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DP17121

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DEVELOPMENT ECONOMICS

ORGANIZATIONAL ECONOMICS

POLITICAL ECONOMY

ISSN 0265-8003

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Discussion Paper DP17121
Published 19 March 2022
Submitted 15 March 2022

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www.cepr.org

This Discussion Paper is issued under the auspices of the Centre's research programmes:

- Development Economics
- Organizational Economics
- Political Economy

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Abstract

Contracts between governments and international firms are difficult to enforce, especially under weak institutions: governments are tempted to renegotiate tax payments after investments occurred. Theoretically, such a hold-up problem is solved by using self-enforcing agreements that increase the value of sustaining the relationship over time. By delaying production, tax payments and investments, firm's threat to terminate following a renegotiation becomes more effective. Using rich proprietary data on the oil and gas industry, we show that contracts between the oil majors and petro-rich economies with weak institutions are indeed delayed relative to countries with strong institutions. To push for a causal interpretation, we show that this backloading in countries with weak institutions only emerges in early 1970s. We attribute this to a change in the international view towards countries' sovereignty over natural resources brought by decolonization. This new world order made it politically difficult for developed countries to continue the established practice of military interventions to back up the enforcement of the contracts of their oil firms. Fading of (military) enforcement, together with the absence of local legal enforcement, triggered the need to backload the contracts.

JEL Classification: D86, L14, H20, D02, P48, Q30

Keywords: Relational Contracts, Dynamic incentives, political economy, institutions, Oil

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Acknowledgements
We are grateful to Jørgen J Andersen, Jonathan Greenacre, Francine Lafontaine, Rocco Macchiavello, Pepita Miquel-Florensa, Ameet Morjaria, Léo Reitzmann, Pierre-Louis Vezina, Giorgio Zanarone, Kuncheng Zheng and the participants of the ES World Congress, IIOC, SIOE, Norwegian Virtual Political Economy Workshop, 7th Workshop on Relational Contracts, EALE, CEPR-IMO, NEUDC, EWMES and the seminars at NES and SITE for many insightful comments. We thank Anton Didenko, Alina Gafanova, Maria Loskutnikova, Kira Silvestrovich, Alexander Tonis and Dmitrii Urentsov for excellent research assistance. Paltseva's work on this project was partially funded by The Research Council of Norway, Grant 275387. Any remaining errors are our own.

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Relational Contracts in the Oil Industry

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March 15, 2022

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"Perhaps decolonization and the general postwar weakening of the OECD members as political and military actors is an experiment where expropriation is first viewed as impossible and then becomes possible."

— Eaton, Gersovitz and Herring (1983)

1 INTRODUCTION

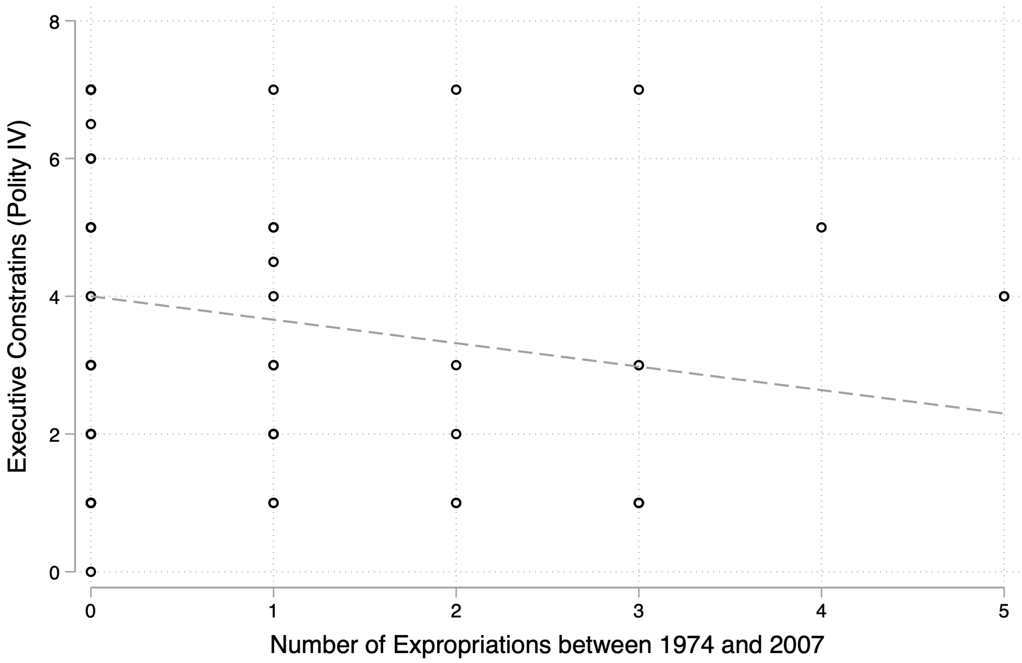
Imperfect contract enforcement is pervasive, especially in developing economies. A weak rule of law cannot prevent the government from abusing its power vis-a-vis private investors. In particular, once private investment is in place, governments have an incentive to hold up firms by changing contractual and fiscal terms and, in the extreme, expropriating them (Kobrin (1980), Rigobon (2010)). Figure 1 shows that expropriations (in the oil and gas sector) are indeed more likely to take place under regimes with weaker constraints on the executive (Guriev, Kolotilin and Sonin, 2011). Contracting frictions have contributed to the inability of resource-rich developing countries to exploit their natural resources efficiently and move out of poverty (Van der Ploeg, 2011; Venables, 2016).

Nevertheless, the government reneging on contracts or seizing assets remain rare events. For instance, Kobrin (1980) finds that even during the peak of expropriations in 1960-1976, only less than 5 % of all foreign-owned firms in the developing countries were expropriated. The rarity of expropriations is not due to the absence of assets to expropriate: according to Giroud and Ivarsson (2020), FDI to developing world in 2019 constituted 85% of the one to developed countries.

This paper aims to understand how firms overcome the issues associated with the lack of formal contract enforcement by establishing self-enforcing agreements instead. Self-enforcing agreements use the future value of the relationship to deter short-term opportunism (Malcomson, 2013). We exploit a peculiarity of the firm-government relationship, namely that subsidies are very rare. When this is the case, a large body of theory has found the optimal dynamic patterns of these relationships (Ray, 2002).[1] We are the first to show their existence empirically.

[1]See Lazear (1981), Harris and Holmstrom (1982) and Fong and Li (2017) for a labor setting, Albuquerque and Hopenhayn (2004) and Fuchs, Green and Levine (forthcoming) for a credit setting and Thomas and Worrall

Figure 1: EXPROPRIATIONS IN OIL AND GAS



Note: This figure shows the correlation between the strength of *executive constraints* (as a country specific median for the period 1974 - 2007) with the number of expropriations in the oil and gas sector between 1974 and 2007. Data on the executive constraints (xcons) is taken from Polity IV. Data on expropriations is taken from Stroebel and Van Benthem (2013) who extended the data set originally constructed by Guriev, Kolotilin and Sonin (2011).

We focus on the oil & gas industry. This industry is the perfect setting for our study because: (1) it is *the* capital intensive industry,[2] making the holdup problem particularly important, (2) the government-firm agreements last over a large number of years, which allows us to study the relationships dynamics in detail and, (3) the oil rich countries vary greatly in terms of the quality of their formal institutions[3] and, hence, in the need for the agreement to be self-enforced.

To guide our empirical analysis, we present a model of a repeated relationship between a government and an oil & gas firm. We use a stylized version of Thomas and Worrall (1994) where we explicitly model the quality of external contract enforcement coming from formal

(1994) for an investment setting.

[2]For example, the US oil and gas companies invest around 3.2 million US$ per worker, the next industry in line being utilities with 0.75 million US$ per worker (Ross, 2012).

[3]Djankov et al. (2003) document a large variation in the quality of formal enforcement across different countries.

institutions.[4] We use the variation in quality of institutions to derive our main testable hypothesis. In the model, every period, the firm invests, produces and pays taxes to the government. The government can threaten to expropriate but the probability to succeed is determined by the quality of the institutions. In equilibrium, a self-enforcing agreement requires that the government's short-term incentive to expropriate is less valuable than the long-term gains from having the firm invest and pay taxes in the future. The government's inability to pay subsidies in advance (akin to a limited liability constraint), determines the dynamic investment, production and taxation paths. In particular, if the quality of institutions is sufficiently low, the government should be given an increasing continuation payoff over time, so that the firm's threat to leave the country following an expropriation is more effective. As a result, the contract is delayed (i.e.backloaded) with investment, production and tax payments increasing as the relationship evolves. Eventually, the promised future taxes need to be paid. At this point, the government ends up getting so much value that no longer wants to expropriate and backloading disappears. Hence, the first prediction of the model is that contract backloading is more prominent as the quality of institutions deteriorates. The second prediction is that, as the relationship between the country and the firm evolves, the backloading vanishes.

To test these predictions, we exploit a proprietary database, collected and provided to us by Rystad Energy.[5] We use information on size, production, costs, revenues, taxes and a variety of other observable characteristics on the asset level[6] owned or operated by the seven largest multinational oil and gas companies, so-called supermajors or Big Oil. Our baseline dataset covers assets which started production between 1974 and 1999, and we follow these assets until 2019. This amounts to 2620 assets, 124 country-firm combinations, and 49 countries. For our identification strategy, we extend the dataset to cover assets with a start-up period between 1960 and 1999. This leaves us with a total of 3494 asset, and 130 country-firm relations in the same countries. In our preferred specification, we classify the countries' quality of institutions using the level of constraints imposed on the country's executives, taken from Polity IV[7]. Polity IV is a database which provides information on the quality of institutions for a large number of countries going back to the 19^{th} century.

[4] In Thomas and Worrall (1994), there is no formal contract enforcement.

[5] Rystad Energy is a leading consultancy in the energy industry. See https://www.rystadenergy.com

[6] An asset contains at least one production well and be operated by at least one firm in one country.

[7] We also use other measures of Polity IV as well as the initial membership to the OECD as a proxy for good quality of institutions. The results are unaffected by these other choices.

Our key finding is that contracts between the multinationals and oil-rich economies with weak institutions are backloaded relative to countries with strong institutions, in line with the above theory. First, using the raw data, we illustrate the presence of backloading by differentiating between countries with strong and weak institutions. Then, we estimate a variety of OLS specifications that control for a large number of observables which would have the potential to confound our results such as differences in the geographic location, the size of reservoirs, climatic conditions, type of fossil fuel extracted as well as the operating company. Our results are robust to the additional controls and suggest that capital expenditure, production as well as tax payments are delayed by 2 years in countries with weak institutions relative to countries with strong institutions.

To transform the 2 years delay into a monetary value, we calculate the net present value (NPV) of an asset in countries with weak institutions and compare it to the NPV of an asset in countries with strong institutions. Informed by the descriptive statistics presented in Table 6, we assume that an asset produces the *same* total output in 30 years in a country with weak institutions, and in just 28 years in a country with strong institutions.[8] Using group specific average production dynamics observed in our data for countries with weak and strong institutions, we allocate total output to individual periods, accounting for the two year difference in the average life time of an asset. To abstract from other differences which may affect the NPV of an asset, we assume the price of the resource as well as the interest rate to be constant across space and time. With an interest rate of 10%, the NPV of an asset in countries with weak institutions is around 8% lower when compared to the NPV of an asset in countries with strong institutions.[9] With an average cumulative tax payment of just below 1 billion US$ in countries with weak institutions, the 2 year delay in production translates into a loss of 1bln*8%=80 Mln US$ per asset in taxes. This is roughly 120 Million US$ per year in a country with weak institutions since majors initiate on average 1-2 assets per year in such countries in our sample.

One can argue that this delay may be attributed more generally to the difficulty of doing business in countries with weak institutions (e.g. poor infrastructure, red tape, corruption, etc.).

[8]As shown in the descriptive statistics, the size of the assets does not differ significantly across countries, while the life time of an asset is slightly shorter in countries with strong institutions.

[9]The loss goes down to 5% if the interest rate is assumed to be 5% and up to 10% with an interest rate around 15%.

To give this delay a casual interpretation, we exploit the change in the relationship between oil producing nations, oil consuming nations, and international oil companies that took place between 1968 and 1973 and that resulted in expropriations "becoming possible" (Eaton, Gersovitz and Herring, 1983). Prior to 1968, major oil-consuming nations threaten with, or simply used, their military power to enforce the contracts of their oil firms thereby protecting the security of their oil supply.[10] However, the wave of decolonization brought about the developing world's movement for sovereignty over their natural resources. While it was not immediately successful, it eventually changed the world's view on the right of the state to nationalize its resources.[11] The use of the military power to achieve political goals became more costly both due to international pressure and domestic resistance. A good example of the latter are the anti-war protests in the US related to the Vietnam war that led to election of Richard Nixon in 1968, and a full withdrawal of US troops from Vietnam by 1973. Indeed, the average number of military interventions by the US, the UK and France fell from 2.5 a year to 1 per year in the mid 1960s (Sullivan and Koch, 2009). Eventually, the change in the world oil order became apparent to everybody by the end of 1973 when the Arab-Israeli Yom Kippur War unfolded. Since the US decided to support Israel, the OPEC countries responded by imposing an oil embargo on the US. But OPEC's cut of the supply of oil did not trigger any military response, completing the transition to a new world order which is best summarized by Yergin (2011):

"The postwar petroleum order in the Middle East had been developed and sustained under American-British ascendancy. By the latter half of the 1960s, the power of both nations was in political recession, and that meant the political basis for the petroleum order was also weakening. [...] For some in the developing world [...] the lessons of Vietnam were [...] that the dangers and costs of challenging the United States were less than they had been in the past, certainly nowhere near as high as they had been for Mossadegh, [the Iranian politician challenging UK and US before the coup d'etat in 1953], while the gains could be considerable."

[10]Maybe the most famous example is the coup d'etat against Iranian prime minister Mossadegh backed by the CIA, with the help of Britain's MI6, following his attempt to renegotiate the fiscal regime with Anglo Persian Oil Company (nowadays BP) in 1953. As the British officials at the Ministry of Fuel and Power put it in September 1951: "If we reached settlement on Mussadiq's (sic) terms, we would jeopardise not only British but also American oil interests throughout the world. We would destroy prospects of the investments of foreign capital in backward countries. We would strike a fatal blow to international law. We have a duty to stay and use force to protect our interest" Abrahamian (2013). See 1956 Suez crisis for an other example.

[11]Accordingly, Kobrin (1984) documents how expropriations are concentrated during the early 1970s and their incidence declined significantly after 1975.

