Division of Economics and Business
Working Paper Series

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Mohammad Kemal
Ian Lange

Working Paper 2016-06
http://econbus.mines.edu/working-papers/wp201606.pdf

Colorado School of Mines
Division of Economics and Business
1500 Illinois Street
Golden, CO 80401

August 2016

Colorado School of Mines
Division of Economics and Business
Working Paper No. **2016-06**
August 2016

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Changes in Institutional Design, Expropriation Risk and Extraction Path*

Author(s):
Mohammad Kemal
SKKMIGAS
Jakarta, Indonesia, 12710
mkemal@skkmigas.go.id

Ian Lange
Division of Economics and Business
Colorado School of Mines
Golden, CO 80401-1887
ilange@mines.edu

ABSTRACT

The impact of expropriation risk on the extraction path of non-renewable resources has been shown as theoretically ambiguous. It depends on capital intensity of the extraction process and the size of resource stocks. By employing producing field-level data in the South East Asia region, we observe the impact of a change in institutional design of oil governance in Indonesia on expropriation risk and extraction path. From the empirical results, we make an inference that a change in oil governance reduces expropriation risk, and the impact of the reduction on the extraction path is different for different sizes of resource stock. The results confirm the theory that for small resource stocks, reduction in expropriation risk leads to a slower extraction path. This reiterates the importance of strengthening ownership rights such that expropriation risk can be reduced, over-extraction can be avoided and more sustainable economic welfare can be achieved.

JEL **classifications: Q32, Q35, Q48**
Keywords: Oil governance, expropriation risk, extraction path

*The authors wish to thank Harrison Fell, Pete Maniloff, and Wendy Davis and seminar participants at the Colorado School of Mines for their helpful suggestions.

1. Introduction

Over-extraction of natural resources can cause many problems, from reservoir damage[1] to socially inefficient time path of benefits. Over-extraction by private firms which can deplete the resource faster than socially preferred is possible if there is an economic incentive. This is the essence of a concern which was raised by Solow (1974, p.8). By referring to the Hotelling (1931) model, he writes “If it is true that the market rate of interest exceeds the social rate of time preference, then scarcity rents and market prices will rise faster than they "ought to" and production will have to fall correspondingly faster along the demand curve. Thus the resource will be exploited too fast and exhausted too soon”. One of the most discussed reasons for over-extraction by private firms is uncertainty of the ownership of the extracted resource due to expropriation risk. Oil firms which face uncertainty due to expropriation risk may incorporate it by raising their risk-adjusted discount rate.

This problem can get even more complicated because in more recent theoretical models, the impact of expropriation risk on extraction path is ambiguous (see Neher (1981), Lassare (1982), Farzin (1984), Olsen (1987) and Bohn and Deacon (2000)) and depends on the capital intensity of the extraction process and size of the resource stock. Therefore, an effort to reduce expropriation risk can also cause higher extraction rate and lead to faster depletion. This is particularly concerning in countries which are endowed with few natural resources (Farzin (1984). Since the impact of expropriation risk on extraction path is theoretically ambiguous, this paper is interested in empirically investigating the impact of reducing the expropriation risk due to a change in institutional design of oil governance on the extraction path.

[1] In the petroleum engineering literature, critical flow rate has been discussed thoroughly (see Høyland et al. (1989). Kuo (1983) points out that water coning is caused by a higher extraction rate than critical levels and therefore it is important to know when it happens and performance of the well after that.

As the cost of expropriation increases, the risk of expropriation decreases (Stroebel and van Benthem, 2013). Since a regulatory agency does not possess the inputs necessary to extract oil and gas, the shift in ownership rights to a regulatory agency lowers the risk of expropriation. This analysis uses the change in ownership rights for oil and gas in Indonesia, a difference-in-difference methodology is used to show that reducing expropriation risk slows the rate of extraction from oil and gas fields. Results find that reduced expropriation risk leads to a roughly 40% reduction in the extraction rate. The magnitude of the reduction is greatest for small field and the effect wanes as the field size increases. These results are robust to numerous econometrics specifications and alternative definitions of control variables.

Notably, Bohn and Deacon (2000) and Olsen (2013) conducted empirical studies of the impact of expropriation risk on the extraction path of the exhaustible resource[2]. They investigate capital intensity as a source of ambiguity on the impact of expropriation risk on the natural resource extraction path. However, to the extent of our knowledge, there has been no study investigating resource stocks as a source of ambiguity, though these have been shown theoretically as a plausible source. Therefore, by observing a change in the institutional design of oil governance in Indonesia which reduced expropriation risk, we aim to answer the following research question: what is the impact of reduction in expropriation risk on the extraction path for different sizes of resource stock?

This essay makes two primary contributions. First, it provides empirical evidence of how changes in oil governance affect expropriation risk. By employing a difference-in-difference econometric model, we can make an inference that the change in oil governance reduces expropriation risk and causes oil companies to choose a slower extraction path. Second, it will

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[2] There are some other empirical papers on determinants of expropriation (Guriev et al (2011), Stroebel and Van Benthem (2013), Mahdavi (2014).

contribute to the exhaustible resource extraction literature by providing empirical evidence of another source of ambiguity in determining the impact of expropriation risk on oil extraction path: the size of resource stocks. Regression results show that the impacts of the reduction in expropriation risk are different for different sizes of resource stocks. Specifically, reduced expropriation risk causes oil companies to choose a slower extraction path for smaller resources. Our results reiterate the importance of strengthening institutions to influence the extraction path such that over-extraction can be avoided and a more sustainable extraction path can be achieved.

To answer the research question posed above, the remainder of this essay will be structured as follows. In section 2, we will provide a discussion of how the change in institutional design of oil governance can reduce expropriation risk and affect the extraction path. In section 3, we will discuss an econometric model. In section 4, we will identify potential problems that might affect our results, which will be described in section 5. Concluding remarks are in section 6.

