim that (i) the mineral sector usually consists of only a few firms, and (ii) recent expropriations only affected a single firm. From this outset they construct a game theoretic framework with two firms, which have an agreement with the government of extracting from a common-pool resource. A typical example would be large oil fields where a few firms compete to extract from the same "pool" of reserves. The exogenous expropriation risk is known by both firms, but they do not know, *ex ante*, the identity of the to-be excluded firm. Both firms have an expected value that comprises both the loss in the event of expropriation and the gain from ending up as the only extracting firm, should the other firm be expropriated. This gain is a result of the alleviation of the externality caused by multiple firms exploiting a common-pool resource, known as the tragedy of the commons. The total effect of the expropriation risk ultimately depends on the elasticity of demand, i.e. how strong the tragedy of the commons is (see e.g. Koulovatianos & Mirman, 2007). If the expected gain outweighs the expected loss, extraction rates will go down, because of increased incentives for long-run management of the resource. This theory implies that Bohn and Deacon's (2000) results in the oil production estimation may not only be driven by capital intensity, which could be tested empirically by comparing offshore and onshore oil production, which likely have different average sunk costs, but should be similar with respect to Laurent-Lucchetti and Santugini's assumptions.[11]

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[10] See http://www.pcr.uu.se/research/UCDP/.

[11] This difference in cost structures leads Bohn and Deacon (2000) to exclude offshore fields from the sample.

6 Conclusion

This thesis has been concerned with how risk of expropriation affects the decisions of mine owners, specifically whether mineral extraction rates are affected positively or negatively by this risk. Although the theoretical literature is not unanimous in its predictions, most papers argue that the direction of the effects is related to the need for investments in exploration and mining capital (Olsen, 1987; Farzin, 1984; Lasserre, 1982; Peterson, 1978; Bohn & Deacon, 2000). Bohn and Deacon (2000) provide evidence of a negative effect if capital intensity is high enough; however, the evidence for resources with low capital intensity is less compelling. I have argued that we should test the theory on resources that are similar in most aspects, but differ in terms of capital intensity.

Comparisons of investment–output ratios show that iron and bituminous coal are both significantly more capital-intensive than non-bituminous coal, and that iron is likely also more capital-intensive than bituminous coal. Results from pooled OLS regressions indicate that the effect of expropriation risk on extraction rates is negative for all minerals, but more strongly negative for iron and bituminous coal. Depending on model specification, iron extraction is also more negatively affected by risk than is bituminous coal extraction. The effects are large, implying substantial economic consequences of expropriation risk, through its impact on natural resource exploitation. OLS regressions most likely capture the long run effects of expropriation risk, because institutions tend to be persistent within countries, and investments take time to materialize. Fixed effects regressions give some evidence of a positive short run effect of risk on coal extraction, but the results are not robust to changes in the sample, and seem very much driven by Chinese mines.

To the best of my knowledge, this thesis is the first attempt to use cross-country data to empirically examine the effects of property rights institutions on non-fluent mineral extraction. Extensions, modifications and new approaches may be appropriate for deeper investigation into the matter at hand. I nevertheless believe that my analysis, though perhaps somewhat preliminary, represents an original and independent contribution to the empirical literature on the subject.