In terms of our model, from the firm's perspective, the use of a military response in the initial periods can be seen as a substitute for strong local formal institutions, thereby eliminating the need for contracts to be self-enforced and backloaded. Indeed, in this early epoch, governments were discouraged from expropriating not by their own court rulings but by the threat of military intervention from oil consuming countries. Once this threat disappears, contracts need to be self-enforced. Accordingly, firms respond to this new need by backloading the agreements. Indeed, we find that around 1968-1973 the multinationals adjusted and started backloading production, tax payments and eventually investments. Our Difference in Differences specification, in which we estimate the extend of backloading in countries with weak institutions, using countries with strong institutions as the counterfactual, suggests that investment, production and tax payments are delayed by 5 years in the years just after the transition to the new equilibrium. We also discuss that these results are unlikely to be driven by potential confounding factors like country specific costs of borrowing, changes in the government's bargaining power, or merely the oil price jump in 1974.

Finally, after establishing the causal relationship between the firms' inability to enforce a contract and the backloading of the contract, we test the second prediction of the model, namely whether backloading disappears in the long-run. To test this, we define the start of the relationship to be either the year in which a firm is awarded an extractive license for the first time or 1974 in case the firm entered before that year. The latter is motivated by the previously discussed resetting of any existing relationship. Using the start of the relationship date to infer relationship duration, we show that while the initial backloading is around 4 years at firm's entrance in countries with weak institutions, it vanishes after approximately 20 years of the relationship.

The findings of this paper contribute to three large strands of the literature. To the best of our knowledge, we are the first to provide empirical evidence about contract backloading established by a large body of theoretical literature on dynamic contracting without commitment and limited transferable payoffs (Ray, 2002). Thus, we contribute to the empirical literature on self-enforcing contracts (McMillan and Woodruff (1999), Antràs and Foley (2015), Macchiavello and Morjaria (2015), Gibbons and Henderson (2013) and Blader et al. (2015)).[12] The

[12] See Gil and Zanarone (2017) for a recent survey. Within this literature, Brugues (2020) is concerned with contract dynamics in the provision of trade credit in Ecuador in a setting where buyers have private information

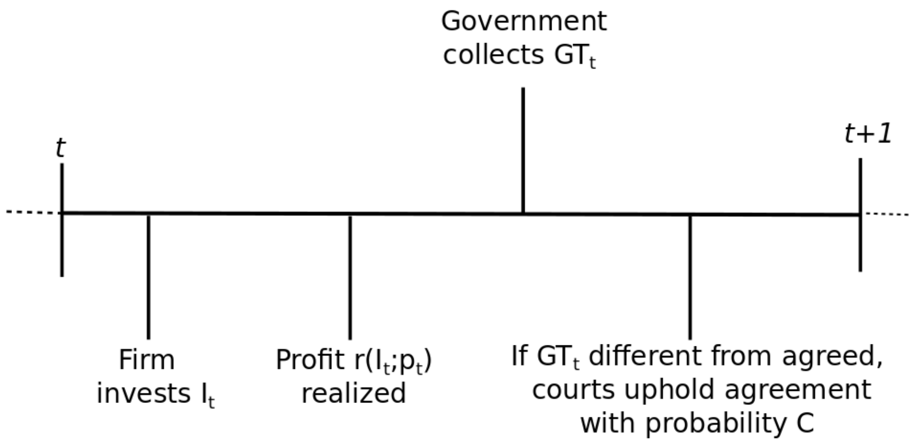
progress of this literature has been limited by the unavailability of transaction data in environments with limited or no formal contract enforcement and it has focused on inter and intra-firm relationships. Instead, in our paper, one contracting party is the government allowing us to explore whether public entities can also establish these informal relationships. Therefore, the second literature we contribute to is the one on political economy (Bulow and Rogoff (1989), Atkeson (1991)). We are the first to show empirically that firms can establish self-enforcing relationships with governments and backload taxes as way to overcome the lack of formal institutions.

The third strand of related literature looks at the effect of institutions on firms' behavior such as firms' organization (Lafontaine, Perrigot and Wilson, 2017), performance (Levy and Spiller, 1994) or investment (Javorcik, 2004). A number of papers focus in the oil industry in particular. Cust and Harding (2020) show that exploration in oil and gas is less likely to take place in countries with weak institutions by exploring the area around the political border between two resource rich economies. In Guriev, Kolotilin and Sonin (2011), the oil company (not the government) can renege on the taxes in which case the government expropriates. Hence, when oil prices are high so are the taxes and that is why expropriations are more likely to occur. In Stroebel and Van Benthem (2013), the oil company can provide the government with insurance and the government's expropriation cost is private information. Both papers consider stationary contracts and they empirically find that expropriations are more likely when oil prices are high and when oil companies offer more insurance. Finally, Jaakkola, Spiro and Van Benthem (2019) show that taxation and investment exhibit cycles by using a model where the government's commitment is limited to one period and the company cannot commit to never invest in the future. We are the first to document empirically the consequences of lack of commitment on the timing of production, investment and tax collection.

In the next section, we set up a model and derive the hypotheses. In section 3 we describe the data and the stylized facts. In section 4, we present the results and discuss the alternative explanation for our results. In section 5 we discuss a case study in which we take into account the presence of national oil companies and the long term dynamics of relationship contract. In the last section we conclude.

about their willingness to pay and cannot commit to repay while sellers can commit to a dynamic linear-pricing contract.

Figure 2: TIMELINE



2 MODEL

We present a stylized model of the ongoing informal relationship between a government (he) and an oil & gas firm (she), where the firm invests and pays taxes while the government decides whether to expropriate or not. In order to derive empirical predictions, we extend Thomas and Worrall (1994) to explicitly model legal constraints limiting the government ability to expropriate.

In the model, the government and the firm interact repeatedly over an infinite horizon of periods. The timeline for each period is shown in Figure 2. Every period, the government and the firm agree on an investment I_t and a transfer GT_t (i.e. overall government take). Then, the firm invests I_t (which depreciates within one period[13]). Next, an $i.i.d.$ oil price shock is realized: oil price can be low ($p = 0$) or high ($p = 1$) with equal probabilities. Oil price, together with the investment, determines the firm's profit $r(I_t; p_t) = p_t 4\sqrt{I_t}$. The government chooses a transfer GT_t, leaving the firm a net profit of $r(I_t; p_t) - GT_t$. If the government collects a different GT_t from the one initially promised (i.e. expropriates), the legal constraints imposed on the government can uphold the initial agreement with probability $C \in [0, 1]$.[14]

[13] Thomas and Worrall (1994) show that allowing for capital accumulation does not qualitatively change the nature of the game.

[14] See Kvaløy and Olsen (2009) for a relational contract model where the probability of legal enforcement is

The government and the firm have the same discount factor δ and are credit-constrained: $r(I_t; p_t) - GT_t \geq 0$ and $GT_t \geq 0$.[15] Regarding the information structure, everything is observable to everyone. The expected value functions of the government V_t and the firm U_t can be written respectively as follows:

$$V_t = \mathbb{E}\left[GT_t\right] + \delta\mathbb{E}\left[V_{t+1}\right]$$
$$U_t = -I_t + \mathbb{E}\left[r(I_t; p_t) - GT_t\right] + \delta\mathbb{E}\left[U_{t+1}\right]$$

An agreement A at time t is a pair (I_t, GT_t) that depends on the history up to time $t-1$ and the current price realization. The agreement needs to be self-enforcing, that is, neither the government nor the firm should ever have an incentive to violate it ex-post. If the government deviates from the agreed transfer in A, it is assumed that the firm will never again invest in the country. Therefore, if the government deviates, he tries to appropriate all the profits. The extend to which the government succeeds in expropriating depends on the legal constraints C imposed on him. The following self-enforcing condition ensures that, for a given p_t and C, the government has incentives to honor the agreement at time t:

$$GT_t + \delta V_{t+1} \geq GT_t + (1-C)[r(I_t; p_t) - GT_t] \qquad \text{(SE)}$$

This constraint requires that the discounted future value of the relationship δV_{t+1} (in terms of future taxes) is larger than what the government is allowed to expropriate in the current period. Note that when $C = 1$, the agreement is perfectly enforced by the courts. As a result, the constraint (SE) is always slack. At the other end, if $C = 0$, there are no constraints on the government and the agreement may need to be self-enforced. In this case, the model is equivalent to that of Thomas and Worrall (1994).

Parallel to Thomas and Worrall (1994), we focus on the Pareto efficient equilibrium that maximizes the firm's payoff at the beginning of the game.[16] As a benchmark, we first consider

endogenous.

[15] Governments are usually unable to subsidize firms upfront. Doing so would solve the holdup problem since governments could transfer to the firms the cost of investment before it is incurred by the firms. Figure 13 shows that the share of subsidies relative to the total cost of production (within the first five years of production) is below 10% regardless of the quality of institutions in the country.

[16] Concentrating on the equilibrium that is best from the point of view of the firm does not alter the character-

the optimal contract in the absence of enforceability frictions. Define I^* as the efficient total surplus maximizing level of investment: it solves the FOC for total surplus $E[r'(I^*; p_t)] = 1$, that is, $I^* = 1$. Whenever the quality of institutions is high enough such that the self-enforcing constraint (SE) is slack, the firm invests I^* every period. The transfers will determine how the government and the firm share the surplus but will not affect the level of investment. For instance, the contract that maximizes the firm's payoff will have no transfers so the government gets his outside option of zero.[17] Therefore, the optimal agreement with perfect enforcement is stationary and gives the same value to the government and the firm every period.

However, if institutions are weak enough such that condition (SE) binds, the efficient level of investment is not immediately achievable and the self-enforcing agreement A is "back-loaded". In other words, the government's value from the relationship increases over time. The firm achieves this first, by progressively increasing investment until the first best level I^* is achieved, and second, by increasing the taxes paid to the government.[18]

The rationale behind this result is that, the firm, by delaying the payment of taxes and the investment, makes the threat of terminating the relationship more effective by increasing the government's cost of deviation. In other words, a backloaded agreement enhances the government's credibility by pushing potential gains towards later parts of the relationship. We summarize these results in the following proposition:

Proposition 1. *When the self-enforcing constraint (SE) binds, investment and production are increasing over time to reach the (maximum) efficient steady state value at which the self-enforcing constraint (SE) no longer binds. Tax payments to the government are zero until the period before the maximum value of investment/production is attained.*

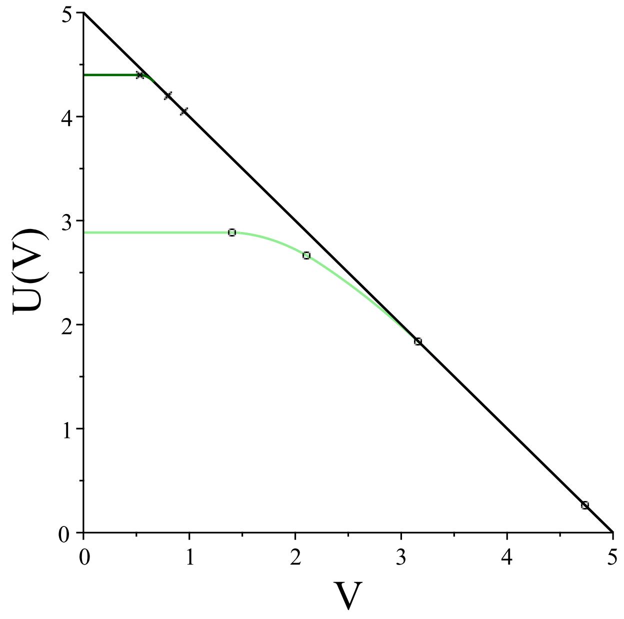
The proof of this Proposition, which is akin to Proposition 1 in Thomas and Worrall (1994), can be found in the Appendix. The initial underinvestment (and associated underproduction) is

ization of the contract significantly. By doing so, we are selecting the most backloaded contract (Ray, 2002). In addition, for exposition purposes, we focus on a parameter range such that efficient first best Pareto frontier is eventually reached: $\delta > \dfrac{2(1-C)}{1+2(1-C)}$. See the Appendix for more details.

[17] Any path with positive transfers (that satisfy the firm's participation constraint) is also possible.

[18] When the oil price is low $p = 0$, there are no revenues to expropriate and the firm does not need to increase the government's value to eliminate the temptation to expropriate. More precisely, the government's value stays the same $V_t = V_{t+1}$. As a result, we refer to periods as the ones where oil price is high $p = 1$ and hence trigger a dynamic behavior. See the Appendix for more details.

Figure 3: VALUE FUNCTION ($\delta = 0.8$ & $C \in \{1, 0.8, 0\}$)



because the government's incentive to expropriate increases with investment. By delaying the payment of taxes to later periods, the current level of investment remains unaffected since the government cares about the value of discounted government take but not when the payments take place. However, as time when the initially delayed payments are due approaches, the discounted government take is larger and the temptation to renege is diminished. This allows the firm to increase the investment and production in later periods without fearing expropriation. Once the efficient level of investment and production is reached, the past promise of paying taxes need to be fullfiled. However, at this point, the choice of current and future tax payment is not uniquely defined.

Figure 3 depicts the firm's value $U(V)$ as a function of the value given to the government, V, for three different levels of institutional quality: $C \in \{1, 0.8, 0\}$. When $C = 1$, $U(V)$ belongs to the efficient frontier, depicted in black, where any point can be sustained as a stationary contract. Note that the point corresponding to the contract that maximizes the firm's utility will give the government $V = 0$. However, if the government has more bargaining power or a better outside option, the firm will need to at least give this value.

For lower values of C ($C = 0.8$ or $C = 0$), the constraint (SE) binds. As a result, the efficient frontier cannot be immediately achieved and its upper part, which provides more initial value to the firm, is not feasible. The government (and the firm) value is depicted by the Pareto frontier in dark-green ($C = 0.8$) and light-green ($C = 0$), respectively. In addition, the contract is backloaded and the crosses and dots on the frontiers represent the path of government value over time following the realization of a high oil price for $C = 0.8$ and $C = 0$, respectively. As seen from Figure 3, it takes several periods for the relationship to achieve the (black) efficient frontier. Once the efficient frontier is achieved, the contract becomes stationary.

Note also that when $C = 0.8$, the efficient frontier is achieved faster than when $C = 0$. This is not a coincidence. The weaker are the institutions, the longer the threat of government expropriation delays efficient levels of investment and production.The following Lemma addresses this comparative statics.