2. Change in oil governance, risk of expropriation and extraction path

In order to extract oil and gas, governments of oil-producing countries typically work with oil and gas companies who have the technological, labor and capital capabilities to explore and to produce oil and gas. Depending on the institutional design, the government appoints NOC or a government entity to hold a bidding round, to award an oil and gas contract and then to monitor and regulate it. Expropriation risk can be defined broadly as any act of government that can curtail private firms' claim on their income from an investment project, including capital levies, unexpected taxes or even nationalization. However, to be consistent with the theory in which model expropriation risk is a 0 or 1 event, the term "expropriation risk" in this paper is interchangeable with the term "threat of nationalization."

In 1971, Indonesia created a NOC named Pertamina[3]. As the NOC, Pertamina not only explored and produced from its own oil and gas fields but also was appointed to do the tasks listed above. Since the creation of Pertamina, oil companies that wanted to work in Indonesia had to enter into an oil and gas contract scheme, called a Production Sharing Contract (PSC), with Pertamina. Driven by worldwide trends in economic globalization, Indonesia changed its institutional design of oil governance in 2002, creating a separate regulatory entity called BPMIGAS. The task of BPMIGAS was to replace Pertamina in managing and regulating PSCs, such that Pertamina had to act only as a business entity which only explores and produces from its own fields, similar to other international oil companies. With the creation of BPMIGAS, all oil companies (including Pertamina) enter into PSCs with it. This switch of the contracting party in the PSC from Pertamina, which possesses the technological, labor and capital capability to explore and produce in an oil field, to a separate regulatory entity arguably increases the cost of expropriation and reduces expropriation risk.

Stroebel and Van Benthem (2013) argue that due to incomplete information about the cost of expropriation, even in an optimal contract, expropriation is a possible event with positive probability. The probability is even higher when the benefit of expropriation to the government exceeds the cost of expropriations. Therefore, the occurrence of expropriation is more likely at high oil prices or in countries with low cost of expropriations. Hence, oil governance in which oil companies are making contracts with the NOC rather than with a separate regulatory entity has a higher expropriation risk because the cost to expropriate is lower. Unlike a NOC, a separate regulatory entity does not have the technological, labor and capital capability to take over the operation after the expropriation. The regulatory entity can appoint the NOC (or other oil

[3] Hertzmark (2007) provides a thorough discussion on Pertamina.

company) to take over the operation, but there will be a time gap to transfer knowledge and assets, which incurs an opportunity cost to the government. Therefore, the change in oil governance increases the cost of expropriation and reduces expropriation risk. However, the impact of the change in oil governance on the extraction path is ambiguous because in theory, the impact of reducing the expropriation risk on the extraction path is unclear.

The impact of expropriation risk on oil extraction path was formalized by Long (1975) and can be explained with simplicity using the Hotelling (1931) model. If oil firms face uncertainty due to expropriation risk, they may incorporate it by raising their risk-adjusted discount rate. A higher discount rate causes oil extraction to be tilted to the present and eventually causes faster depletion. However, these models[4] do not include capital, which is an important characteristic in oil and gas extraction.

Oil and gas extraction is a capital-intensive sector. Prior to extraction, capital is required to find reserves (exploration drilling, seismic, geological & geophysical study, etc.) and to develop them (production facility, pipeline, development drilling, etc.). When capital is introduced into the theoretical model, the impact of expropriation risk on extraction path can become ambiguous (see Neher (1981), Lassare (1982), Farzin (1984), Olsen (1987) and Bohn and Deacon (2000)). Intuitively, higher risk-adjusted discount rate reduces the value of the resource stock in the ground, which causes faster extraction. However, it also increases the cost of capital, which causes slower extraction due to under-investment. Therefore, the oil extraction path is affected by two opposing forces of expropriation risk. It can follow the standard Hotelling rule or the inverse Hotelling rule. If the direct effect of the expropriation risk dominates the indirect effect through investment, it

[4] Capital was first introduced as a factor in non-renewable extraction by Campbell (1980). He shows that under certainty, investing in the beginning (at time t = 0) is always optimal and extraction is always at capacity for some period of time.

will follow the standard Hotelling rule (i.e., higher discount rate will cause firms to choose higher extraction rate). If the indirect effect of the expropriation risk dominates the direct effect, it will follow the inverse Hotelling rule (i.e., higher discount rate will cause firms to choose slower extraction rate).

Neher (1981), Lassare (1982), Farzin (1984) and Olsen (1987) show that the ambiguity of the impact of expropriation risk on the extraction path depends on capital intensity and the size of the resource stock. They basically show that, for a large enough resource stock, the capital intensity term will dominate the size of the resource stocks term such that reduction in expropriation risk leads to a faster extraction path (inverse Hotelling rule). It is vice versa for small enough resource stocks: the size of the resource stocks term will dominate the capital intensity term such that a reduction in expropriation risk leads to slower extraction (standard Hotelling rule). Since the impact of reduction in expropriation risk on the extraction path is theoretically ambiguous, the problem is empirical.

3. Econometric model

To empirically study the impact of a change in the institutional design of oil governance on expropriation risk and extraction path, we observe producing oil and gas fields in the South East Asia region during the period of 1996 – 2012. We source the dataset from IHS which consists of 5688 observations of field-level oil and gas production, recoverable & in-place reserves (proven and probable), number of development drilling projects, production start year and some other field characteristics from 620 fields, 55 basins and 9 countries. Observations start in 1996 mainly because data on the number of development drilling projects, which is an important control variable, is not reliable prior to that year.