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Appendices

A | Data and summary statistics

Table A.1: Mine-years in sample by country

		Sample		Iron mines		Coal mines	
Country	World region	No.	Pct.	No.	Pct.	No.	Pct.
Algeria	Africa	33	0.20	33	1.55		
Argentina	Latin Am.	6	0.04			6	0.04
Australia	Oceania	1087	6.70	216	10.16	871	6.18
Austria	Europe	17	0.10	17	0.80		
Bangladesh	Asia	1	0.01			1	0.01
Botswana	Africa	12	0.07			12	0.09
Brazil	Latin Am.	133	0.82	128	6.02	5	0.04
Canada	North Am.	275	1.70	53	2.49	222	1.58
Chile	Latin Am.	58	0.36	58	2.73		
China	Asia	4497	27.73	4	0.19	4493	31.89
Colombia	Latin Am.	53	0.33			53	0.38
Czech Rep.	Europe	78	0.48			78	0.55
Egypt	Africa	22	0.14	17	0.80	5	0.04
Germany	Europe	3	0.02			3	0.02
Greece	Europe	60	0.37			60	0.43
Hungary	Europe	25	0.15			25	0.18
India	Asia	2581	15.92	697	32.80	1884	13.37
Indonesia	Asia	226	1.39			226	1.60
Iran	Asia	74	0.46	74	3.48		
Kazakhstan	Asia	76	0.47	24	1.13	52	0.37
Liberia	Africa	1	0.01	1	0.05		
Mauritania	Africa	32	0.20	32	1.51		
Mexico	Latin Am.	82	0.51	58	2.73	24	0.17
Mongolia	Asia	45	0.28			45	0.32
Mozambique	Africa	1	0.01			1	0.01
New Zealand	Oceania	96	0.59	32	1.51	64	0.45
Niger	Africa	6	0.04			6	0.04
Norway	Europe	61	0.38	25	1.18	36	0.26
Peru	Latin Am.	17	0.10	17	0.80		
Philippines	Asia	10	0.06			10	0.07
Poland	Europe	454	2.80			454	3.22
Romania	Europe	132	0.81			132	0.94
Russia	Europe	2517	15.52	225	10.59	2292	16.27
Serbia	Europe	4	0.02			4	0.03
South Africa	Africa	503	3.10	56	2.64	447	3.17
Swaziland	Africa	12	0.07			12	0.09
Sweden	Europe	34	0.21	34	1.60		
Thailand	Asia	10	0.06			10	0.07
Tunisia	Africa	4	0.02	4	0.19		
Turkey	Asia	177	1.09	37	1.74	140	0.99
UK	Europe	74	0.46			74	0.53
USA	North Am.	1642	10.13	137	6.45	1505	10.68
Ukraine	Europe	902	5.56	96	4.52	806	5.72
Uzbekistan	Asia	1	0.01			1	0.01
Venezuela	Latin Am.	69	0.43	50	2.35	19	0.13
Zimbabwe	Africa	12	0.07			12	0.09
Total		16215	100	2125	100	14090	100

Notes: Source: IntierraRMG Raw Materials Data. Table gives the distribution of the total number of observations in the sample..

Table A.2: Mineral statistics by country

	Non-bituminous coal			Bituminous coal			Iron		
Country	Prod.	Prodrate	Reserves	Prod.	Prodrate	Reserves	Prod.	Prodrate	Reserves
Algeria							1.7	.0033	2004
Argentina	.15	.0002	750						
Australia	44	.12	1171	292	.13	11678	242	.18	6368
Austria							1.9	.019	100
Bangladesh				.1	.0014	70			
Botswana				.88	.00017	5080			
Brazil				.98	.024	40	167	.038	13715
Canada	36	.26	747	33	.12	1202	37	.03	1936
Chile							9.9	.034	677
China	422	.082	35991	525	.039	36612	1.9	.0032	612
Colombia				61	.043	2649			
Czech Rep.	39	.17	735	11	.059	195			
Egypt				.34	.017	20	2.2	.028	78
Germany	36	.027	1300						
Greece	64	.016	7755						
Hungary	7.1	.19	633						
India	86	.06	2933	256	.022	13740	116	.059	4779
Indonesia	87	.041	4189	44	.075	826			
Iran							15	.012	1684
Kazakhstan	4.2	.024	177	70	.022	3982	1.6	.021	2806
Liberia							1.3	.093	14
Mauritania							7.3	.012	750
Mexico	4.9	.05	99	4	.018	219	8.3	.1	305
Mongolia	5.1	.0077	950	3.7	.0098	334			
Mozambique				.62	.00065	952			
New Zealand	2.3	.14	19	2.2	.19	26	2.2	.0091	288
Niger				.17	.034	5			
Norway				2.5	.1	16	1.7	.007	517
Peru							6.2	.021	300
Philippines	3.9	.042	93						
Poland	60	.066	1309	94	.03	4962			
Romania	31	.13	635						
Russia	75	.1	7449	227	.095	15099	81	.014	25957
Serbia	7	.25	30						
South Africa	4.6	.058	159	218	.12	7032	43	.072	1765
Swaziland	.35	.1	3.5						
Sweden							22	.024	945
Thailand	.51	.64	.79						
Tunisia							.09	.0018	50
Turkey	28	.029	1509	2.2	.0042	1016	.62	.055	17
UK	.13	.025	5.3	9	.27	64			
USA	438	.092	11196	281	.1	5987	52	.11	2011
Ukraine	7.8	.015	624	62	.017	4770	43	.017	3417
Uzbekistan				.085	.000085	1000			
Venezuela				6	.026	208	18	.045	667
Zimbabwe				2.4	.017	141			
Total	1494	.089	80463	2208	.066	117924	883	.061	71763