Lemma 1. *The number of periods to achieve the efficient frontier in agreement A decreases with the institutional quality C.*

Intuitively, the weaker formal institutions are, the more backloading is needed to deter expropriation. However, to make this intuition operational, one would need to introduce a formal (and empirically relevant) definition of backloading. Relying on over-time evolution of the *levels* of investment, production and government take - as in the left panel of Figure 4 - may prove difficult in the empirical analysis of the oil & gas industry. The optimal level of investment (or production) is likely to differ across assets based, e.g., on geological or technological conditions. Further, the technological constraints (not accounted in the above stylized model) are also likely to differentially impact the patterns of over-time oil extraction, making it difficult to build a comparative backloading measure based on the levels of the variables in question.

To circumvent these concerns, we use an alternative way to track the timing of investment, production and government take which would make an empirical analysis of backloading more tractable. Instead of operating with levels of the variables in question, we compare how fast they accumulate. That is, we study the evolution of their cumulative shares over a fixed number of periods. For example, for investment we define the corresponding cumulative share as

$$CS_n^I = \frac{\sum_{p=1}^{n} I_p}{\sum_{p=1}^{P} I_p} \tag{1}$$

where $n \in \{1, \ldots, P\}$ and P is exogenously set. Based on these variables we can introduce an empirically feasible definition of backloading.

Backloading measure: Investment / production / government take under agreement $A1$ is more backloaded than under an agreement $A2$ if it accumulates faster under $A2$ than under $A1$. That is, the share of investment / production / government take under $A2$ is weakly higher than under $A1$ at each period $n \in \{1, \ldots, P\}$.

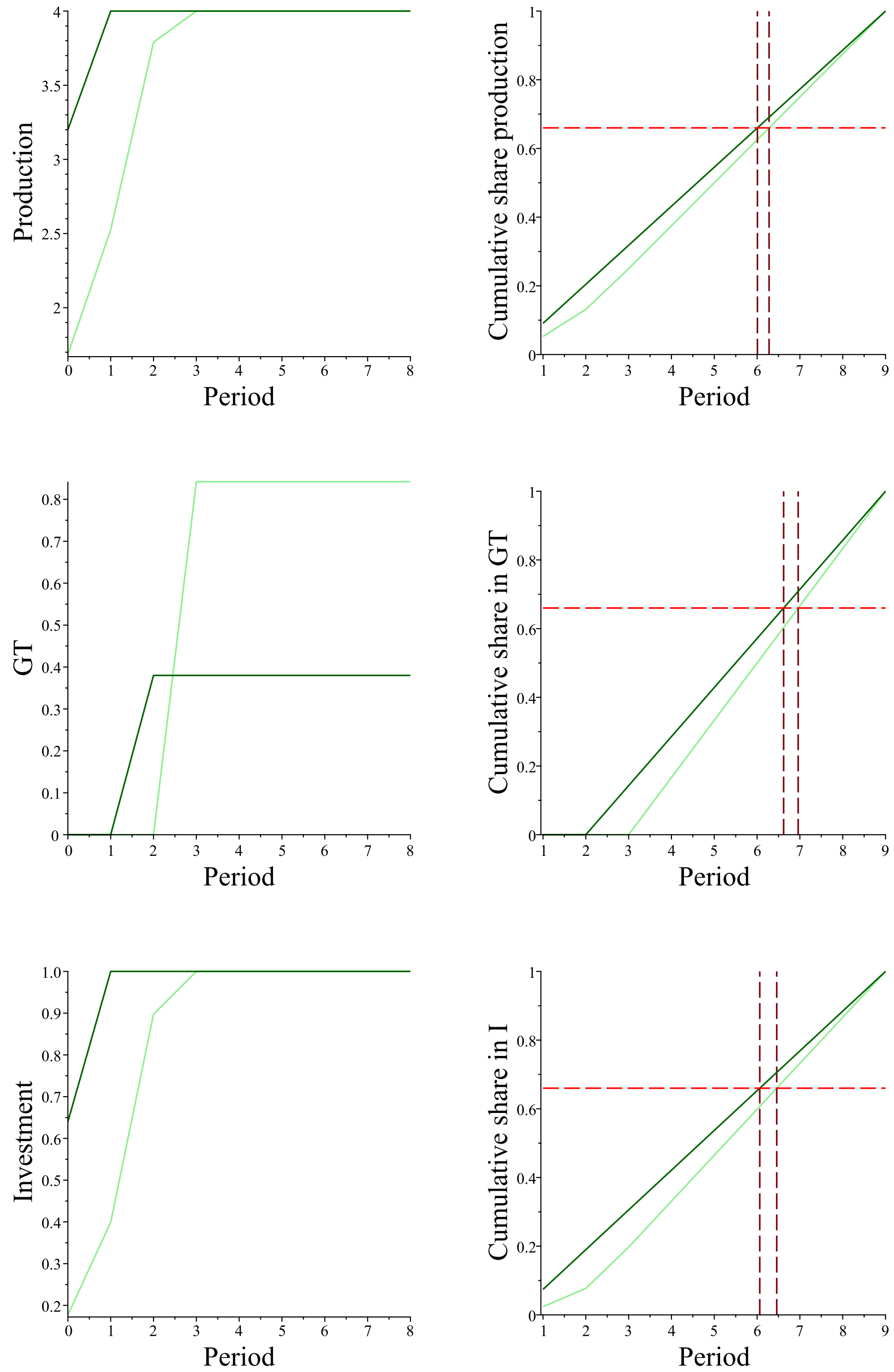
Using this definition, the following Proposition shows that there is less need to delay giving utility to the government when institutions are stronger.

Proposition 2. *Investment and production are more backloaded the weaker the formal institutions are. It takes longer to start paying government take under weaker institutions.*

In countries with weak institutions, investment and production steadily increases until it reaches the efficient level which is maintained ever after. As a result, investment and production accumulates slower in those countries. The prediction concerning the payment of government take is less clear cut. A delay to start paying to the government under weaker institutions points to slower accumulation of government take, which is exactly in line with the backloading result. However, once government take starts being paid, there are multiple paths it can follow, and that may affect the evolution of its cumulative share. On the efficient frontier current government take can be traded against future government take without affecting the efficient level of investment. Thus, government take under weaker institutions may be more or less backloaded, which becomes an empirical question.

Figure 4 illustrates these predictions, also bringing up the relation between the levels and the cumulative shares of the variables. In its left column, we depict the optimal investment, production and government take over time (i.e. periods where price is high - see footnote 18) for $C = 0.8$ and $C = 0$. In a setting with strong institutions (i.e. $C = 0.8$), investment starts being larger and achieves the first best level ($I^* = 1$) earlier than with weak institutions (i.e. $C = 0$). The situation with production is similar. Recall also, that the delay in giving value to the government is achieved by delaying investment and the payment of the government take. As a result, the payment of government take starts earlier when institutions are strong. Note that the stationary amount of government take is larger when institutions are weaker. This is

Figure 4: OPTIMAL AGREEMENT ($\delta = 0.8$ & $C \in \{0.8, 0\}$)



because governments in countries with weak institutions need to be given more rents so that they do not have incentives to expropriate.

The right column of Figure 4 depicts the cumulative share of investment, government take and production in the first six periods for the same levels of C. The accumulation of investment, production and government take (for the chosen set of parameters) is delayed under weaker institutions.

To make the measure of such delay more straight-forward, we define out empircal measure of backloading as the number of periods (i.e. years) it takes to reach the 66% of the cumulative share of the relevant variable. Graphically, the horizontal dashed line marks the 66% of the cumulative share while the vertical dashed lines indicate how many periods with high oil price it takes to reach this level.

Using this measure, we formulate the empirical predictions derived by Propositions 2 and 1 to form the hypothesis for our empirical analysis:

Hypothesis 1. The 66% of cumulative share in production, and investment is reached faster in countries with strong institutions compared to those with weak institutions. It may be either way for the government take

Hypothesis 2. The differences in contract backloading between countries with strong and weak institutions disappears as the firm-government relationship matures.

3 DATA AND EMPIRICAL FACTS

SOURCE: The micro level data on oil and gas projects is coming from Rystad Energy, an energy consultancy based in Norway. Its U-Cube database contains current and historical data on physical, geological and financial features for the universe of oil and gas assets on the global level. Rystad collects the data from a wide range of sources, including oil and gas company reports, government reports, as well as expert interviews. In some cases, Rystad imputes observations and Asker, Collard-Wexler and De Loecker (2019) provide a detailed description of the data construction process. Our discussions with Rystad representatives as well as people working with the data suggests that Rystad provides the highest quality data available in the industry and that the information on the physical production volumes on the asset level as well as asset level tax payments are particularly accurate.

SAMPLE: We focus on the assets owned by the oil majors. An asset may be thought of containing *at least* one production well and be operated by *at least* one firm with the initial property right being owned by *at least* one country. The group of oil majors consists of BP, Chevron, ConocoPhillips, Eni, ExxonMobil, Royal Dutch Shell and Total. Historically, these are the largest private firms in the industry. They have been active for a long period of time and they have been owning assets in many countries. Jointly, these two characteristics imply that we have sufficient spatial variation as well as the necessary variation over time which is needed to capture backloading in long term dynamic relationships. We restrict our analysis to those assets which began production between 1960 and 1999 and we only use assets which have been in operation for at least 20 years. To construct our backlogging measures we need surplus generating assets which can be taxed. Thus, we drop all assets which do not generate a surplus within 35 years. In total, this implies that we are dropping around 3% of the cumulative production which has been generated by the oil majors over the full sample period. Finally, for the presentation of the empirical facts we focus on the sample from 1974 onward, while we extend the sample back to 1960 for the causal analysis.

VARIABLES: For all assets, we observe the year in which exploration rights to an asset have been awarded and the eventual start of production. Yearly data on the type of the fiscal regime under which the production takes place, the ownership rights, physical production, different types of capital as well as operational expenditures, revenues, profits, different forms of taxes paid, physical reserves, local climate conditions, type of commodity extracted, whether the asset is located off- or onshore as well as the exact geographical location. In what follows, we briefly describe all these variables in greater detail.

YEAR OF AWARD AND START OF PRODUCTION: The years when the exploration license is granted and production starts, respectively. Discovery takes place between the award of a license and production and is followed by the development of an asset. before production starts.

FISCAL REGIME: There are essentially three different types of ownership. If the firm is granted 100% ownership of the product extracted, the agreement is referred to as a concession. The agreement is referred to as a service contract if the firm is granted 0% ownership and as a production sharing agreement if the firm is granted between 0% and 100% ownership. Such agreements imply that at least a share of the produced fossil fuel is owned by the government of the country in which the firm is operating. In general, formats of negotiation and the exact share of the revenues and profits received by both parties vary greatly and depend on a country's petroleum laws and regulations. as well as the geological features of the assets.

OWNERSHIP: At least one of the majors has to be involved in the operation of an assets to be included in our sample. For almost all of our assets a major is also the company that started production implying that a transfer of ownership from a major to a non-major if any, has happened in the later years of assets' existence. We exclude the assets which were not discovered and initially operated by majors.

PHYSICAL PRODUCTION AND REVENUES: For each asset we observe yearly physical production, revenue sand profits. Production is given in thousands of barrels for liquids, or barrels of oil equivalent for gas, per day. Revenue is the physical amount produced on the asset level multiplied by the price for which the hydrocarbon is sold. Note that prices can vary due to the heterogeneity in the type as well as the quality of the hydrocarbon which is extracted, such that equality in the amounts produced, does not need to imply equality in revenues generated. Revenues are documented in millions current USD. To make them comparable across time, we discount them using the US CPI to obtain values in real 2018 USD. If the asset is jointly operated by several companies, we observe their levels of production, revenues and profits from this asset separately according to the agreement. We exclude assets with negative profits from our sample, as the absence of profits does not allow us to measure the allocation of surplus between the government and the firm.

OPERATIONAL AND CAPITAL EXPENDITURE: On the asset level we observe well CAPEX, which is defined as capitalized costs related to well construction, including drilling costs, rig lease, well completion, well stimulation, steel costs and the necessary materials. And we also observe operational expenditure, which is defined as costs related to materials, tools, maintenance, equipment leases as well as salaries. Both are denominated in millions of real 2018 US dollars.

GOVERNMENT TAKE: Using the available information on tax payments under a variety of fiscal regimes in every point in time, we construct the *government take*, which captures the total amount of payments received by the government from an asset. It is the the most common statistic used for the evaluation of contracts (Johnston, 2007; Venables, 2016).[19] It consists of all cash flows destined to the authorities and land owners, including royalties, government profit oil (PSA equivalent to petroleum taxes), export duties, bonuses, income taxes and profit taxes. It is denominated in millions of real 2018 US dollars. Since we are measuring the extent of backloading by calculating the cumulative share in tax payments received by the government over a specific period of time, we need to abstract from subsidies (negative tax payments) to achieve monotonically increasing cumulative distribution functions over the production cycle. In particular, in the empirical section we will use to alternative measures of government take. Either we just use royalties and profit taxes, which do not contain any subsidies, and we abstract from the income tax component of the government take, which may contain subsidies. Alternatively, we simply abstract from the subsidies paid by setting the value of the income tax to zero in periods in which the reported government take is negative. Note that this does not appear to be a strong assumption since the cumulative amount of subsidies received by the median asset in our sample adds up to 2% of the cumulative government take received by the government and for over 90% of the observations in our sample this share remained well below 10%.

RESERVES, TYPES, LOCATION AND CLIMATE: Reserves are defined in the data as the remaining economically recoverable physical volumes. We use reserves at the beginning of asset's production as a proxy for asset size. We also have information on the type of hy-

[19] See Johnston (2007) for a discussion of the advantages and the disadvantages of such a measure. In practice, the total amount and the structure of payments received by the government in the framework of an agreement are typically referred to as a fiscal regime. In some countries, a single fiscal regime applies to the entire country; in others, a variety of fiscal regimes exist. In many cases, the agreements allocated to the same firm within the same country are also interlinked in a variety of ways, such as a joint calculation of the tax base. See the Global Oil and Gas Tax Guide 2021 for examples.

drocarbon (oil or gas,) as well as the exact location of the asset and the climatic conditions in which the asset is located. All of these represent potential confounding factors for which we are accounting for in the empirical analysis.

EXECUTIVE CONSTRAINTS: To differentiate countries by institutional quality we use Polity IV. In particular, we use country level annual information on the executive constraints (XCONST), which measures the extent of institutional constraints on the decision-making powers of the chief executive, whether an individual or a collective executive. To reduce reverse causality concerns from the oil wealth to institutions, we rely on the median score which was given to a particular country over the period of 1950 to 1975. In particular, we consider a country to have strong institutions if the received median score was 6 or 7, while countries which have received a median score of less than 6 are defined as countries having weak institutions.[20] Choosing the cut-off between 5 and 6 implies that roughly 1/3 of the countries, or 17 out of 49, are defined as having strong institutions and around 43% of all the assets which started production between 1960 and 2000 are located in countries with weak institutions. In the empirical section we extend the number of groups to three by splitting the countries with weak institutions into two groups: the weak (XCONST of 3-5) and the very weak (XCONST of 1-2). Alternatively, we also use the initial, before and including the early 1970s, OECD membership to differentiate between countries with strong and with weak institutions. Our results remain robust to these changes and are available on request.