In estimating the relationship between how the change in oil governance impacts expropriation risk and extraction path, we use a difference-in-difference method. This method is powerful in estimating the impact of a policy provided that it is possible to observe some fields characteristics prior to and after implementation of the policy for groups that are affected by the policy (treatment group) and are not affected by the policy (control group). In this paper, our treatment group is all producing oil and gas fields in Indonesia after 2002. The control group is other fields in the South East Asia region. Since our dataset covers the period prior to and after the change in oil governance in Indonesia for the treatment group and the control group, the difference-in-difference method can be employed. The challenge of this method is that it requires some underlying assumptions hold. These assumptions will be discussed in the identification section. Our difference-in-difference model is:

$$Y_{ict} = \alpha_i + \gamma_t + X'_{ict}\beta + \tau D_{ict} + \varepsilon_{ict} \quad (1)$$

The dependent variable, Y_{ict}, is oil and gas extraction rate at field i, country *c* and year *t*, defined as log of production to reserve ratio ($\log(q_{ict}/R_{ict})$). This variable definition has been used previously in Bohn and Deacon (2003) and Olsen (2013). Olsen (2013) points out since higher and lower oil and gas extraction rates will intersect at some point in time *t* (as shown in Figure A1) then the relative speed of extraction will depend on the time *t* when the observation is made. After the intersection time t_I, a relatively faster extraction path will become slower and vice versa. Therefore, using oil and gas production by itself as a proxy for extraction rate is not appropriate. Using a formal proof, Olsen (2013) shows that using the production to reserve ratio will solve this problem (i.e., faster/slower extraction path will be independent of time).

Since number of development drilling projects (a proxy for capital), which is an important control variable, cannot be differentiated between oil and gas wells, we sum oil and gas production as the numerator in the extraction rate variable. To do that, we convert gas production from mscf (million standard cubic feet) of gas to BOE (Barrel of Oil Equivalence) using a conversion factor (6 mscf = 1 BOE). For the denominator in the extraction rate, we calculate the reserve at field i, country *c* and year *t* using recoverable reserve and in-place reserve data[5]. Since the reserves from producing field data is generally fixed, a new commercial discovery will be developed under a new field, then oil and gas reserve at year t (R_{ict}) can be calculated as the initial recoverable or in-place reserve (R_{ic0}) minus cumulative production before year t ($R_{ict} = R_{ic0} - \sum_{0}^{t-1} q_{ict}$). The consequence of this calculation is that we need to drop fields whose production data are not starting from the beginning (year 1) of their production because the cumulative production is not correct. We also drop fields whose reserve is negative at some year *t* because this condition indicates that cumulative production is bigger than initial reserve, which implies an error in the data.

Independent variables consist an oil governance dummy (D_{ict}) and time varying control variables (X'_{ict}). Time varying control variables are a proxy for the depletion effect and log capital to reserve ratio. We also include year (γ_t) and field (α_i) fixed effects to capture unobserved variables which vary by year (price, technology, etc.) and time-invariant unobserved variables which vary by fields (geological condition, geographical condition, etc.), respectively. The oil governance dummy variable captures the impact of the change in oil governance; it is equal to 1 for all oil and gas producing fields in Indonesia each year after 2002 and equal to 0 otherwise. This form is due to the fact that Indonesia moved from ownership rights with the NOC to ownership rights with a regulatory agency in 2002 and all other countries in South East Asian kept the ownership rights with their NOC during the sample. As a proxy for the depletion effect, we choose to use number of years in production instead of cumulative production because number of years in production is not affected by treatment and is correlated with the extraction path as shown in Figure

[5] Recoverable reserve will be used in the main estimation, and in-place reserve will be used as a robustness check.

A2 and Figure A3. As a proxy for flow of capital, we use number of development drilling projects, which is more preferable than other types of capital such as production facilities for two main reasons. First, a production facility is typically built before the start of production (i.e., up-front capital) unless there is a modification or the field is developed in phases, whereas development drilling is spread out across production years as shown in Figure A4. Therefore, development drilling is more suitable to be used in a panel setting. Second, using a physical measure (number of drilling projects) rather than cost is less prone to measurement error. To avoid taking the log of zero which will result in missing observations, we scale up the number of development drilling projects by adding one to all development drilling observations.

Summary statistics can be found in Table A1. Given that the treatment period (2002-2012) corresponds to higher oil prices than the control period (1996-2001), it is not surprising that both the treatment and control groups increased their extraction rate from the control to treatment periods, not controlling for other factors. As Stroebel and van Benthem (2013) point out, higher oil prices lead to higher benefits of expropriation and thus a higher expropriation risk. The fact that the increase in extraction rate for fields in Indonesia is more modest provides evidence that the change in oil governance reduced expropriation risk.

4. Identification

The reliability of the difference-in-difference estimate depends on two important assumptions. First, the difference between the treatment and control groups does not change in the absence of treatment (i.e., both groups must have the same trend prior to treatment). Second, the treatment is exogenous.

We test the first assumption by determining if prior to treatment, the treatment and control groups have the same trend. This assumption is tested by employing a model:

$$Y_{ict} = \alpha_i + \gamma_t + X'_{ict}\beta + \sum_{\delta=0}^{q} \tau_{-\delta} D_{ict-\delta} + \sum_{\delta=1}^{r} \tau_{\delta} D_{ict+\delta} + \varepsilon_{it} \quad (2)$$

This model can capture the differences in extraction rate between the treatment and control groups in the pre-treatment period (parameter $\tau_{-\delta}$) and post-treatment period (parameter$\tau_{+\delta}$). The differences (shown in **Figure 1**) confirm that prior to treatment, there are no significant differences between the treatment and control groups, and a significant break exists after treatment.

With regard to the second assumption, the main driver of the change in oil governance in Indonesia was economic globalization which was trending worldwide. Discussion about oil and gas law in Indonesia was only triggered after Indonesia hosted the Asian Pacific Economic Cooperation (APEC) in 1994. The discussion was halted several times, but after working with the IMF, Indonesia finally enacted the Oil and Gas Law in 2002. Therefore, looking at the event which initiated the discussion and the enactment of the Oil and Gas Law, the treatment is exogenous.