Notes: Source: IntierraRMG Raw Materials Data. 'Prod.' is the accumulated country production over all years in the sample, 'Prodrate' is the average extraction rate, and 'Reserves' is the sum of reserves over all mines in the sample.

Table A.3: Distribution of coal ranks

	Dataset		Sample	
Coal rank	Freq.	Percent	Freq.	Percent
Not specified	896	33.51	88	6.26
Anthracite	134	5.01		
Anthracite, Bituminous	14	0.52		
Bituminous	1,242	46.45	995	70.77
Bituminous, Anthracite	3	0.11		
Bituminous, Lignite	3	0.11		
Bituminous, Sub-Bituminous	1	0.04		
Lignite	189	7.07	151	10.74
Lignite, Sub-Bituminous	1	0.04		
Sub-Bituminous	182	6.81	172	12.23
Sub-Bituminous, Bituminous	1	0.04		
Sub-Bituminous, Lignite	8	0.30		
Total	2,674	100.00	1,406	100.00

Source: Raw Materials Data

Table A.4: Commodity prices, USD per metric tonne

Year	Bituminous	Sub-bitum.	Lignite	Iron
1995				35.50
1996				35.98
1997				36.38
1998				37.38
1999				31.42
2000	27.22	8.02	12.86	29.26
2001	27.95	7.35	12.70	27.02
2002	28.82	7.96	12.01	28.12
2003	28.40	8.21	11.90	32.91
2004	31.57	8.39	12.68	38.05
2005	36.80	8.68	13.49	43.80
2006	38.09	9.64	13.56	52.12
2007	38.41	10.06	14.02	55.95
2008	47.33	11.34	15.20	67.76
2009	50.52	12.17	15.73	85.20
2010	54.85	12.71	16.90	87.72
2011	50.85	13.94	17.10	87.89

Source: USGS and US Energy Information Administration

Table A.5: Variable definitions and sources

Variable	Source	Definition	Unit/range
production	RMD	Annual production of iron ore concentrate and run-of-mine coal	Million tonnes
reserves	RMD	Sum of proven and probable ore reserves	Million tonnes
lprodrate	RMD	ln(production/reserves)	
projectcost	RMD	Actual or estimated cost of current or recent project	Million USD
iron	RMD	Dummy for iron mines	$\{0,1\}$
bituminous	RMD	Dummy for bituminous coal mines	$\{0,1\}$
longwall	RMD	Dummy for longwall coal mining	$\{0,1\}$
exprisk	IEF	Expropriation risk index, 100−‘property rights’	$[0,100]$
expriskiron	IEF/RMD	Expropriation risk interacted with iron dummy	$[0,100]$
expriskbitum	IEF/RMD	Expropriation risk interacted with bituminous dummy	$[0,100]$
exprisklongwall	IEF/RMD	Expropriation risk interacted with longwall dummy	$[0,100]$
ki	PENN	Investment share of PPP converted GDP per capita, 2005 USD	Percent
ironki	PENN/RMD	Investment share interacted with the dummy for iron mines	Percent
bitumki	PENN/RMD	Investment share interacted with the dummy for bituminous coal mines	Percent
lprice	USGS/USEIA	Log of average annual coal/iron price	USD per tonne

RMD: Raw Materials Data. Copyright: IntierraRMG, Stockholm, 2013.