DESCRIPTIVE STATISTICS: Using our baseline distinction according to Polity IV between countries with weak and strong institutions we provide the summary statistics for the

[20]A few remarks are in order. The countries which have a median score of 6 or 7 consist of countries which joined the OECD by the early 1970s, as well as Bangladesh, Brunei, Colombia, Malaysia, and Trinidad and Tobago. Surprisingly, France is below this threshold which we attribute to the extraordinary power Charles de Gaulle received during his presidency, which positions France among the countries with weak institutions. But since only 12 assets are operated by the majors in France during our sample period, adding France to either of the groups barely affects the results. Since Brunei remained part of the UK until 1984 and since it is completely surrounded by Malaysia, we classify Brunei as country with strong institutions. In our baseline specification all the remaining countries are classified as having weak institutions. But note that for some countries few observations are used to determine the score, since they became independent after 1960 with the number in parentheses indicating the exact year: Angola (1975), Bangladesh (1971), Nigeria (1960), Papua New Guinea (1975), Qatar (1971), UAE (1971). We also use the median score of the USSR for all the former Soviet Union countries as well as the median score of Yugoslavia for all the former Yugoslavian countries. And we use the score of West Germany for Germany, while we use the median score of North and South Yemen (which are the same) for Yemen. Finally, some of the wells are jointly managed by several countries. We drop the 284 observations assigned to such wells. To the best of our knowledge, none of these choices significantly impacts our results.

Table 1: DESCRIPTIVE STATISTICS (1974-1999)

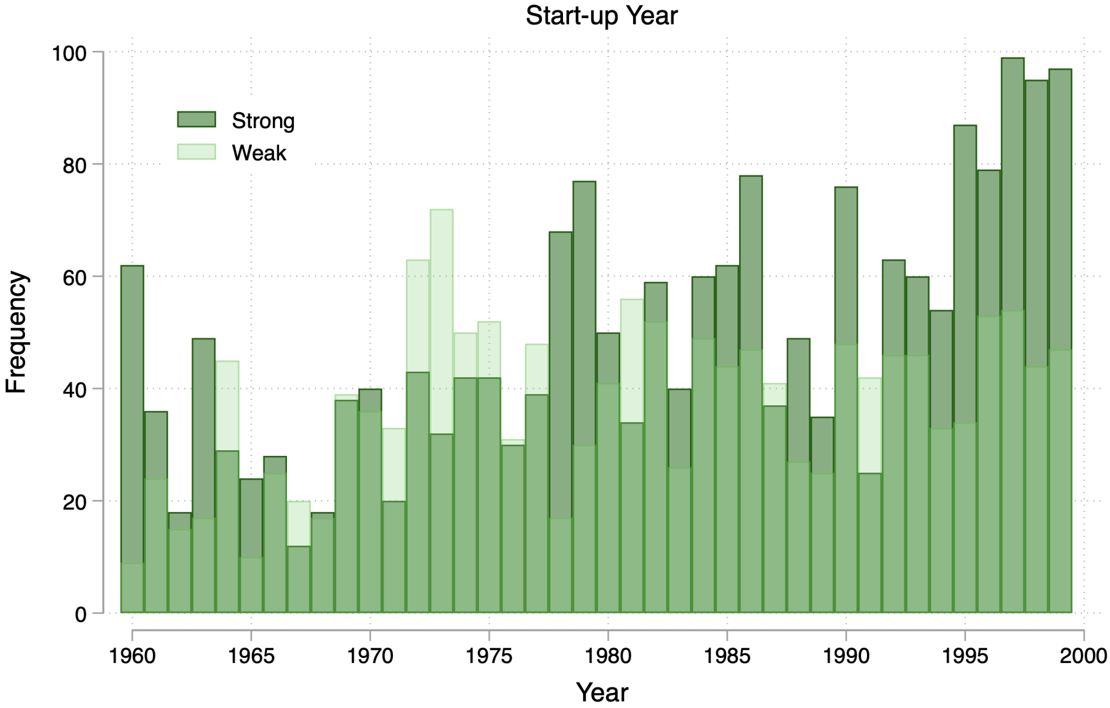
	strong institutions		weak institutions		mean comparison	
	mean	sd	mean	sd	difference	p-value
Asset Lifetime, years	28	0.2	29	0.2	-1	0.00
Cum. Production, MMbbl	40	4.9	38	3.3	2	0.73
Cum. Real Revenue, MUSD	1721	251	1798	179	-78	0.82
Cum. Real Cost, MUSD	696	92	460	39	236	0.04
Cum. Real Gov. Take, MUSD	707	112	975	101	-267	0.09
Cum. Real Profit, MUSD	316	51	364	50	- 47	0.53
Number of Assets	1537		1083			

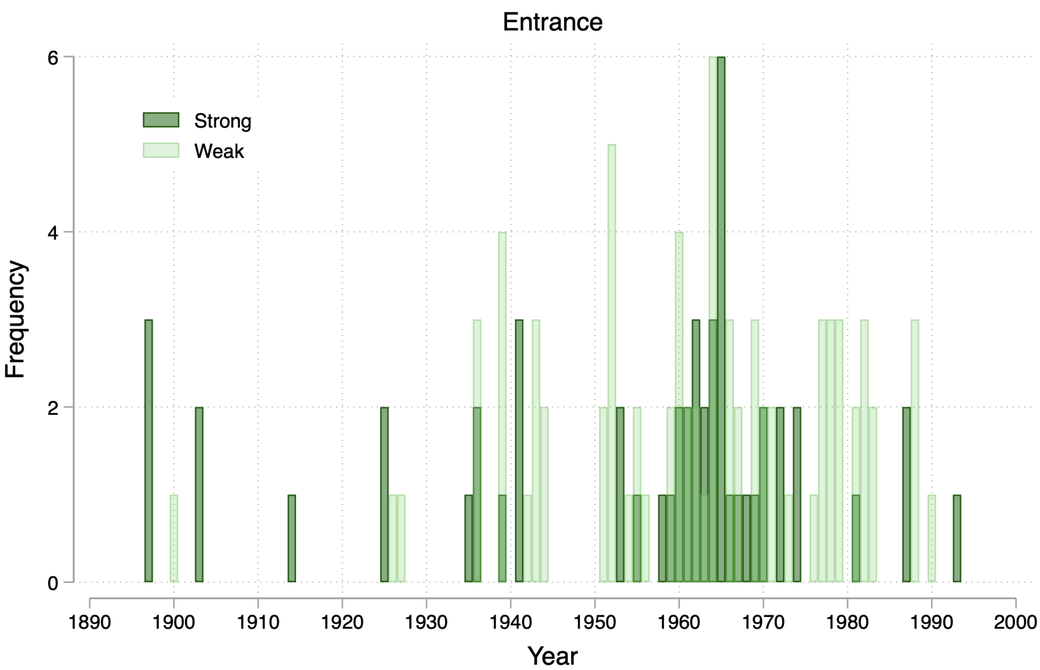
Note: Monetary measures are presented in real 2018 US dollars. The life time of the asses is restricted to 35 years to be in line with our baseline sample. A simple t-test is used to get an estimate for the calculation of the p-values. The results suggest that the assets do not differ in size between countries with weak and strong institutions, and that they are equally profitable on average. On the other hand, lower extraction costs in countries with weak institutions are compensated by larger government takes. The significantly longer lifetime of the asset in countries with weak institutions is already indicating the presence of backloading.

baseline sample of operating assets since 1974 in Table 1. Note that the cumulative production of wells and the revenues received do not differ much across countries, while the duration of the lifetime of the asset is longer in countries with weak institutions relative to countries with strong institutions. This is already very much in line with the presence of backloading in countries with weak institutions, since equally sized assets which are operated by the same group of firms over the same sample period require more time to be extracted. Further below in Table 1, we see that the total cost of extraction is higher in developed countries, while the amount of taxes paid is lower. The former is well known and may be explained by the fact that the exploration of oil and gas has been practiced much more extensively in the developed world such that the easy to access wells have already been exhausted. On the other hand, the latter indicates that the remaining rents (revenues minus extraction costs) of the scarce resource are going to the owner of the resource as theoretically would be expected (Venables, 2016). This leaves the majors indifferent between assets located in developing and developed countries. This is confirmed by the last row of Table 1 which suggests that asset level profits received by the majors do not differ significantly on average between countries with weak and strong institutions. Albeit, they are still higher on average by approximately 50 MUSD, which may be rationalized by the pricing of risks the majors are exposed to in countries with weak institutions.

In Figure 5 and Figure 6, we graph the time as well as the spatial variation of the assets

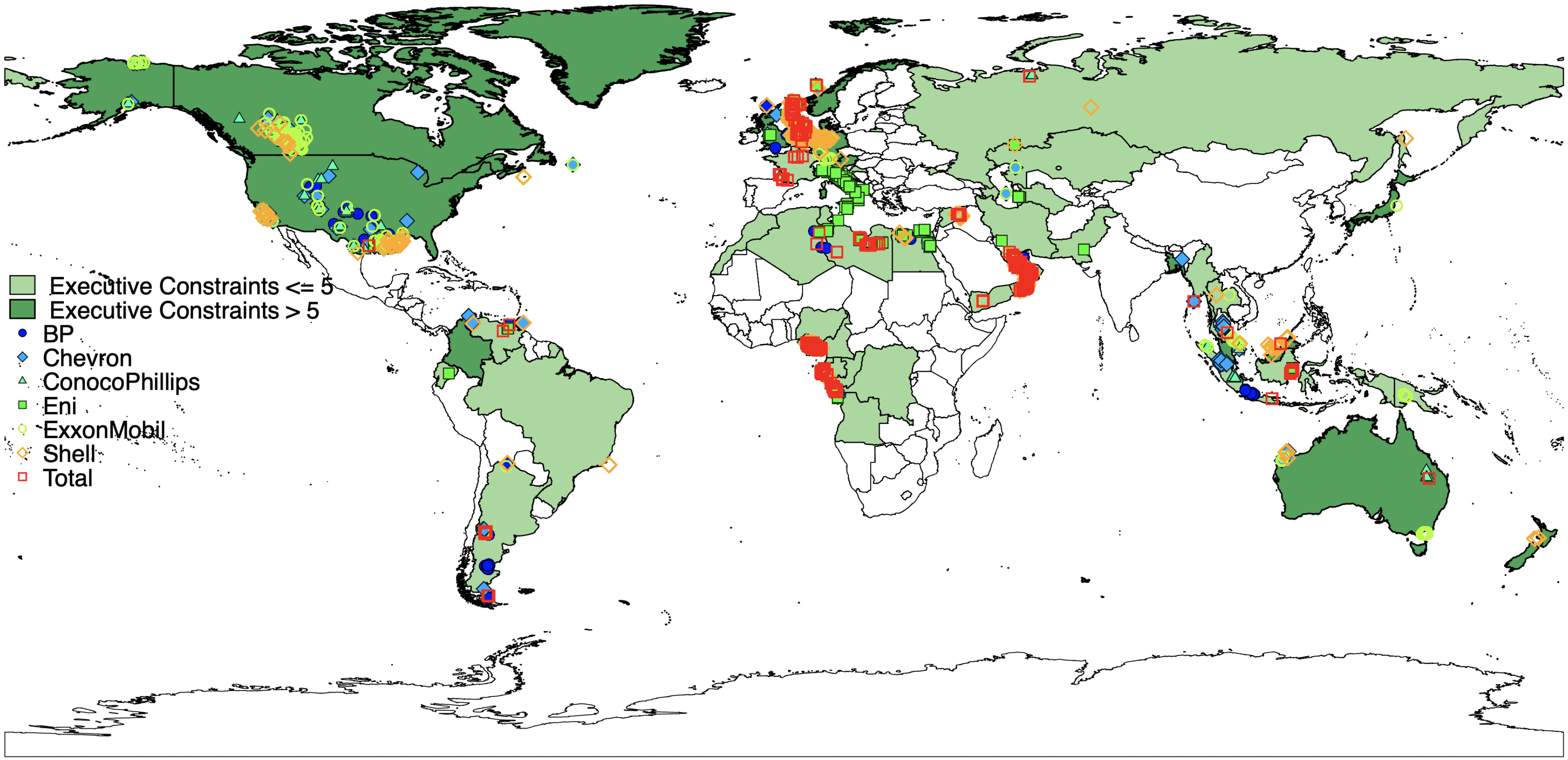
Figure 5: START OF PRODUCTION AND ENTRANCE





Note: We use the year in which the production of an assets starts for the construction of the graph at the top. To construct the graph at the bottom we us the year in which an award has been allocated by a country to a firm for the very first time.

Figure 6: SPATIAL DISTRIBUTION OF ASSETS AND INSTITUTIONAL QUALITY



Note: Longitude and Latitude of individual assets is provided by Rystad. An asset may be thought of containing at *least one* production well and be operated by at *least one* one firm with the initial property right being owned by at *least one* country. The executive constraint indicator is taken from PolityIV and we use the median from the period 1950 to 1975 to define whether the country is considered as having strong or weak institutions. The cut-off of 5 implies that roughly 1/3 of the countries are defined as having strong institutions and roughly 50% of all the assets which started operation between 1950 and 2000 are located in countries with weak institutions.

owned by the oil majors in our sample. In Figure 5 we see that the number of producing assets (top) appears to be balanced and on an upwards trajoctory in both, weak and strong countries. While the number of entrances (bottom) experienced a peak between 1950 and 1970, before slowing down. As discussed further below, this is consistent with oil consuming countries backing oil majors in the search to secure new assets (Yergin, 2011). In Figure 6, we plot the spatial allocation of the assets owned by the oil majors.