An improvement this analysis has over previous literature is the use of field level data. Previous work, like Bohn and Deacon (2000), use data aggregated to the country level. The aggregation problem might bias the result of an empirical model analyzing the supply behavior of exhaustible resources[6]. Many empirical models use aggregated data, but the theory is built on an individual/firm level. The problem is not merely consistency between the theoretical and empirical models; aggregating across individuals with different characteristics can be particularly problematic in non-renewable extraction. Fields are different in their reserve size and geological characteristics, and firms are different in their technological, labor and capital capabilities. Therefore, each firm will have different responses to changes in conditions (price, depletion effect, regulations, etc.) depending on their characteristics. Thus, our econometric model which uses

[6] See Bohi and Toman (1984) chapter 6 for a thorough discussion of aggregation bias on non-renewable supply model.

producing field-level data can provide a more reliable estimate of the response of oil companies to the change in oil governance. Moreover, by using producing field-level data, we can isolate the impact from exploration since new commercial discovery will be developed under new fields. Hence, we can also overcome the interdependency problem between exploration and production, another criticism which is pointed out by Bohi and Toman (1984).

5. Results

The main regression results from the difference-in-difference method are shown in **Table 1**. The coefficient of the oil governance dummy variable in specification 1 and 2 is negative and statistically significant, even after controlling for the depletion effect. From these two specifications, it is clear that the change in oil governance causes oil companies to choose a slower extraction path. However, the mechanism is still not clear because we cannot infer the impact of the change in oil governance to expropriation risk. Therefore, in specifications 3 to 8, we control for the indirect effect of expropriation risk by controlling for capital. We control not just for the current flow of capital but also for the lagged effect of flow of capital (in an effort to account for installation lag). We also try to control for stock of capital by using the cumulative number of development drilling projects in the past 3 years[7]. By controlling for the indirect effect of expropriation risk, the coefficient for the oil governance dummy now only captures the direct effect of expropriation risk. The coefficient is negative and statistically significant at the 99% confidence level, which shows that the direct effect of expropriation risk causes oil firms to choose a slower extraction path. Since there is no ambiguity in the direct effect of the expropriation risk (i.e., reduction in expropriation risk leads to slower extraction path), we can infer from these results that the change in oil governance reduces the expropriation risk. Thus, from specification 1 and 2

[7] We assume that after 3 years, development wells have been fully depreciated.

results, we can also make an inference that the reduction in expropriation risk decreases the extraction rate by roughly 40% or decreases the production to reserve ratio from 6% to 3.6% which significantly increases production life of the fields.

All results are consistent with theory which shows that for small enough resource stocks, the impact of reduction in expropriation risk will follow the standard Hotelling rule (i.e., direct effect dominates indirect effect such that reduction in expropriation risk leads to slower extraction path). We will further confirm this result later in this section by employing another econometric model which includes an interaction term between the oil governance dummy and the size of reserve dummy, but first we are going to explain some interesting results for the control variables.

The coefficients of the control variables for flow of capital, lag of flow of capital and stock of capital are positive and statistically significant at the 99% confidence level. These results show that an increase in flow (current or lag) or stock of capital leads to an increase in extraction rates. These results make intuitive sense as the more wells are drilled, the higher the extraction rate of the field.

The coefficient for the depletion effect in all specifications except specification 6 is positive and statistically significant at the 99% confidence level, which shows that as the number of years in production increase, the higher the extraction rate of the field. These results seem counterintuitive because the extraction rate is supposed to be declining over years of production. This intuition can also be confirmed from a scatter plot of extraction rates from all fields (shown in Figure A2). However, by plotting the extraction rate from a random selection of fields shown in Figure A3, the extraction path in an individual field is not just declining over time but has a bell shape. Therefore, as a robustness check, we include the square function of the depletion effect in the model in Table A2. The coefficient is negative and statistically significant for the quadratic term and is positive and statistically significant for the linear term, which confirms the bell shape of the individual field extraction paths. More importantly, the coefficients for the oil governance change dummy are still robust.

To further investigate the impact of reduction in expropriation risk at different reserve sizes, we employ another econometric model which includes an interaction term between the oil governance dummy and the size of reserve dummy:

$$Y_{ict} = \alpha_i + \gamma_t + X'_{ict}\beta + \tau_1 D_{ict} + \tau_2 D_{ict} * MedRes_{ict} + \tau_3 D_{ict} * LrgRes_{ict} + \tau_4 MedRes_{ict} + \tau_5 LrgRes_{ict} + \varepsilon_{it} \quad (3)$$

We define fields whose reserve in 2001[8] is below the 25th percentile as small reserve fields, between the 25th and 75th percentile as medium reserve fields and above the 75th percentile as large reserve fields. With this model, we can estimate the impact of reduction in expropriation risk in small, medium and large reserve fields. The marginal effect for a small reserve field is τ_1, for a medium reserve field is $\tau_1 + \tau_2$ and for a large reserve field is $\tau_1 + \tau_3$. We will also generate the joint hypothesis standard error ($\tau_1 + \tau_2$ and $\tau_1 + \tau_3$) to test the significance of the result.

The regression results for this model are shown in **Table 2**, and the marginal effects for small, medium and large reserves are shown in **Table 3**. In **Table 2**, the coefficient for the interaction term between the oil governance change dummy and small reserve fields is negative and statistically significant, whereas coefficient for the interaction term between the oil governance change dummy and medium reserve fields is positive and statistically significant. It is even more positive and statistically significant for the interaction term between the oil governance change dummy and large reserve fields. These results show that the extraction rate for large reserve fields

[8] We choose reserve in 2001 as the base reserve to divide the fields into 3 percentile groups because reserve in this year is not affected by the change in oil governance.

is faster than for medium reserve fields, and the extraction rate for medium reserve fields is faster than for small reserve fields. The marginal effect (shown in **Table 3**) shows that reduced expropriation risk causes oil companies to choose a slower extraction path for medium reserve fields but not as slow as for small reserve fields. More importantly, the impact of reduction in expropriation risk on extraction path is not significant for large reserve fields because the indirect effect through capital investment offsets the direct effect. In theory, though it is not shown in our empirical results, for a large enough reserve, a reduction in expropriation risk can cause oil firms to choose a faster extraction path (i.e., the coefficient flips to positive). To summarize the results from the model with interaction terms between the oil governance change dummy and the size of reserve dummy, the impact of reduction in expropriation risk is different for different sizes of reserve. Specifically, the extraction path is slower for smaller reserve fields.