IEF: Heritage Foundation 2013 Index of Economic Freedom.

PENN: Penn World Tables 7.1, November 2012.

USGS: US Geological Survey Historical Statistics for Mineral and Material Commodities in the United States.

USEIA: US Energy Information Administration.

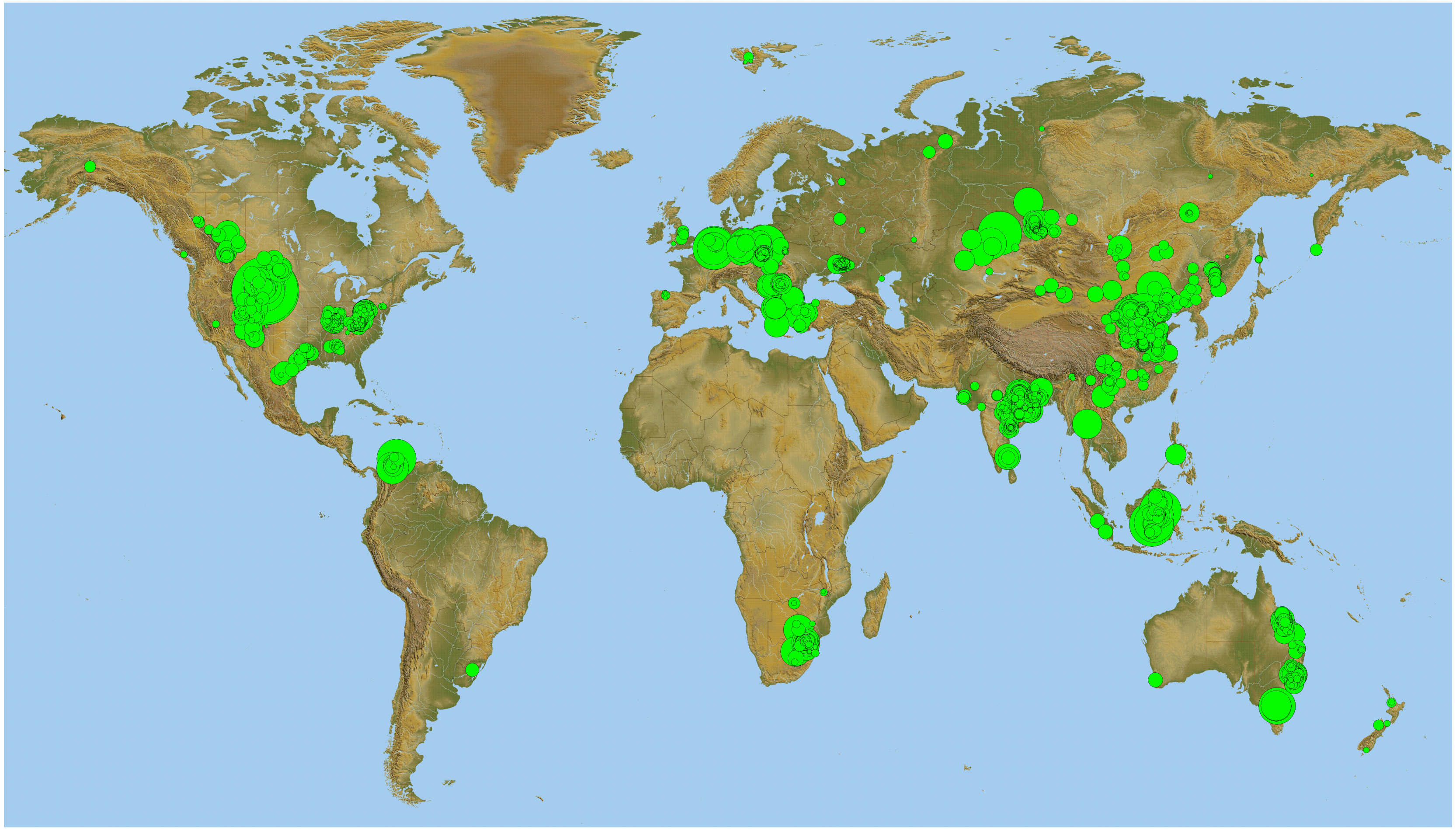
Table A.6: Countries in sample sorted by mean *exprisk*