MEASURING BACKLOADING: Before proceeding to the empirical analysis, we use raw data at the asset level to illustrate the presence of backloading for several asset level characteristics, as well as introduce our main left hand side variable. The asset level characteristics are well CAPEX and production OPEX which proxy investment on the asset level; physical production, which we consider to be our most reliable indicator since according to Rystad it has the highest quality and moreover does not require any discounting over time; and the two alternative measures of government take, overall government take without subsidies and royalty & profit tax only. The measure used to capture the delay in investment, production and tax payments is the *number of years that are needed to reach the S^{th} share of the cumulative investment, production and tax payments over the life cycle of the asset.* To this end, we first construct the following measure for all the key variables with X indicating the *real* values of investment, and tax payment as well as physical production of an asset a in period p. Period p equals 1 in the year in which production starts and we choose in our baseline P to be 35 years, which is around 20% above the mean of an asset's lifetime in our baseline sample.[21] Finally, $\bar{p}$ is the number of periods such that investment, production and tax payments reach a particular cumulative share $S_{a\bar{p}}$ of the overall investment, production and tax payments over the chosen life time P, or more formally:

$$\mathrm{S}_{a\bar{p}} = \frac{\sum_{p=-5}^{\bar{p}} X_{a,p}}{\sum_{p=-5}^{P} X_{a,p}}, \tag{2}$$

In Figure 7, we plot $S_{a\bar{p}}$ against p by differentiating between countries with weak and strong institutions. First, note that on all graphs the measures are monotonically increasing for both groups and that in period 0, $S_{a0} = 0$, while in period $P = 35$, $S_{a35} = 1$, as it should be. Our main LHS variable y_a is depicted on the x-axis in Figure 7 and indicates the number of periods $\bar{p}$ which are necessary to reach the $S_{a\bar{p}} = 66\%$ threshold on the asset level, indicated by

[21] In the empirical analysis we allow for alternative choices of P and our results are robust to these choices.

the red horizontal and dashed line.[22] For all the asset characteristics oil majors need 1-3 years more in order to reach 66% in countries with weak institutions relative to countries with strong institutions. For our preferred measure, physical production, we extend the number of groups to three by splitting the countries with weak institutions into two groups: the weak (XCONST of 3-5) and the very weak (XCONST of 1-2) and illustrate the results in the top right panel of Figure 7, next to the illustration according to our baseline with just two groups. All the remaining characteristics are illustrated in the middle as well as the bottom rows of Figure 7. The "first order stochastic dominance" of the average CDF in countries with strong institutions relative to countries with weak institutions, illustrated for all of our measures in Figures 7 is consistent with the presence of backloading as predicted by the theory.

4 IDENTIFICATION AND RESULTS

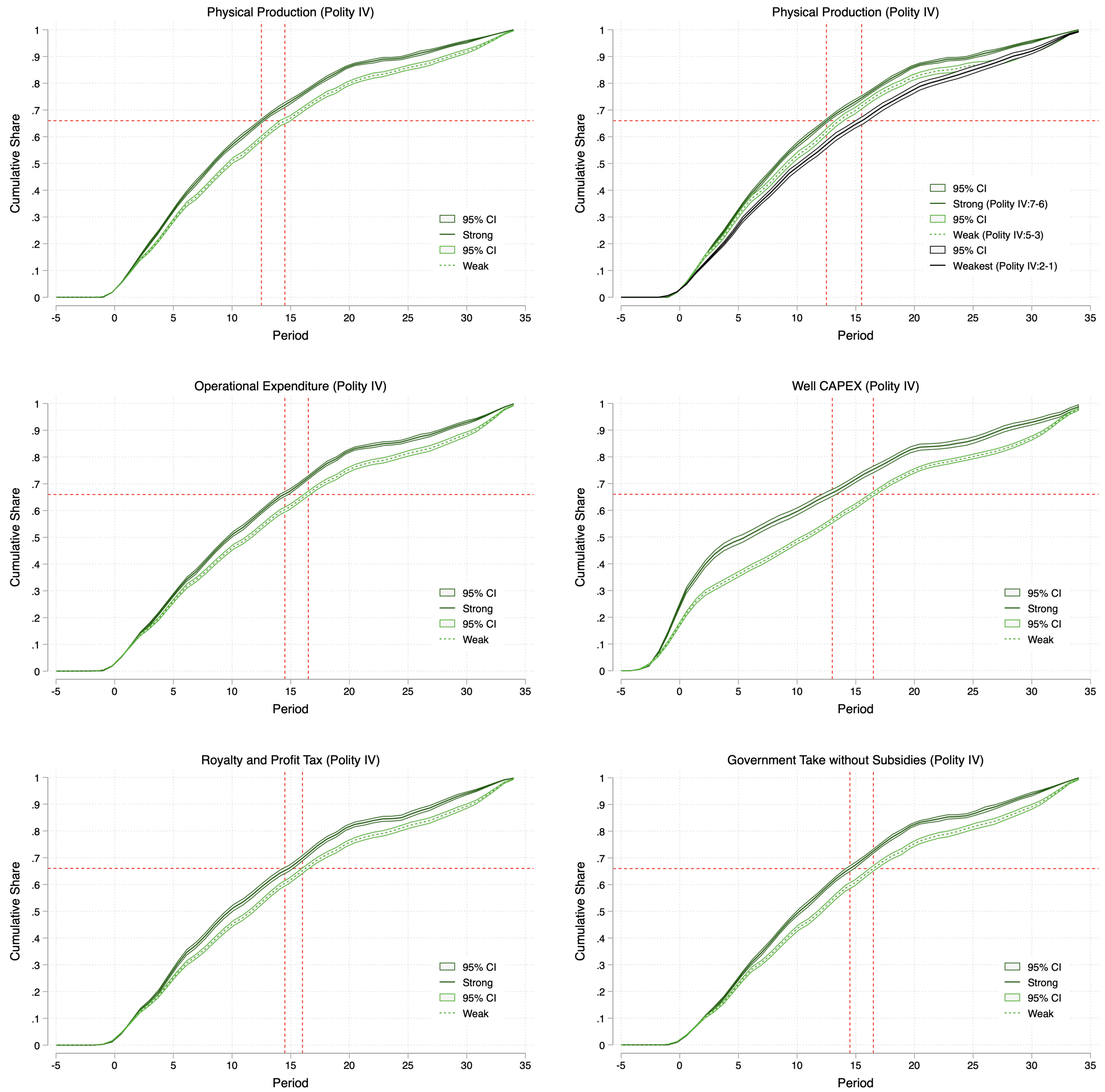
4.1 BACKLOADED CONTRACTS

Thanks to the richness of our dataset, we are able to account for a large number of asset characteristics to ensure that differences in backloading between assets located in countries with strong and weak institutions, illustrated in Figure 7, are not driven by geological and geographical as well as other asset specific characteristics, which may be correlated with the quality of institutions on the country level. The set of geographical characteristics includes the exact location, whether the asset is being developed onshore or offshore as well as climatic conditions. The set of geological characteristics includes the size of the reservoir and the type of fossil fuel extracted. To capture some basic relationship characteristics, we also account for the firm operating the asset, as well as the type of the fiscal regime associated with the asset. Finally, we also account for the year in which production started and the life time of the asset (i.e. the total number of years for which we observe the assets since the beginning of production). Conditional on these controls, we estimate the following specification with y_a indicating the asset specific number of years $\bar{p}$ (see equation 2), which are necessary to reach 66 % of the cumulative flows of X, as graphically depicted in Figure 7:

$$y_a = \beta \text{Weak}_{c(a)} + \Omega_a' \gamma + \varepsilon_a \tag{3}$$

[22] In the empirical analysis we allow for alternative choices of S and our results are robust to these choices.

Figure 7: YEARS TO REACH 66% OF CUMULATIVE FLOWS IN 35 YEARS



Source: We use the epanechnikov kernel with an optimally chosen bandwidth to plot the cumulative production, investment, and tax payments over the 35 year life span of the asset. Based on our baseline we group countries into two groups, countries with strong and weak institutions. Our institutional measure of choice is the executive constraint indicator from Polity IV and we use the median from the period 1950 to 1970 to define whether the country is considered to have strong or weak institutions. The cut-off of 5 implies that roughly 1/3 of the countries are defined as having strong institutions and roughly 50% of all the assets which started operation between 1960 and 1999 are located in countries with weak institutions. Production is in a vast majority of cases based on raw data. Asset level tax agreement are used to calculate tax payment based on production and the current price of oil. Operational and Capital Expenditure are estimated by Rystad based on an internal model.

TABLE 2
YEARS TO REACH 66% OF CUMULATIVE FLOWS IN 35 YEARS

	(1) Production	(2) Production	(3) R&P	(4) R&P	(5) GT	(6) GT	(7) OPEX	(8) OPEX	(9) CAPEX	(10) CAPEX
Weak (Polity IV)	1.483**	2.071***	1.509	1.892**	1.291*	1.725**	1.454*	1.244*	3.859*	1.977**
	(0.648)	(0.525)	(0.927)	(0.841)	(0.739)	(0.674)	(0.848)	(0.723)	(1.878)	(0.924)
N	2620	2616	2046	2042	2620	2616	2620	2616	1463	1461
R-sq	0.23	0.37	0.14	0.32	0.15	0.33	0.12	0.27	0.13	0.49
Start-Up Year	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Asset Lifetime	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Location (Long. and Lat.)	N	Y	N	Y	N	Y	N	Y	N	Y
Onshore vs. Offshore	N	Y	N	Y	N	Y	N	Y	N	Y
Climatic Conditions	N	Y	N	Y	N	Y	N	Y	N	Y
Fossil Fuel Type	N	Y	N	Y	N	Y	N	Y	N	Y
Reservoir Size (logged)	N	Y	N	Y	N	Y	N	Y	N	Y
Fiscal Regime	N	Y	N	Y	N	Y	N	Y	N	Y
Firm	N	Y	N	Y	N	Y	N	Y	N	Y

Notes: Year of Start-Up FE and the lifetime of the asset are included in all regressions. In columns with even numbers, we also control for a large number of asset specific observable characteristics. Left hand side variable is capturing the number of years until 66% of cumulative level of OPEX, Well CAPEX , production and tax payments after 35 years is reached. SE in parenthesis is clustered by country and Start Up Year. * stands for statistical significance at the 10% level, ** at the 5% level and *** at the 1% percent level.

$Weak_{c(a)}$ is a dummy variable which is equal to 1 if the asset is located in a country which is categorized as having weak institutions. Our coefficient of interest β, provides an estimate for the difference in the number of years which are necessary to reach 66% of production, investment as well as tax payments by differentiating between countries with strong and weak institutions. Ω_a is a vector of asset specific characteristics for which we control. The standard errors are clustered by country and start-up year. The estimates of β are presented in Table 2. In columns with even numbers, we present the results with the controls, while we present the results without most controls (except the year in which production starts and the asset's lifetime) in the columns with uneven numbers. Overall, the results in Table 2 are robust to the inclusion of all controls[23] and suggest that it takes approximately 2 years longer in countries with weak institutions to reach the same level of cumulative investment, production and tax payments as in a country with strong institutions.

The results in Table 2 rely on specific assumptions with regards to the classification of countries to have weak or strong institutions, the choice of the 66% threshold, as well as the total number of years which are used to calculate this threshold (P and S in equation 2). However, our results are robust to these choices. A summary table of results based on alternative choices

[23]The only exception being CAPEX, where the coefficient drops by a factor of 2 when moving from column 3 to column 4, and which is driven by the inclusion of the offshore dummy. Oil majors are less likely to develop offshore assets in countries with weak institutions and offshore assets differ from onshore assets in their production technology, requiring a larger share of CAPEX to be invested early on and reaching 66% of the cumulative capital expenditure earlier. Thus, not controlling for the differences in drilling location and the associated technology, biases the coefficient upwards.

is provided in the Appendix in Table 4, with a limited set of controls including the year in which production starts and the life time of the asset, and Table 5, with all controls. Note that our results in Panel A, our preferred measure, are particularly robust to these changes.

4.2 TRANSITION TO A NEW WORLD OIL ORDER

During WWII it became apparent that access to oil and energy security was an essential part of a country's strategic interests. The US government started wondering *"What would a pervasive and lasting shortage [in oil] mean for America's security and for its future?"*. Thus, the government set policies with the goal to secure access to oil: *"The State Department should work out a program to [...] promote the expansion of United States oil holdings abroad, and to protect such holdings as already exist."* (Yergin, 2011). This implied that activities in the oil and gas sector were elevated to become part of national security, since a secured source of energy was too important to be left to businesses alone (Yergin, 2011).[24] This agenda implied that the US would, if needed, deploy its army to secure the energy stability and the on-going economic recovery of Western Europe and the US. The most infamous case of US intervention would result in Iran's coup d'etat in the early 1950s and eventually lead up to the 1979 Iranian revolution just two decades later.[25] Scared by the Iranian example, only few oil rich economies attempted the renegotiation of initially established oil deals with the big oil firms throughout the next decade.

In terms of the model in Section 2, the governments in countries with weak institutions

[24]As a consequence of the governments involvement, the real price of oil would remain extraordinary stable over the period 1945 to 1965. The automatic stabilizer policy of the US required that any fluctuations in demand would be mirrored by changes in supply with the explicit objective to stabilize the price of oil in order to avoid any disruption in the economic post war recovery.