To test the robustness of the main regression results, we provide some different ways in standard error clustering and also some alternative specifications to the econometric model. First, we clustered standard error at field, basin and country level to tackle possible group-wise heterokedasticity. As shown in Tables A3, A4 and A5, the results are robust to these different ways in standard error clustering.

Second, one might be concerned that the results are driven by new fields whose production started after the change in oil governance in 2002. Since new fields might have a low production to reserve ratio, they might drive the regression results to show a slower extraction path. Therefore, as a further robustness check, we dropped fields whose production started after 2002. The results are still robust (see Table A6). All the coefficients are still following the same sign as the main regression results and are statistically significant.

Third, Olsen (2013) points out that using recoverable reserve data might be problematic because they might be affected by expropriation risk. By definition, recoverable reserve is the part of a physical reserve which it is economically viable to extract. Therefore, expropriation risk which theoretically can influence economic incentive might affect recoverable reserve data. As a further robustness check we use in-place reserve, which is a more physical measure of reserve than recoverable reserve. The results show that all the coefficients get larger but are still following the same sign as the main regression results and are statistically significant (see Table A7).

Lastly, the reserve calculation might introduce endogeneity into the model. As mentioned above, the dependent variable (Y_{ict}) is log of production to reserve ratio ($\log(q_{ict}/R_{ict})$), which is equal to log of production ($\log(q_{ict})$) minus log of reserve ($log(R_{ict}) = log(R_{ic0} - \sum_0^{t-1} q_{ict})$). If log of reserve is moved to the right-hand side of the main econometric model (Equation 1), the model might contain a lag effect of the dependent variable which might be correlated with the error term. Hence, as a final robustness check, we follow Olsen (2013) in using the log of production to fixed reserve (measure at some year t) ratio. He shows that by using the fixed reserve, the behavior of the relative speed of extraction does not change (i.e., it is still independent of the time of observation) as long as the fixed reserve observation is made after the production observations. Fortunately, in our model, fixed reserve will be controlled automatically through the field fixed effect so that our model will only include the log of production as a dependent variable. The results in Table A8 show that the coefficient of the oil governance change dummy is still negative and statistically significant, which confirms the robustness of the results.

6. Conclusion

Expropriation risk can be reduced by a change in the institutional design of oil governance which creates a separate regulatory entity whose task is to take on the role of a NOC in managing and regulating PSCs. By controlling for the indirect effect of the change in expropriation risk through capital, the regression results show that the direct effect causes oil firms to choose a slower extraction path. Since there is no ambiguity in the direct effect of reduction in expropriation risk, we can infer that the change in oil governance reduces expropriation risk. The impact of the reduction in expropriation risk is different for different sizes of reserves in that the extraction path is slower for smaller reserve fields. These results are robust to some alternative specifications and different ways in standard error clustering. They confirm the theory that if the resource stock is small enough, the extraction path will follow a standard Hotelling model rule (i.e., reduction in expropriation risk results in a slower extraction path and vice versa). Thus, the results reiterate the importance of strengthening institutions to influence the extraction path even in a country endowed with small resource stocks such that over-extraction can be avoided and a more sustainable extraction path can be achieved.

References

Bohi, D. R., & Toman, M. A. (1984). Analyzing Nonrenewable Resource Supply, *Resources for the Future*. ISBN, 915707055, 10-41.

Bohn, H., & Deacon, R. T. (2000). Ownership risk, investment, and the use of natural resources. *American Economic Review*, 526-549.

Campbell, H. F. (1980). The effect of capital intensity on the optimal rate of extraction of a mineral deposit. *The Canadian Journal of Economics/Revue Canadienne d'Economique*, *13*(2), 349-356.

Farzin, Y. H. (1984). The effect of the discount rate on depletion of exhaustible resources. *The Journal of Political Economy*, 841-851.

Guriev, S., Kolotilin, A., & Sonin, K. (2011). Determinants of nationalization in the oil sector: A theory and evidence from panel data. *Journal of Law, Economics, and Organization*, *27*(2), 301-323.

Hertzmark, D. (2007). Pertamina: Indonesia’s State-Owned Oil Company. *Rice University*.

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

Høyland, L. A., Papatzacos, P., & Skjaeveland, S. M. (1989). Critical rate for water coning: Correlation and analytical solution. *SPE Reservoir Engineering*, *4*(04), 495-502.

Kuo, M. C. T. (1983). A simplified method for water coning predictions. *SPE Annual Technical Conference and Exhibition*. Society of Petroleum Engineers.

Lasserre, P. (1982). Exhaustible-resource extraction with capital. In *Natural Resources Conference,* Vancouver.

Mahdavi, P. (2014). Why do leaders nationalize the oil industry? The politics of resource expropriation. *Energy Policy*, *75*, 228-243.

Neher, P. A. (1982). RENT‐A‐RIG. *Australian Economic Papers*, *21*(38), 170-176.

Olsen, E. H. (2013). Expropriation risk and natural resource extraction: A matter of capital intensity. Retrieved from https://www.duo.uio.no/handle/10852/35718

Olsen, T. E. (1987). Resource extraction and capital investments under uncertainty. *Resources and Energy*, *9*(3), 209-222.

Solow, R. (1974). The Economics of Resources or the Resources of Economics. *American Economic Review*, *64*(2), 1-14.

Stroebel, J., & Van Benthem, A. (2013). Resource extraction contracts under threat of expropriation: Theory and evidence. *Review of Economics and Statistics*, *95*(5), 1622-1639.

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

Figure 1: The differences in extraction paths between treatment and control groups in pre-treatment and post-treatment periods.