Country	Mean	Std.dev.
Iran	90.00	0.00
Zimbabwe	89.58	6.56
China	74.36	4.96
Mauritania	70.94	1.98
Venezuela	70.00	16.36
Kazakhstan	70.00	2.31
Bangladesh	70.00	0.00
Liberia	70.00	0.00
Mozambique	70.00	0.00
Niger	70.00	0.00
Serbia	70.00	0.00
Uzbekistan	70.00	0.00
Ukraine	69.89	1.49
Indonesia	68.67	4.99
Romania	67.92	3.81
Russia	67.89	8.09
Philippines	66.00	8.43
Algeria	63.94	9.33
Mongolia	61.11	10.05
Colombia	60.19	8.88
Peru	57.65	10.91
Argentina	56.67	16.33
Egypt	53.18	5.68
Brazil	50.00	0.00
India	50.00	0.00
South Africa	50.00	0.00
Tunisia	50.00	0.00
Mexico	49.51	3.10
Turkey	48.87	4.63
Swaziland	47.92	8.91
Greece	45.83	7.66
Poland	42.04	9.10
Thailand	42.00	10.33
Czech Republic	31.15	2.12
Hungary	30.40	1.38
Botswana	29.58	1.44
Sweden	16.76	9.99
Chile	10.86	1.91
USA	10.81	1.85
UK	10.68	1.72
Australia	10.00	0.00
Austria	10.00	0.00
Canada	10.00	0.00
Germany	10.00	0.00
Norway	10.00	0.00
New Zealand	8.80	2.15
Total	53.06	24.49

Source: Heritage Foundation IEF

B | Figures

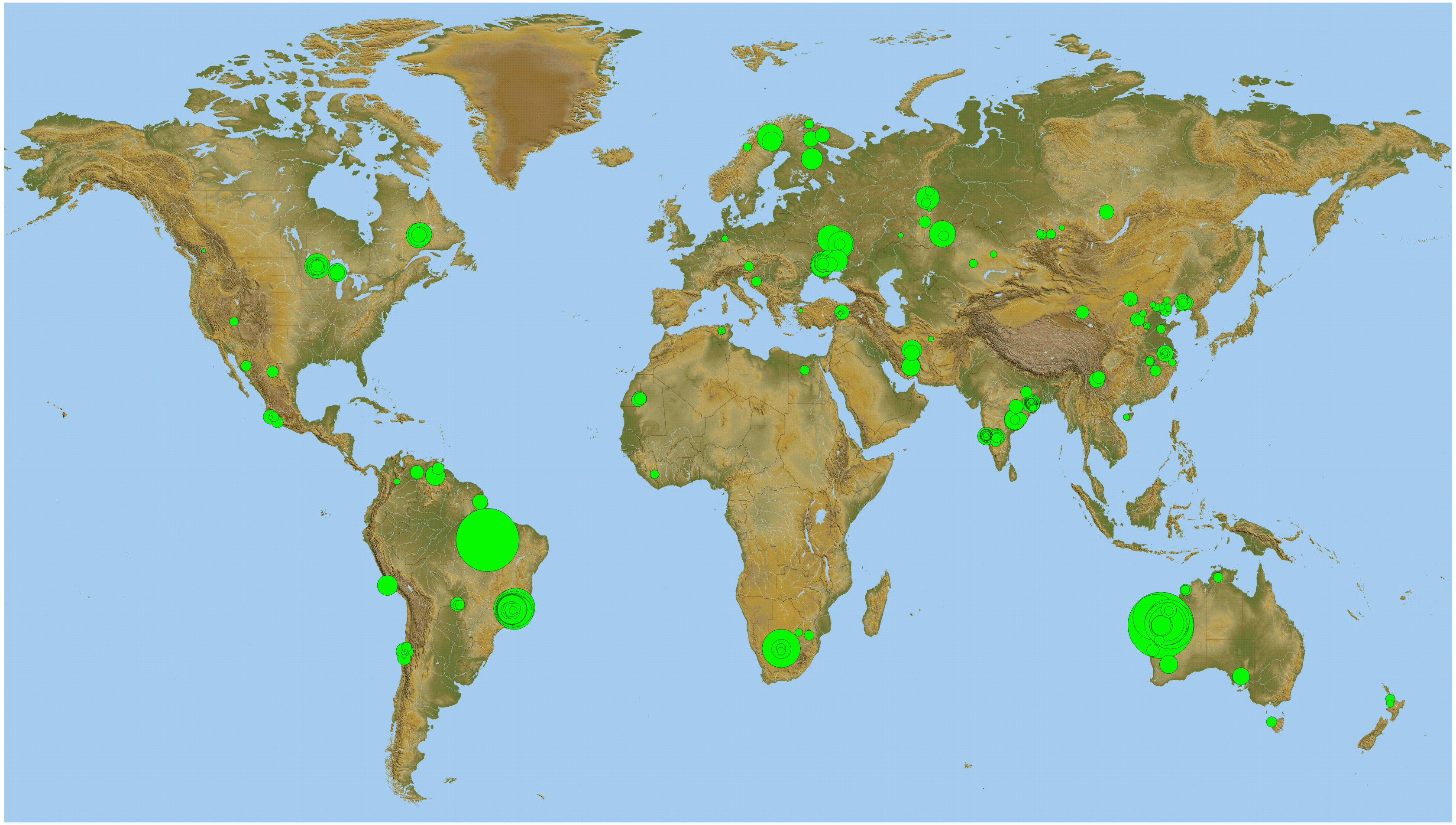
Figure B.1: 2011 Coal production.