[25]The situation started unfolding after WWII, when oil rich economies demanded to get a bigger share of the oil rents from the oil majors, typically referred to as Seven Sisters (nowadays consisting of BP, Chevron, ExxonMobile and Shell). In particular, the resource rich economies started demanding 50-50 deals. Eventually, Saudi Arabia succeeded in securing such a deal in 1950. When the word of the deal reached Tehran, the accumulated grievances of the people resulted in huge rallies in support of nationalization of the Anglo-Iranian Oil Company (nowadays BP). However, neither BP nor the UK government were interested in giving up the generated oil rents. Eventually, the Iranian government under the leadership of Mohammad Mosaddegh decided to nationalize BP's oil assets. Bounded by their energy security goals, the US and the UK used their political influence and military force to reduce global take up of Iranian oil. In particular, they would deploy military ships to the Persian Gulf aiming at the restriction of Iranian's exports. The generated loss in revenues triggered the state of bankruptcy such that the initially supported government started loosing support. Eventually, a coup d'etat in 1953 lead to an overthrowing of the Iranian government, replacing an initially democratic government with a monarchical rule of Mohammad Reza Pahlavi which would last until 1979, the next Iranian revolution (Yergin, 2011).

were facing the following adjusted self-enforcing constraint:

$$GT_t + \delta V_{t+1} \geq GT_t + (1 - C)[r(I_t; p_t) - GT_t] - K \tag{SE'}$$

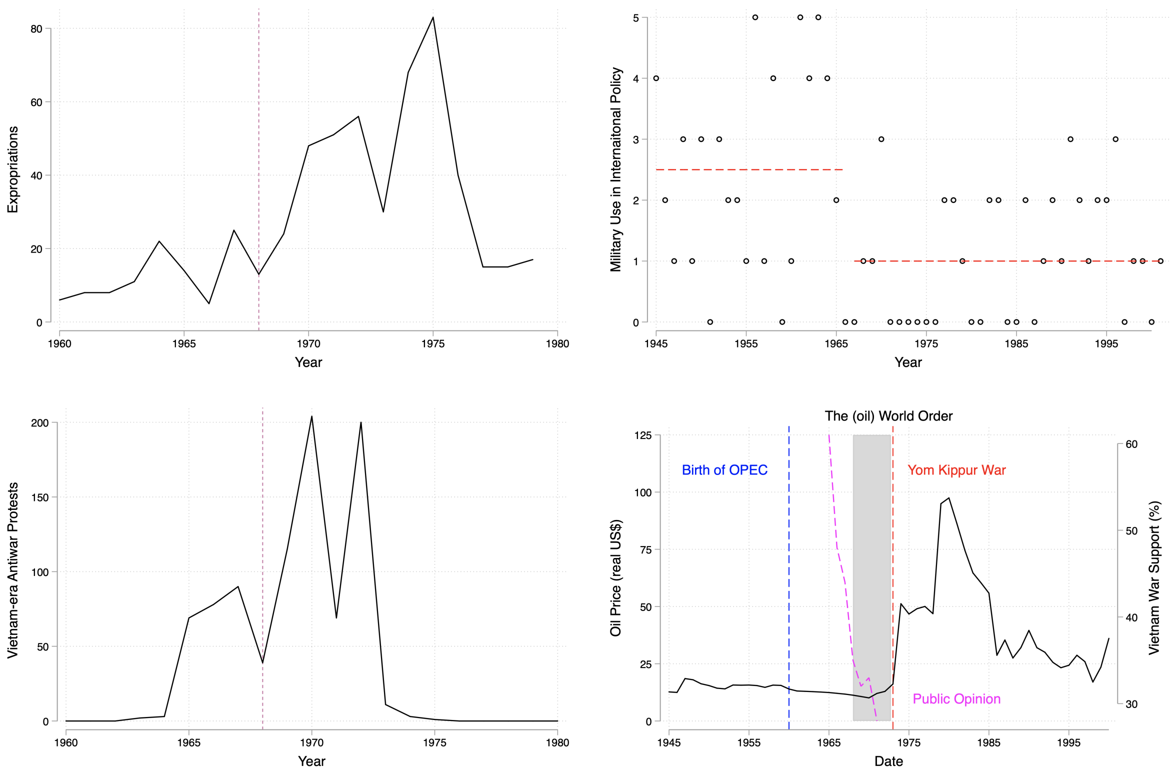
where K is the cost imposed on the country by the military intervention inflicted by the firm's country of origin. For any C, if K is large enough, the constraint (SE') does not bind. In other words, external military intervention acts as a substitute for a strong rule of law in the oil rich country. For large K and small C, the agreement is enforced not by the local institutions but by the threat of military intervention following the government's deviation. And since the agreement is enforced, it does not need to be backloaded.

However, the post-war period was marked by a wave of decolonization. The newly acquired political independence combined with perceived lack of economic independence motivated the developing world to push for change in the international economic system, putting in focus countries' right for self-determination and sovereignty over natural resources. While these attempts were not immediately successful, they eventually changed the world views on the right of the states to nationalize natural resources and control the activities of multinational corporations operating within their territory. This, in turn, undermined the use of military interventions by the Western world.[26] As a result, the period around 1968 to 1973 has signified a change in the world (oil) order: *"During this period long-established relationships among oil producing nations, oil consuming nations, and international oil companies underwent a tumultuous realignment. As traditional contractual arrangements between producing nations and international oil corporations broke down, political and economic influence shifted from consuming nations to producing states"* (Office of the Historian Bureau of Public Affairs US Department of State, 2011). In terms of our model, we see these limitations on the use of military power as a reduction in K, and argue that this reduction contributed to the transition to a new equilibrium with backloading.

Despite an escalating number of expropriations since 1968, as documented by Kobrin (1984) and presented here in the top left of Figure 10, military interventions by the US, the

[26] A good illustration is gradual retreat of Britain's military presence in the Middle East, culminating in the 1968 announcement of complete withdrawal of British forces deployed *"East of Suez"*, including from the Persian Gulf, by the end of 1971.

Figure 8: TRANSITION TO A NEW WORLD ORDER



Notes: Data on expropriation in all industries is presented in the top left corner and is taken from Kobrin (1984). Data on Militarily Intervention is taken from Sullivan and Koch (2009) and is presented in the top right. It depicts the average number of military interventions by the US, UK and France between 1959 and 2000. In the bottom left we plot the number of anti-war protest taking place in the US during the Vietnam war and we get the data from Mapping American Social Movement. In the bottom right we summarize the shift in the balance of power.

UK as well as France dropped. To see the latter we get data on the number of military interventions between 1959 and 2001 by the US, the UK and France, collected by Sullivan and Koch (2009). As shown in the top right of Figure 10 the transition to the new world order is associated with a decline in the number of events in which these countries would use their military for political goals. More formally, we employ a single structural break test to determine the year in which the average number of military interventions by these countries dropped. The Wald test statistic indicates clearly that a single structural break in the average number of military interventions occurred between 1966 and 1967 and the results may be found in Figure 14 of the Appendix. After 1966, the average number of military interventions dropped from around 2.5 to 1 per year, despite the documented increase in expropriations.

The prevailing narrative suggests that this reduction in military interventions can be attributed to the increased political costs of using this political tool since the mid-1960s. This was particularly apparent for the US, which at the time was involved in the Vietnam War. By 1964 over 20000 US soldiers would be deployed in Vietnam. Since this did not remain unnoticed by the general public the US government started facing domestic resistance with regards to US foreign military involvement in Vietnam (Lunch and Sperlich, 1979). The increasing number of anti-war protests in the US has been well documented (see bottom graphs in Figure 10). These developments eventually would translate into political consequences resulting in Richard Nixon replacing Lyndon Johnson as the US president in 1968.[27] Eventually, the increasing dissatisfaction with the use of military power for political purposes would contribute to a complete US withdrawal and the end of the Vietnam war by 1973.

The changing paradigm with regards to the sovereignty over natural resources and the resulting new world order with limitations on military backing of resource extractive firms is also illustrated by the creation and evolution of the Organization of Petroleum Exporting Countries, OPEC. OPEC was created in 1960 with the intention to gain control over the oil market (see bottom right in Figure 10). Initially, Iran, Iraq, Kuwait, Saudi Arabia and Venezuela formally decided to join forces by creating OPEC. By 1971 this group of countries was joined by Algeria, Indonesia, Libya, Nigeria, Qatar and the UAE. In the first years of existence, the influence of OPEC on the oil markets was limited; in particular, the attempt of its Arab members to use "oil as a weapon" and initiating an oil embargo following the 1967 Six-Day War with Israel is largely considered a failure. However, the ongoing movement aiming at returning resource sovereignty to the owner of the resources has included OPEC and led to a change in the balance of power in the world oil markets. In 1968, OPEC released the Declaratory Statement of Petroleum Policy in Member Countries which emphasized the right of every nation to have complete sovereignty over their natural resources (OPEC (brief history), (Dietrich, 2017)). In the years following the declaration, several expropriations by OPEC members, such as Libya and Algeria, were tolerated by the Western world. This was in clear contrast to the reactions by the same countries throughout the 1950s. Eventually, in 1973, the unwillingness of the oil consumer countries to use their military power to pursue their energy security goals was unambiguously revealed in the events surrounding the Yom Kippur War. During the Yom Kippur

[27]The Vietnam War was the primary reason for the precipitous decline of President Lyndon B. Johnson's popularity. With regards to the US energy security goals, Nixon's agenda also implied that the US would need to focus on non-military means to secure energy by focusing on other energy sources, technological progress and more efficient use of energy (Morton, 1973).

War, the US and a few of their allies, decided to support Israel, to which the Arab members of OPEC responded by imposing a successful oil embargo against these countries (Vietor and Evans, 2003). Most importantly, OPEC's cuts in oil supply, which were considered costly by the Western World, did not trigger any military response from the US, or any of their allies.

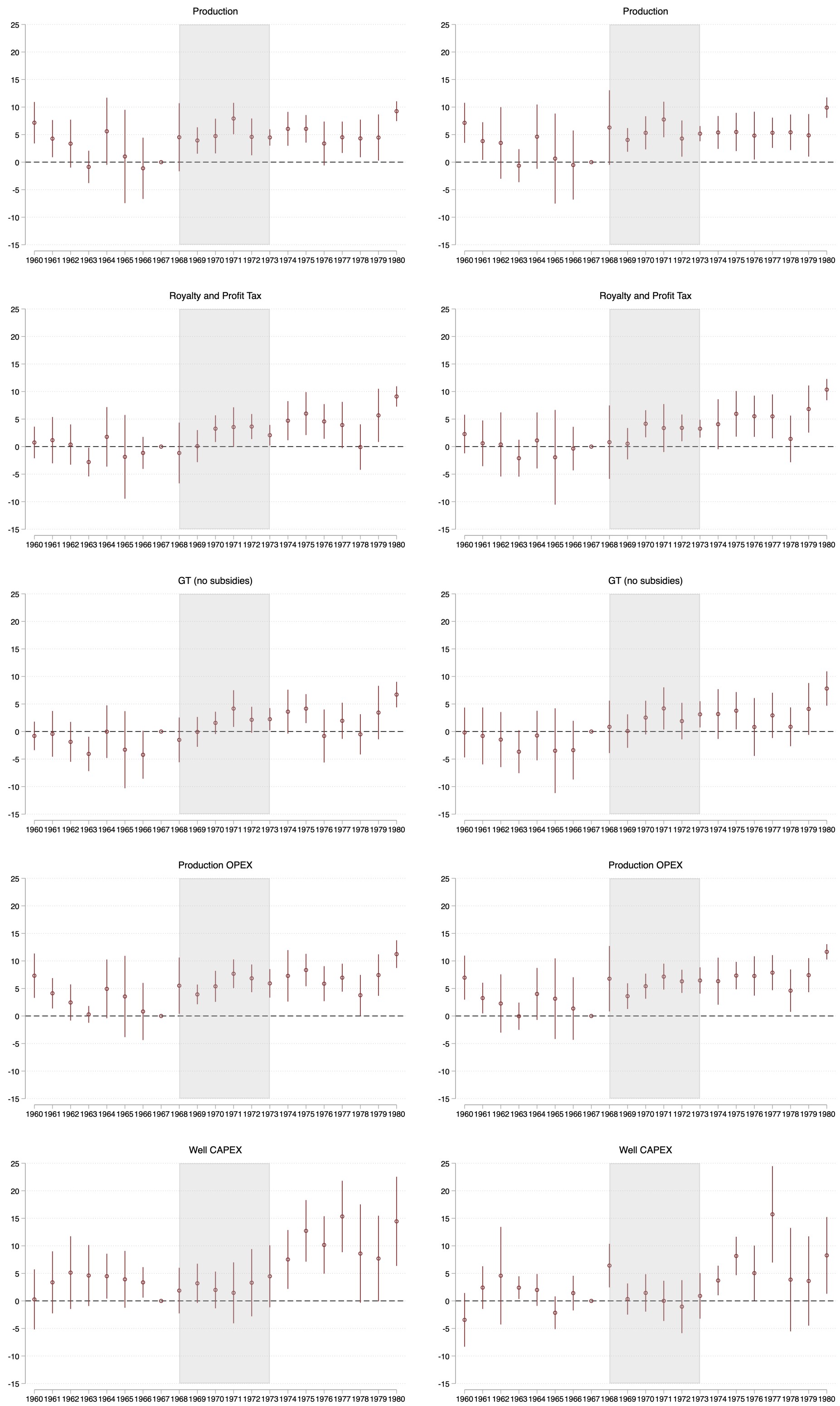
Eventually, the UN general assembly granted resource rich economies permanent sovereignty over its natural resources, which effectively legitimized the expropriations of resource related assets by December 1973. Thus, by late 1973 it was clear to everybody in the oil and gas sector that the rules of the games had changed. While the oil companies could have relied on the US government to intervene and enforce the contracts in the past, they have now been forced to come up with alternative strategies to enforce contracts. These structural changes and its consequences on the expropriation threat are also summarized by Kobrin (1984). *"[T]he success of Third Word countries in pressing for agreement on the issue of National Sovereignty of Natural Resources at the U. N., the ability of Vietnam to withstand US military action, and OPEC's achievement of control over pricing and participation, resulted in a climate that may have exacerbated tendencies toward direct and dramatic action such as expropriation,"* and to which the oil companies had to adjust. In the framework of our model, this implies that after 1973, K is set to zero and the agreements between oil producing countries and the oil companies need to be self-enforcing and hence backloaded.

To test this hypothesis we transform equation 3 into a Difference-in-Differences specification and estimate the following specification for the period 1960 to 1980:

$$y_a = \sum_{j=1960}^{1980} \beta_j \times \text{Year}_j \times \text{Weak}_{c(a)} + \text{Country}_{c(a)} + \text{Year}_{t(a)} + \Omega_a' \gamma + \varepsilon_a \tag{4}$$

As before in equation 3, y_a captures the asset specific number of years $\bar{p}$ (see equation 2), which are necessary to reach 66 % of the cumulative flows of investment, production as well as tax payments. $Weak_{c(a)}$ is a dummy variable which is equal to 1 if the asset is located in a country which is categorized as having weak institutions. Our coefficient of interests, β_j, informs us about the differences in the number of years which are necessary to reach 66% of production, investment as well as tax payments in countries with weak institutions relative to countries with strong institutions between 1960 and 1980, using 1967 as our baseline. As be-

Figure 9: NEW WORLD ORDER IN OIL & GAS



Notes: The dependent variable is the number of years until 66% of OPEX, CAPEX, production and tax payments over a 35 year period is reached. Year of Start Up, country FE and the life time of an asset are included in all regressions. In the graphs on the right, we additionally control for the full set of controls as used in the even columns of Table 2. The shaded area marks period of the transition to a new world order in which military force is not used to respond to expropriations. The plotted interaction terms are on the yearly level and the sample is limited to the period between 1960 and 1980, with 1967 being the baseline. SE are clustered by country and Start Up Year and on the graph we plot the 95% CI.

fore, Ω_a is a vector of asset specific characteristics for which we control and the standard errors are clustered by country and start-up year.

The results are graphically presented in Figure 9 for all our measures. All estimates are conditional on a country dummy, $\text{Country}_{c(a)}$, the year in which production starts, $\text{Year}_{t(a)}$, as well as the lifetime of an asset. In the right column we add the full set of controls, identical to the set of controls added to the even columns of Table 2. The results appear robust to the inclusion of the full set of controls and suggest that, the number of years necessary to reach 66% of the cumulative investment, production as well as tax payments increase by 5 years after 1973, relative to the baseline in 1967.