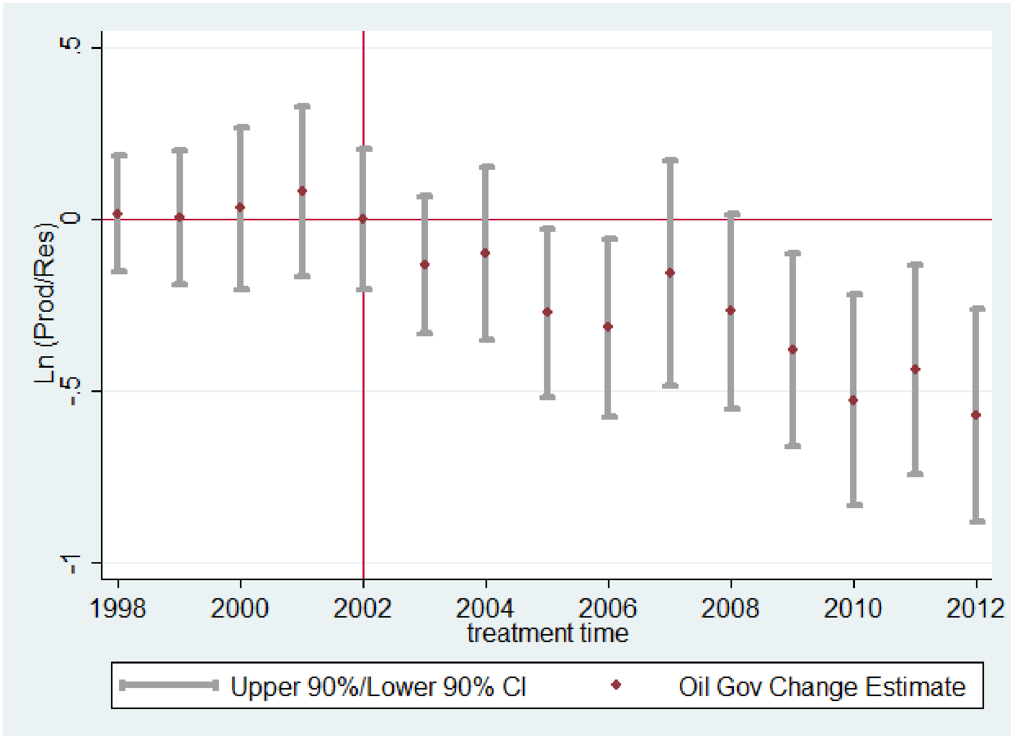

Table 1: Main regression results

	(1) Ln (Prod/Res)	(2) Ln (Prod/Res)	(3) Ln (Prod/Res)	(4) Ln (Prod/Res)	(5) Ln (Prod/Res)	(6) Ln (Prod/Res)	(7) Ln (Prod/Res)	(8) Ln (Prod/Res)
Gov. change	-0.397***	-0.388***	-0.392***	-0.383***	-0.305***	-0.298**	-0.369***	-0.360***
Dummy	(0.136)	(0.136)	(0.133)	(0.133)	(0.117)	(0.117)	(0.121)	(0.121)
Depletion		0.037***		0.032***		0.008		0.024***
effect[a]		(0.010)		(0.009)		(0.008)		(0.009)
Flow of			0.085***	0.084***				
capital[b]			(0.026)	(0.026)				
Lag flow of					0.185***	0.184***		
capital[b]					(0.026)	(0.026)		
Stock of							0.264***	0.264***
capital[c]							(0.029)	(0.029)
Observations	5688	5632	5688	5632	5323	5276	5667	5611

Robust standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, ***, $p < 0.01$
[a] proxy by number of years in production
[b] proxy by number of development drilling/reserve
[c] proxy by number of development drilling projects in the past 3 years/reserve

Table 2: Regression results from model with an interaction term between oil governance change dummy and size of reserve fields.

	(1) Ln (Prod/Res)	(2) Ln (Prod/Res)	(3) Ln (Prod/Res)
Oil Gov Change Dummy	-0.585***	-0.587***	-0.598***
	(0.152)	(0.153)	(0.151)
OGC Dummy X Med Res	0.203*	0.223**	0.229**
	(0.111)	(0.112)	(0.114)
OGC Dummy X Large Res	0.404***	0.403***	0.460***
	(0.138)	(0.140)	(0.140)
Linear term depletion effect[a]		0.037***	0.061***
		(0.010)	(0.013)
Quadratic term depletion effect[a]			-0.001***
			(0.000)
Observations	5688	5632	5632

Robust Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a]proxy by number of years in production

Table 3: Marginal effect of the impact of reduction in expropriation risk on different-sized reserves

	Ln (Prod/Res)
Oil Gov Change Dummy	-0.598***
	(0.151)
OGC Dummy X Med Res	-0.369***
	(0.141)
OGC Dummy X Large Res	-0.138
	(0.160)

Robust Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix
Table A1: Summary Statistics

	A Control before 2002	B Indonesia before 2002	C Control after 2002	D Indonesia After 2002	Diff-in-diff (D-B)-(C-A)
Extraction rate (production per reserve)	0.041 (0.002)	0.061 (0.002)	0.062 (0.002)	0.065 (0.001)	-0.016** (0.005)
# of year in production	14.597 (1.227)	14.515 (0.305)	13.926 (0.663)	17.713 (0.236)	3.870** (1.097)
# of wells drilled per reserve	0.416 (0.077)	0.943 (0.122)	0.792 (0.100)	1.041 (0.217)	-0.278 (0.730)
# of well in the past 3 years per reserve	0.605 (0.086)	1.122 (0.137)	1.301 (0.161)	1.220 (0.218)	-0.598 (0.748)

Table A2: Robustness check with quadratic function of depletion effect

	(1)	(2)	(3)	(4)
	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)
Oil Gov Change Dummy	-0.385***	-0.381***	-0.298**	-0.358***
	(0.132)	(0.128)	(0.116)	(0.114)
Linear term depletion effect[a]	0.059***	0.054***	0.012	0.047***
	(0.013)	(0.013)	(0.011)	(0.011)
Quadratic term depletion effect[a]	-0.001***	-0.001***	-0.000	-0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Flow of capital[b]		0.081***		
		(0.026)		
Lag flow of capital[b]			0.184***	
			(0.026)	
Stock of capital[c]				0.263***
				(0.029)
Observations	5632	5632	5276	5611