Source: Raw Materials Data. Copyright: IntierraRMG, Stockholm, 2013

Notes: Map shows production, reflected by the size of the green bubbles, of all coal mines in the dataset, not only those in the sample.

Figure B.2: 2011 Iron production



Source: Raw Materials Data. Copyright: IntierraRMG, Stockholm, 2013

Notes: Map shows production, reflected by the size of the green bubbles, of all iron mines in the dataset, not only those in the sample.

C Regression-related tables

Table C.1: Covariance matrix from the fixed effects regression in table 5.1

	exprisk	expriskiron	expriskbitum	year	lprice	constant
exprisk	.00001668					
expriskiron	-.00001571	.00001862				
expriskbitum	-.00001177	.00001178	.00001069			
year	-1.222e-06	-3.922e-06	-4.883e-07	.00004597		
lprice	-1.356e-06	.00001996	-3.499e-06	-.00040383	.00479082	
constant	.00203377	.0081525	.0012108	-.09073767	.79384079	179.11083

Notes: Table shows covariances between regression coefficients.

Table C.2: Fixed effects regression, Chinese mines

	(1)	
	ln(production/reserves)	
exprisk	0.00717*	(1.70)
expriskbitum	-0.00585	(-1.10)
lprice	-0.28348***	(-2.78)
year	0.07721***	(10.82)
constant	-158.042***	(-11.27)
N	4497	
adj. R^2	0.289	

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: t statistics in parentheses, robust standard errors, clustered on mines.