There are three things to note. First, physical production and OPEX are quickest to adjust to the changes in the balance of power. In case of both measures, β_{1968} is instantaneously estimated to be around 5 and stays at this level. On the other hand CAPEX and our measures of the government take are more sluggish in their response, which can be rationalized by the fact that decisions on capital expenditures as well as contract renegotiations may require time. Second, while the estimated β_js in the period before 1967 are nearly without exception indistinguishably from zero, production and OPEX indicate some backloading in 1960 and 1961. This coincides with the creation of OPEC in September 1960, and excluding the OPEC countries from the sample results in both of these coefficients not being significantly different from zero, while the overall results remain robust (see Figure 15 in the Appendix). Third, our 5 year estimates are 2-3 times as larger in comparison to our results in the cross-sectional estimation in Table 2. This is consistent with the discussion in the theoretical section, suggesting that production, tax payments and investments may approach the efficient frontier eventually. We discuss this in greater detail in section 5.1.

4.3 DISCUSSION

CONFOUNDING FACTORS: The transition to a new world order in the late 1960s and in the early 1970s coincides with three technological and economic advances which have the potential to bias our results. First, the extraction of natural gas became increasingly more common since the early 1950s, see for example Our World in Data. Second, technological progress allowed the expansion of offshore asset developments. According to our sample, the share of offshore assets started increasing in the late 1940s and early 1950s, represented 50% of all asset developments by the majors in the early 1980s and exceeded the number of onshore assets which started production by the mid 1990s.[28] Third, traditionally most assets would be developed by relying on contractual agreements known as Concessions, which transfer 100% of the property rights to the firm during the development and production phase of the asset. But since the 1950s, Production Sharing Agreements (PSAs), became more common and represented around 10% of all assets starting production throughout the 1960s. PSAs allow the country and the initial owner of the resource to keep a specific share of the asset value during production, such that property rights are not completely transferred to the firm. Throughout the 1970s around 20% of all assets started production as a PSA. This share came close to one-third in the 1980s before returning to 20% in the 1990s. Obviously, such developments may bias our results if they are more likely to take place in countries with weak or strong institutions and at the same time have an effect on the dynamics of investment, production as well as tax payments. This is why we control for all these developments in our empirical analysis and our results are robust to the inclusion of these controls.

But all of the above may also be considered to be bad controls, since they may themselves be strategically used by the firm to reduce the probability of expropriation (Angrist and Pischke, 2014). For instance, natural gas is more difficult and more costly to export (Brown, 2017), which makes it theoretically less profitable and thus less likely to be subject to expropriations in a country with lower quality of institutions. Thus, oil majors may choose to focus on the extraction of natural gas in less developed countries to avoid expropriations. Second, oil majors may choose to develop predominantly offshore assets in countries with weak institutions. Offshore assets are less prone to the hold-up problem for two reasons: first, they are naturally protected by the sea[29] and, second, they are technically much more demanding to exploit. This makes expropriations and subsequent explorations of offshore assets less likely in countries with weaker institutions. Finally, oil majors may choose to develop assets in the framework of production sharing agreements, as opposed to concessions, to keep the country more involved in the production process and reduce the government's gains from holding up and expropriating. More generally, the type of contract may change incentives for extraction

[28] See also a A Brief History of Offshore Oil Drilling, created by the staff of the BP Deep Horizon Oil Spill Commission, following the oil spill.

[29] Andersen, Nordvik and Tesei (2019) and Nordvik (2018) argue that offshore assets are more difficult to attack, and loot, for the rebel groups, and, thus, they are less likely to be associated with a conflict and need less defense.

and for renegotiation on both sides.

To explore whether oil majors actively choose any of the measures above to reduce the probability of expropriations in countries with weaker institutions we proceed as follows. We construct a dummy indicating offshore assets versus onshore assets, with the latter being coded as zero; a dummy indicating the use of Concessions versus PSAs, with the latter being coded as zero; and a dummy indicating the extraction of natural gas as opposed to crude oil, with the latter being coded as zero. Using these three measures as our left hand side variable we reestimate the βs in a specification akin to equation (4), controlling for Country, Start-up Year and Life Time FEs. The results are presented in Figure 16 and suggest that the confounders are unlikely to have an effect on our results. [30]

HIGH INTEREST RATE: The Hotelling Rule is a key theoretical result in the resource economics literature and it posits that a larger interest rate should lead to an increase in the speed with which the resource is extracted with the corresponding adjustments to the price of the resource which reflects the changes in the scacity of the resource (Hotelling, 1931; Krautkraemer, 1998; Anderson, Kellogg and Salant, 2018). Intuitively this is because the government of a resource rich economy and the oil major have two options. They can extract the resource today and place the generated resource rents at a bank account to collect the interest in the next period. Alternatively, they can keep the resource below ground and wait for the next period to extract and benefit from the additional gain in the price of the extracted resource. If the interest rate is large relative to the changes in the price of the resource, both, the government and oil major have an incentive to extract as quickly as possible.

To the extend that the interest rate is country-specific and that it changes over time, in countries with weak institutions relative to countries with strong institutions, this is a potential confounding factor. Newly independent and resource rich economies may be particularly interested in extracting the resource as quickly as possible to avoid borrowing from international markets at a higher interest rate. This issue is explicitly emphasized by Yergin (2011) when discussing the post-WWII world petroleum order :"Royalties on oil were or would soon be

[30]The estimated coefficient of β_{1968} is statistically different from zero for the development of offshore assets and the extraction of crude oil. However, the subsequent estimates of the βs do not indicate a statistically significant difference between these choices.

Table 3: EVOLUTION IN GOVERNMENT'S PROFIT SHARES

	Pre-Treatment (1960-1967)	Treatment (1968-1973)	Post-Treatment (1974-1980)
strong institutions	47 %	52 %	66 %
weak institutions	7 %	32 %	66 %

Note: Median profit shares are calculated by collapsing the raw data to firm country relationship in the three periods indicated in the column titles: pre-treatment, treatment and post-treatment. The data sample used to calculate the reported medians is restricted to observations of assets which started production between 1960 and 1980 and do not exceed the 12^{th} period of production.

the major source of revenues for the countries of the Gulf. As a result, those countries would put continuing pressure — augmented by threats, veiled or otherwise — on the companies to increase production, in order to increase royalty revenues. " Hence, while we may expect that a country specific interest rate may have an effect on the dynamics of investment, production and tax payment, it should lead to a front loading if we expect that countries with weaker institutions may be subject to higher country-specific interest rates, such that our results may be thought of representing a lower bound.[31]

CHANGE IN BARGAINING POWER: In Section 2, we assumed that the firm has all the bargaining power vis-a-vis the government. Under this assumption, we have shown that weaker institutions lead to relatively more backloaded agreements. Instead, if the government were to hold all the bargaining power, weaker institutions would not be associated with contract backloading since the government is already keeping all the profits and would not gain by expropriating the firm. In reality, the bargaining power may be shared by both parties and the relative bargaining power may change over time. In particular, during a transition to a new world oil order, the government's bargaining power may have increased translating into larger government's profit shares in countries with weak institutions.

In Table 3, we document the median profit share which is received by governments with weak and strong institutions between 1960 and 1980, by differentiating between the periods before, during and after the treatment. The median profit share received by the government in countries with weak institutions increased from 7% in the pre-treatment period to 32% in

[31] Unfortunately, we are not aware of a qualitative dataset containing information on country specific interest rates, such that we could address this issue empirically.

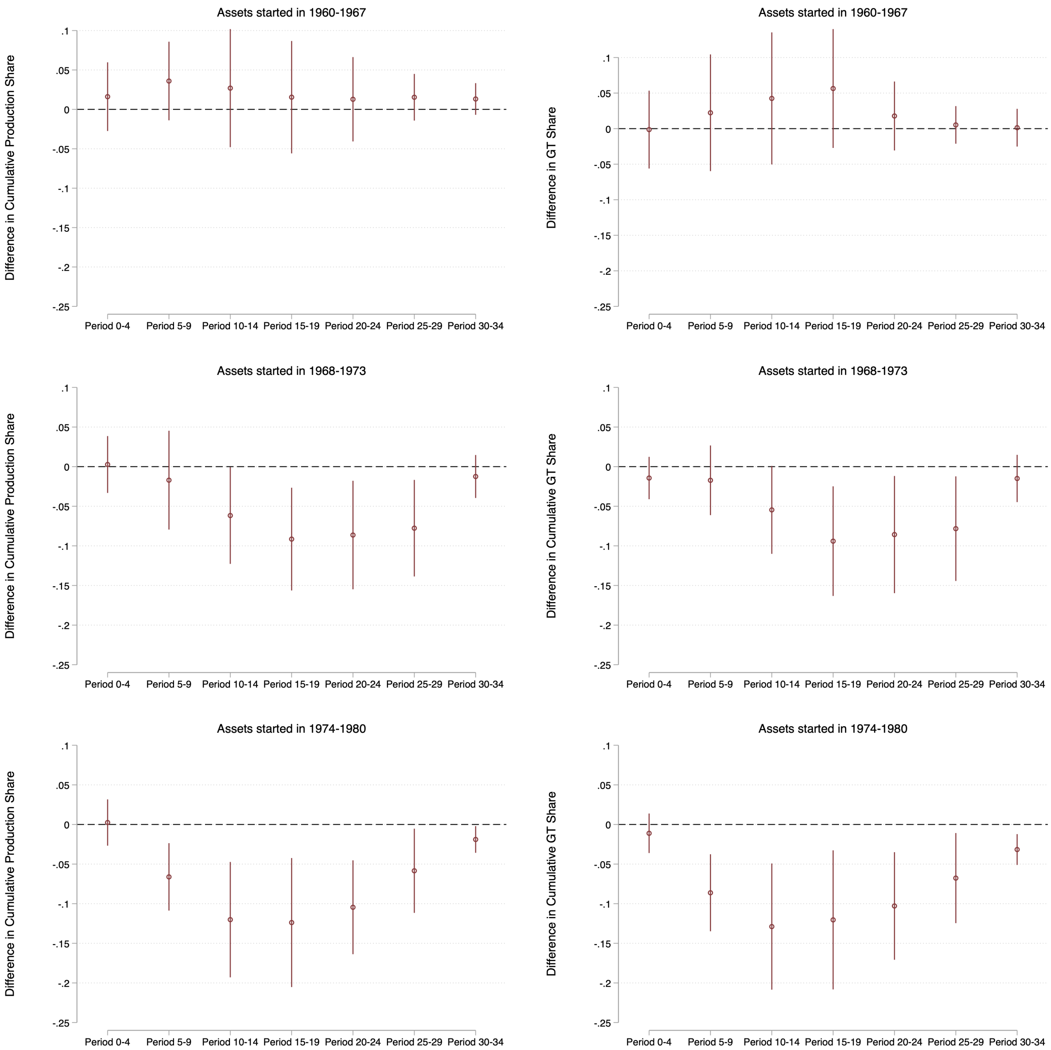
the treatment period and then even doubled in the post treatment period going up to 66%. At the same time, the gains in the median profit share received by countries with strong institutions slowly moved from around 50% in the pre-treatment and treatment period to 66% in the post-treatment period. Overall, the results suggest that the bargaining power of the countries with weak institutions increased and eventually caught up with the bargaining power of the countries with strong institutions. This, in turn, implies that we are estimating the lower bound of the backloading which has been triggered by the transition to a new world order. The extent of the estimated backloading we observe since 1968 would have been even more severe if the bargaining power of the countries with weak institutions would have remained unaffected.

RENEGOTIATION OF CONTRACTS: Our main results indicate that the backloading appears in the data after 1967 and well before the oil price spike in 1974. However, if contracts can be renegotiated on the asset level, the backloading may have appeared in the data after the oil price spike in 1974, as we would expect theoretically according to section 2, and affected our forward looking measures. To explore this in greater detail, we focus on the dynamics of the cumulative share measures, presented in equation (2), over the life time of the asset from period 0 to period 34. In particular, for our preferred measures, physical production and the government take, we estimate equation (5):

$$\text{S}_{ap} = \sum_{j=0}^{34} \beta_j \times \text{Period}_j \times \text{Weak}_{c(a)} + \text{Period}_p + \varepsilon_{ap} \tag{5}$$

The β_j's capture the differences in the cumulative shares reached in countries with weak institutions relative to the countries with strong institutions over the life time of an asset going from period 0 to period 34. The standard errors are clustered by country and period. We estimate equation (5) for three distinct periods: before, during and after the treatment, covering the periods 1960-1967, 1968-1973 and 1974-1980, respectively. The estimated βs are binned into 5 year periods for a simpler representation and the results are plotted in Figure 10. There are several things to note. First, in the top row of Figure 10, we confirm that the cumulative share dynamics do not differ significantly across countries for the assets which started production between 1960 and 1968, confirming our main results in Figure 9. Instead, the backloading appears in countries with weak institutions relative to countries with strong institutions for the assets which start producing during the treatment period (1968-1973) as well as the the post-treatment

Figure 10: RENEGOTIATION OF CONTRACTS



Notes: Left hand side variable in all graphs is indicating the share of cumulative production over a 35 year period generated in a specific period. Year of Start Up, Period FE and the life time of an asset are included in all regressions. The plotted interaction term are the δ_j from specification 5. The results are presented for different intervals: 1960-1967 at the top graph; 1968-1973 in the middle graph; 1974-1980, in the graph at the bottom. The SE are clustered by country and period of production and on the graph we plot the 95% CI.

period (1974-1980). And while the estimated β_j's appear to be smaller in absolute values for assets which started production between 1968 and 1973, the estimates do not differ significantly when compared to the sample of assets which started production in the post-treatment period (see bottom row of Figure 10). Second, consistent with the results presented in Figure 7, we do not observe any significant differences in the cumulative share for the first 5 years of production across time periods and measures. Most likely, this is due to the fact that the initial differences in production are not sufficiently large to be picked up statistically. Instead, it takes several periods of production before the cumulative differences in production turn into economically and statistically significant differences.[32] Most importantly, however, is the fact that we *do* observe the presence of backloading for the assets which stated production during the treatment period, while we *do not* find any evidence for the presence of backloading in the sample for the assets which started production in the pre-treatment period suggests that production dynamics are determined at the beginning of production,with limited scope remaining for subsequent adjustments due to physical and institutional rigidities. Alternatively, dynamic adjustment took place, but they only affected assets which started production during treatment periods, while leaving those which started production before unaffected. In that case, we cannot reject the hypothesis that contracts which started production after 1968 have been renegotiated and the backloading which appeared in the data after 1968 has been at least partly driven by the increase in the price of oil, rather than the transition to a new world oil order.