Robust Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a]proxy by number of years in production
[b]proxy by number of development drilling/reserve
[c]proxy by number of development drilling in the past 3 years/reserve

Table A3: Robustness check by clustering standard error at field level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)
Gov. change	-0.397***	-0.388***	-0.392***	-0.383***	-0.305***	-0.298**	-0.369***	-0.360***
Dummy	(0.136)	(0.136)	(0.133)	(0.133)	(0.117)	(0.117)	(0.121)	(0.121)
Depletion		0.037***		0.032***		0.008		0.024***
effect[a]		(0.010)		(0.009)		(0.008)		(0.009)
Flow of			0.085***	0.084***				
capital[b]			(0.026)	(0.026)				
Lag flow of					0.185***	0.184***		
capital[b]					(0.026)	(0.026)		
Stock of							0.264***	0.264***
capital[c]							(0.029)	(0.029)
Observations	5688	5632	5688	5632	5323	5276	5667	5611

Clustered Standard errors at field level in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a]proxy by number of years in production
[b]proxy by number of development drilling/reserve
[c]proxy by number of development drilling in the past 3 years/reserve

Table A4: Robustness check by clustering standard error at basin level

	(1) Ln (Prod/Res)	(2) Ln (Prod/Res)	(3) Ln (Prod/Res)	(4) Ln (Prod/Res)	(5) Ln (Prod/Res)	(6) Ln (Prod/Res)	(7) Ln (Prod/Res)	(8) Ln (Prod/Res)
Gov. chnge Dummy	-0.397***	-0.388***	-0.392***	-0.383***	-0.305**	-0.298**	-0.369***	-0.360***
	(0.139)	(0.139)	(0.132)	(0.132)	(0.139)	(0.138)	(0.112)	(0.113)
Depletion effect[a]		0.037***		0.032***		0.008		0.024***
		(0.011)		(0.011)		(0.011)		(0.009)
Flow of capital[b]			0.085***	0.084***				
			(0.025)	(0.025)				
Lag flow of capital[b]					0.185***	0.184***		
					(0.030)	(0.030)		
Stock of capital[c]							0.264***	0.264***
							(0.038)	(0.038)
Observations	5688	5632	5688	5632	5323	5276	5667	5611

Clustered Standard errors at basin level in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a]proxy by number of years in production
[b]proxy by number of development drilling/reserve
[c]proxy by number of development drilling in the past 3 years/reserve

Table A5: Robustness check by clustering standard error at country level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)
Gov. change	-0.397***	-0.388***	-0.392***	-0.383***	-0.305*	-0.298*	-0.369***	-0.360***
Dummy	(0.104)	(0.103)	(0.094)	(0.094)	(0.139)	(0.139)	(0.059)	(0.059)
Depletion		0.037***		0.032***		0.008		0.024***
effect[a]		(0.010)		(0.009)		(0.012)		(0.005)
Flow of			0.085***	0.084***				
capital[b]			(0.017)	(0.017)				
Lag flow of					0.185***	0.184***		
capital[b]					(0.030)	(0.031)		
Stock of							0.264***	0.264***
capital[c]							(0.036)	(0.037)
Observations	5688	5632	5688	5632	5323	5276	5667	5611

Clustered Standard errors at country level in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a]proxy by number of years in production
[b]proxy by number of development drilling/reserve
[c]proxy by number of development drilling in the past 3 years/reserve

Table A6: Robustness check by dropping fields whose production started after year of 2002

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)
Gov. change	-0.388***	-0.388***	-0.381***	-0.381***	-0.300**	-0.300**	-0.360***	-0.360***
Dummy	(0.137)	(0.137)	(0.133)	(0.133)	(0.117)	(0.117)	(0.121)	(0.121)
Depletion		0.028***		0.022**		0.005		0.017*
effect[a]		(0.009)		(0.009)		(0.008)		(0.009)
Flow of			0.114***	0.114***				
capital[b]			(0.028)	(0.028)				
Lag flow of					0.190***	0.190***		
capital[b]					(0.028)	(0.028)		
Stock of							0.258***	0.258***
capital[c]							(0.032)	(0.032)
Observations	4764	4764	4764	4764	4595	4595	4750	4750

Robust Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a]proxy by number of years in production
[b]proxy by number of development drilling/reserve
[c]proxy by number of development drilling in the past 3 years/reserve

Table A7: Robustness check by using in-place reserve instead of recoverable reserve

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)	Ln (Prod/Res)
Gov. change	-0.626***	-0.620***	-0.595***	-0.589***	-0.518***	-0.513***	-0.526***	-0.519***
Dummy	(0.131)	(0.131)	(0.127)	(0.128)	(0.114)	(0.114)	(0.115)	(0.115)
Depletion		0.006		0.004		-0.015*		0.002
effect[a]		(0.009)		(0.009)		(0.008)		(0.008)
Flow of			0.132***	0.131***				
capital[b]			(0.026)	(0.026)				
Lag flow of					0.245***	0.246***		
capital[b]					(0.025)	(0.025)		
Stock of							0.307***	0.307***
capital[c]							(0.029)	(0.029)
Observations	5940	5884	5940	5884	5567	5520	5919	5863

Robust Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a]proxy by number of years in production
[b]proxy by number of development drilling/reserve
[c]proxy by number of development drilling in the past 3 years/reserve