Table C.3: Robustness tests of fixed effects regressions

	Dependent variable is ln(production/reserves)				
	(1)	(2)	(3)	(4)	(5)
exprisk	0.00896**	0.00919**	0.00891*	0.0131***	0.0128***
	(2.19)	(2.11)	(1.91)	(3.56)	(3.50)
expriskiron	-0.0125***	-0.0124***	-0.0114**	-0.0172***	-0.0182***
	(-2.90)	(-2.92)	(-2.53)	(-4.25)	(-4.55)
expriskbitum	-0.00562*	-0.00554*	-0.00457	-0.00421*	-0.00426*
	(-1.72)	(-1.74)	(-1.38)	(-1.68)	(-1.76)
lprice	-0.00580	-0.00510	-0.0134	0.116	0.0751
	(-0.08)	(-0.07)	(-0.19)	(1.47)	(1.00)
year	0.0297***	0.0297***	0.0301***	0.0135	0.0154*
	(4.38)	(4.36)	(3.91)	(1.51)	(1.77)
expriskstate		-0.00112	-0.00208	-0.00285	-0.00277
		(-0.46)	(-0.84)	(-1.05)	(-1.02)
ki			0.00429	0.0125***	0.00837*
			(0.97)	(3.37)	(1.92)
ironki					0.0116**
					(2.07)
L.exprisk				0.00197	0.00254
				(0.95)	(1.23)
L2.exprisk				-0.00165	-0.00148
				(-0.87)	(-0.77)
L3.exprisk				0.00135	0.00152
				(0.92)	(1.01)
L4.exprisk				-0.00254	-0.00224
				(-1.51)	(-1.37)
constant	-63.39***	-63.36***	-64.37***	-31.87*	-35.45**
	(-4.74)	(-4.72)	(-4.24)	(-1.80)	(-2.06)
N	16215	16215	14897	10197	10197
adj. R^2	0.065	0.065	0.063	0.043	0.044

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: t-statistics in parentheses, standard errors are robust and clustered on country-years. *expriskstate* is an interaction between a dummy for state owned mines and *exprisk*, *ki* is the investment share of GDP from Penn World Table 7.1, *L.exprisk*, *L2.exprisk* etc., are lags of *exprisk*, and *ironki* is an interaction between *ki* and a dummy for iron mines.

D | Proofs

D.1 Extraction rate with and without risk[1]

Consider the case of a non-capital-intensive mineral.[2] We have two continuous, differentiable functions, $g(t)$ and $f(t)$, defined on $t \in [0, \infty)$ such that:

$$g(0) > f(0) \tag{3}$$

$$g'(t) < f'(t) < 0 \tag{4}$$

$$\exists\, \bar{t} \text{ such that } g(t) \geq f(t) \text{ for } t \leq \bar{t} \text{ and } g(t) < f(t) \text{ for } t > \bar{t} \tag{5}$$

$$G(t') = \int_{t'}^{\infty} g(t)\mathrm{d}t \text{ and } F(t') = \int_{t'}^{\infty} f(t)\mathrm{d}t \tag{6}$$

$$G(0) = F(0) = C > 0 \tag{7}$$

$g(t)$ is the extraction path under risk and $f(t)$ is the path with no risk. Note that $F(t') > G(t')$ for $t' > 0$. I need to prove that the extraction rate will always be larger under risk. That is, I need to prove that

$$\frac{g(t')}{G(t')} > \frac{f(t')}{F(t')} \text{ for all } t' < T \tag{8}$$

where T is defined by $g(T) = G(T) = 0$, assuming that it exists. If T does not exist, we have $F(t') > G(t') > 0$, $\forall\, t \in [0, \infty)$. Notice that (7) obviously holds for $t' < \bar{t}$.

Define $h(t') = g(t')F(t') - f(t')G(t')$, which is continuous because f and g are continuous. We have $h(0) = [g(0) - f(0)]C > 0$. Claim is proved when I can show that $h'(t') > 0$ for all $t' \in (0, T)$.

---

[1] I am indebted to Florian Diekert for this proof.

[2] The proof for the case of a capital-intensive mineral is symmetrical.

Proof by contradiction: Suppose that there is some t' such that $h'(t') = 0$. Then we have (suppressing t'):

$$\begin{aligned} h' = g'F + gf - f'G - fg &= 0 \\ &\Updownarrow \\ g'F &= f'G \\ &\Updownarrow \\ \frac{g'}{f'} &= \frac{G}{F} \end{aligned}$$

This is a contradiction since the left-hand side is larger than 1, and the right-hand side is smaller than 1 for all $t \in (0, T)$. Because h is continuous, this contradiction also excludes the possibility $h'(t') < 0$, Q.E.D.