Table A8: Robustness check by using fixed reserve

	(1) Ln (Prod/Res)	(2) Ln (Prod/Res)	(3) Ln (Prod/Res)	(4) Ln (Prod/Res)	(5) Ln (Prod/Res)	(6) Ln (Prod/Res)	(7) Ln (Prod/Res)	(8) Ln (Prod/Res)
Gov. change	-0.540***	-0.535***	-0.538***	-0.534***	-0.441***	-0.437***	-0.516***	-0.511***
Dummy	(0.141)	(0.141)	(0.140)	(0.140)	(0.126)	(0.126)	(0.125)	(0.125)
Depletion		-0.018*		-0.019*		-0.045***		-0.029***
effect[a]		(0.010)		(0.010)		(0.009)		(0.009)
Flow of			0.025	0.024				
capital[b]			(0.030)	(0.030)				
Lag flow of					0.134***	0.134***		
capital[b]					(0.029)	(0.029)		
Stock of							0.236***	0.235***
capital[c]							(0.032)	(0.032)
Observations	5688	5632	5688	5632	5323	5276	5667	5611

Robust Standard errors in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
[a]proxy by number of years in production
[b]proxy by number of development drilling/reserve
[c]proxy by number of development drilling in the past 3 years/reserve

Figure A1: Extraction path under expropriation risk

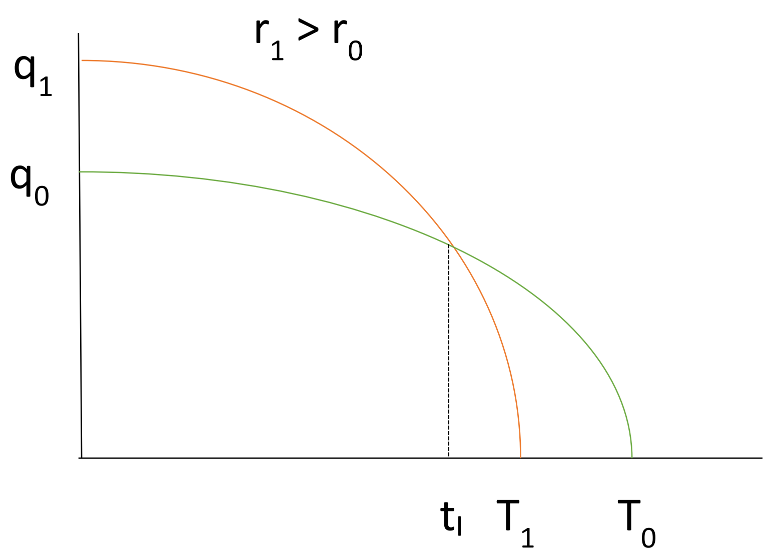

Figure A2: Scatter plot extraction rate vs year in production for all fields

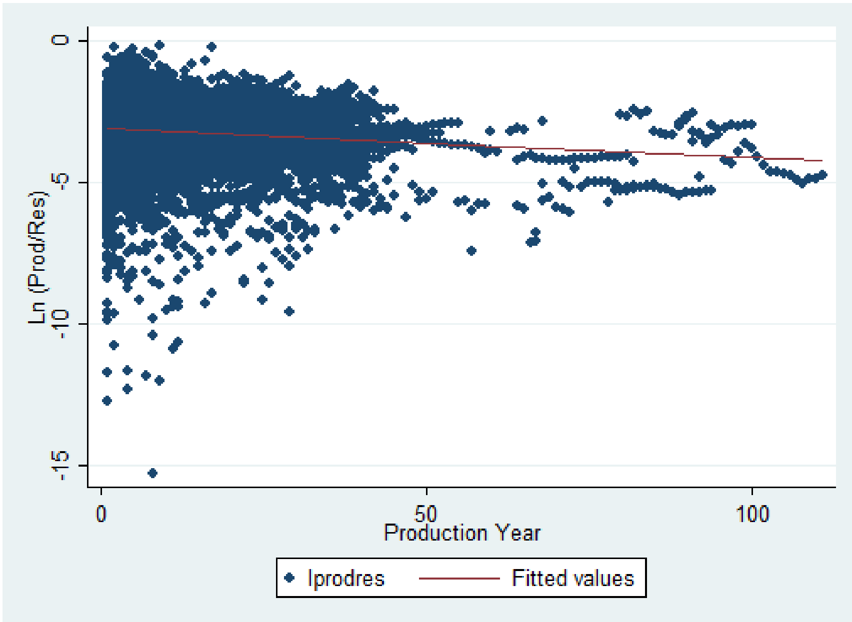

Figure A3: Scatter plot extraction rate vs year in production for 10 random fields

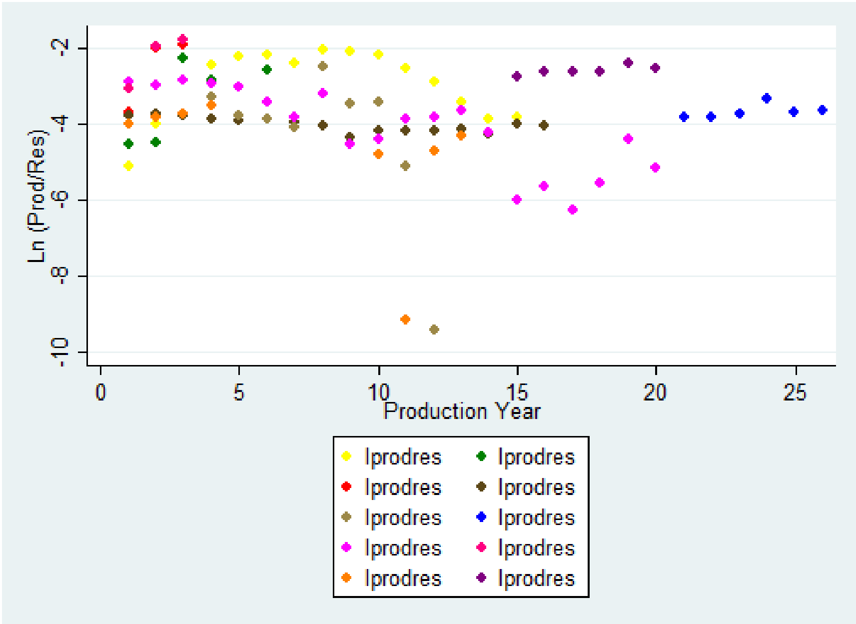

Figure A4: Scatter plot number of development drilling vs year in production