5 LONG RUN DYNAMICS AND NATIONAL OIL FIRMS

5.1 LONG RUN DYNAMICS

In the theoretical section we discussed how the investment, production and tax payments may approach the efficient frontier over time (Proposition 1). To put it differently, we should expect less backloading as the relationship between a firm and a (weak-institutions) country develops.

[32] Alternatively, this may be due to the fact that the the initial level of production is determined by the geological pressures of the developed reservoir and which is determined by nature as opposed to a country's institutions. Only after this initial period, operators may decide to stimulate production by conducting follow up drillings. Naturally, the backloading will then appear in countries with weak institutions in the absence of such additional drillings and the necessary additional investment. See Adelman (1962) or more recently Anderson, Kellogg and Salant (2018) for a discussion on how the initial pressure of the reservoir is determining production of the first well drilled in an asset and how this can be adjusted and stimulated over the life time of an asset by drilling additional wells.

In this section, we test Hypothesis 2.

Assuming that a relationship starts in the year in which a the major is awarded a license for the first time in a particular country,[33] we can evaluate how the distance in the number of years necessary to reach a certain threshold with regards to production, investments as well as tax payments changes over the duration of the relationship, by differentiating between countries with weak and strong institutions. To explore this, we expand our baseline specification in equation 3 and interact our $Weak_{c(a)}$ country dummy with a variable proxing the duration of the relationship between the country and the firm at the time an assets a starts production, $RelationDuration_{d(a)}$. Formally, we estimate the following specification:

$$y_a = \beta \text{Weak}_{c(a)} + \alpha \text{Relation Duration}_{d(a)} + \gamma \text{Weak}_{c(a)} \times \text{Relation Duration}_{d(a)} + \Omega_a' \gamma + \varepsilon_a \quad (6)$$

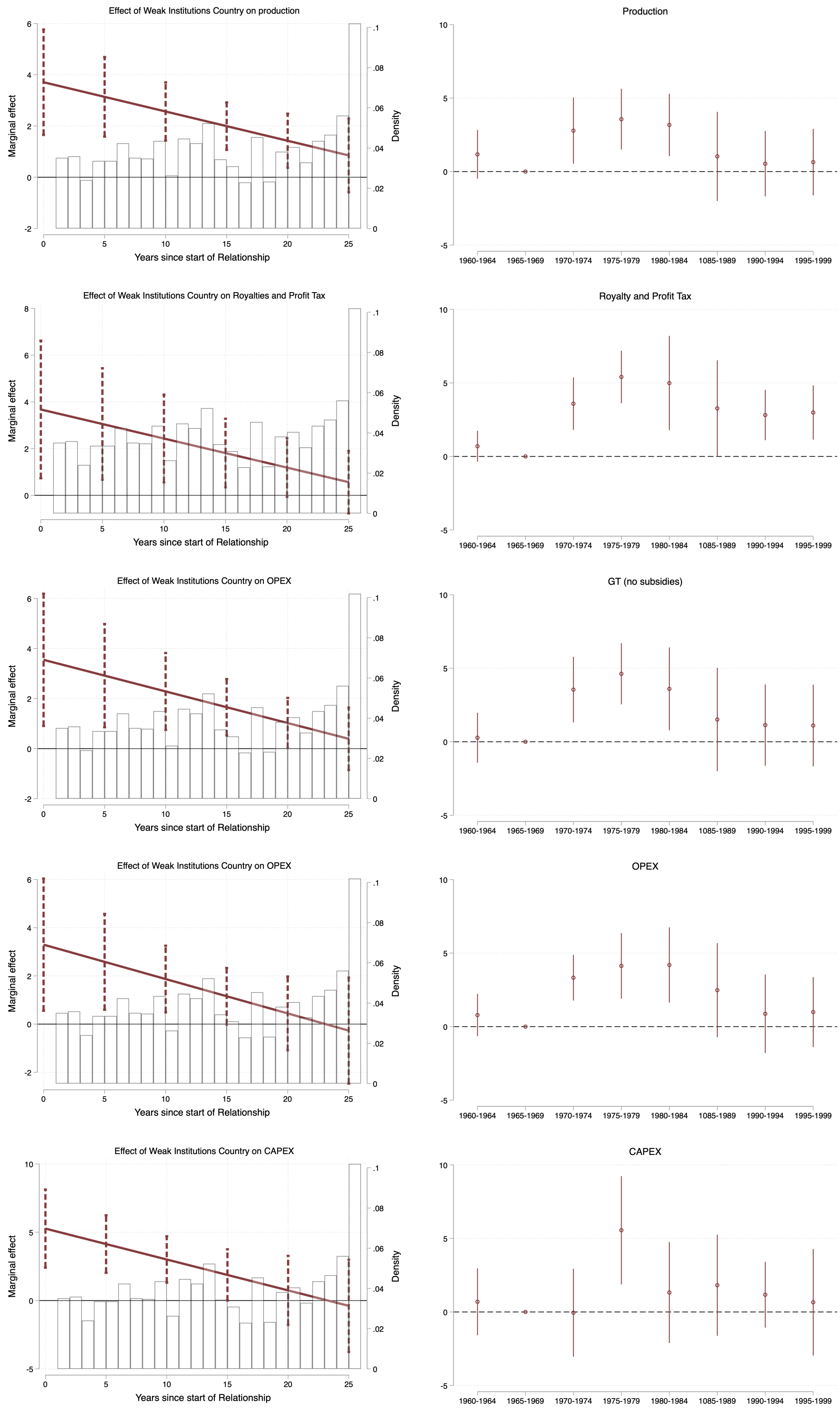
As before in equation 3, y_a captures the asset specific number of years, which are necessary to reach 66 % of the cumulative flows of investment, production as well as tax payments. And as before, Ω_a is a vector of asset specific characteristics for which we control and the standard errors are clustered by country and start-up year. We are interested in the marginal effects ($\beta + \gamma \text{Relation Duration}_{d(a)}$) which are presented in the left column of Figure 11. For all variables of interest they exhibit the same pattern: in the beginning of the relationship backloading is positive and significant. At the first years of the relationship time to reach our 66% threshold is delayed by 4-5 years for all the variables. Note that this is in line with our results presented in Figure 9. As relationship proceeds, however, the extent of backloading diminishes. On average, backloading becomes statistically insignificant around 20 years for all our measure of interest of interest. Extending our specification in equation 4 and cover the years 1960-1999 and by aggregating the interaction terms to 5-years bins we see in the right column of Figure 11 the vanishing of the backloading on the global level. A direct consequence of the progressing relationships in the new world order.

5.2 NATIONAL OIL COMPANIES

In this section, we explore the impact of having a National Oil Company (NOC) operating in the country. Intuitively, the presence of a NOC increases the government's incentive to expropriate

[33] And resetting the relationships to zero in 1973 due to the shift to a new world order which we documented in the previous section.

Figure 11: LONG-RUN DYNAMICS



Notes: Left hand side variable in all graphs is indicating the number of years until 66% of of OPEC, CAPEX, production and tax payments over a 35 year period is reached. The full set of controls is included in all results, identical to the set of controls used in the even columns of Table 2. In the left column, we document the estimated marginal effect from equation 6. In the right column, we present the results from estimating a specification which is akin to 4, but the interaction terms are aggregated to in 5-year bins, the sample is extended to 2000 and the baseline is 1965-1969. The SE are clustered by country and Start Up Year and on the graph we plot the 95% CI.

the firm because the NOC can operate the expropriated assets allowing the country to continue to explore, produce and export oil in the absence of the oil major. In the model, this is akin to having a positive government's outside option following expropriation V_{NOC}:

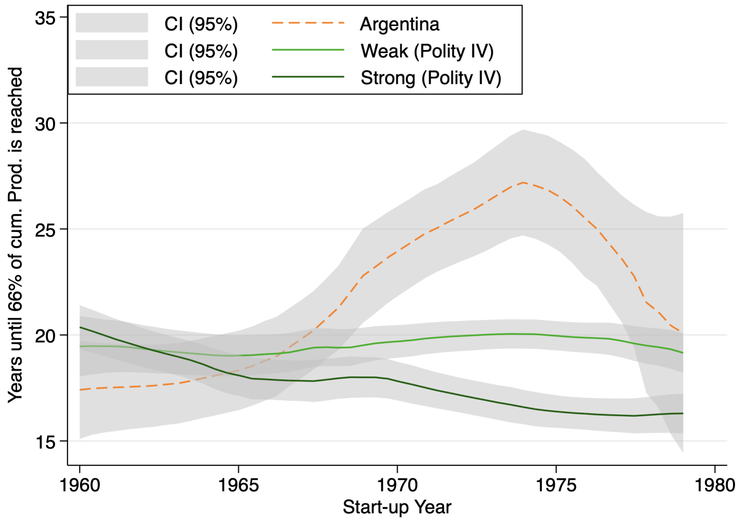
$$GT_t + \delta V_{t+1} \geq GT_t + (1 - C)[r(I_t; p_t) - GT_t] + \delta V_{NOC} \tag{SE''}$$

It is easy to see that, everything equal, the constraint (SE'') will be more binding if $V_{NOC} > 0$. As a result, we expect the firm to backload more the agreement as compared to the situat ion where there is no NOC $V_{NOC} = 0$.

Unfortunately, from an empirical point of view, it is difficult to test this hypothesis in the oil and gas sector for the following reasons. Either, the creation of state owned oil companies follows or even coincides with the transition to the new world order such that it is difficult to disentangle the effects these events have on the backloading of contracts. Alternatively, the creation of a NOC precedes the transition to a new world order. In that case, the oil majors often stop operating in the country long before the sector transitions to a new world order because they are banned from operating in the country or because they are expropriated or because they are bought up by the NOC (e.g. Saudi Arabia). The latter makes the empirical exploration of contract backloading impossible. Thus, identifying the impact on backloading during the transition in a country with a NOC company is made difficult in either case. However, the developments in Argentina between 1922 and 1930 offer a nice case study which we briefly discus in what follows (Buchanan, 1973; Wilkins, 1974; Solberg, 1979).

Since the discovery of oil in Argentina in 1907 , the political elites were occupied with the idea that Argentina possessed vast oil reserves which were the key to industrialization and economic independence (Buchanan, 1973). By 1922, YPF (Yacimientos Petrolíferos Fiscales) was created and Enrique Mosconi, a devote nationalist, would be put in charge of the company. Enrique Mosconi would lead the company until 1930, when he would be arrested and removed from his position during a coup d'etat (Buchanan, 1973). Until 1930, he was managing the oil sector efficiently and even started fighting the two giants of hydrocarbon exploitation present in Argentina in that time, Shell and Standard Oil. During this fight, YPF increased its gasoline sales to 15% of the domestic market until 1929. And by 1929, they reduced prices such that foreign firms would be forced to follow (Wilkins, 1974). When YPF, on top of that, began nego-

Figure 12: NOC IN ARGENTINA



Notes: We use the epanechnikov kernel with an optimal bandwidth.

tiations with the Russians, aiming to import oil from the Soviet Union, everybody was sure that the Argentine oil industry would be nationalized. However, it never came to an expropriation due to a coup d'etat in 1930. However, YPF survived the coup d'etat and oil production at YPF surpassed 80% of the nation's total by 1955 (Solberg, 1979). Thus, Argentina is particularly well suited to study the impact of the transition to a new world order between 1968 to 1974 in the presence of an efficient state owned oil company. As we show in Figure 12 Argentina does not only exhibit stronger back loading than most other countries with weak institutions, oil firms also reacted significantly stronger relative to other countries with weak institutions during the transition to a new world order.

6 Conclusion

Our rich dataset allows us to study relational contracting between the governments and firms over an extensive period of time. We provide evidence that, since the early 70s, investment, production and financial flows are coming through two years later in countries with weak institutions relative to countries with strong institutions. Exploiting a historical change in the ability to enforce contracts, we show that countries and firms respond by backloading contracts therefore pushing towards causality. Finally, we show that the backloading disappears as the relationship between a country and a firm develops. All these findings are consistent with a large body of theory and to the best of our knowledge, we are the first to document such long term dynamics of contracts in the presence of weak property rights.

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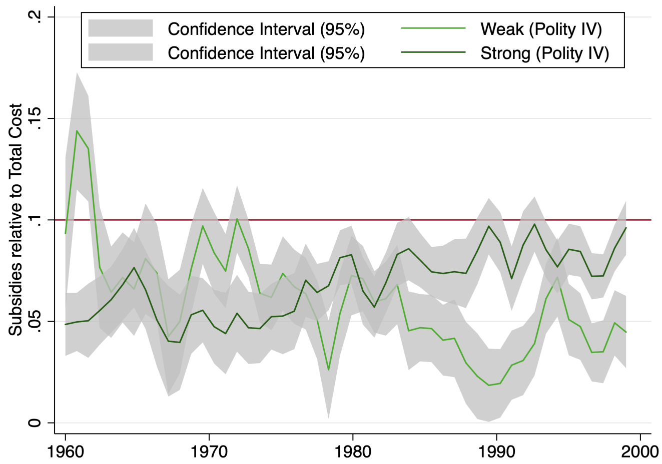
Appendix

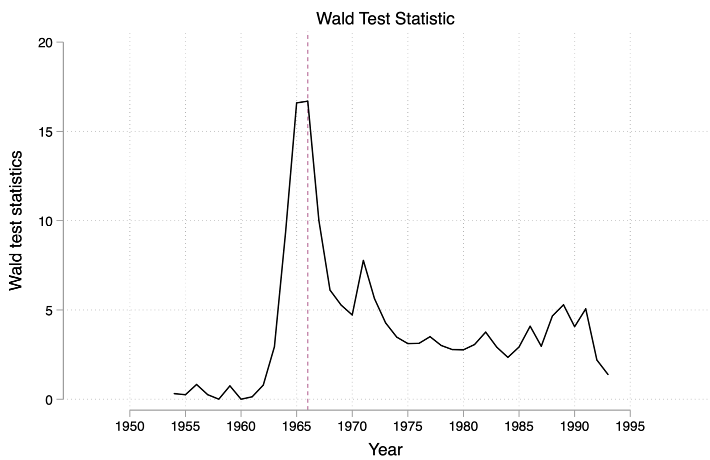
A Additional Results

Figure 13: SHARE OF SUBSIDES IN TOTAL COSTS



Source: Raw data from Rystad. This figure depicts the average share of subsidies over total production cost. We focus on the *upfront* subsidies that are made within the first five years of production.

Figure 14: WALD TEST



Notes: Here we document the Wald Test for the endogenous structural break choise.

TABLE 4

ROBUSTNESS WITHOUT CONTROLS

Panel A: Production (Physical)

	(1) Prod 25Y (50%)	(2) Prod 30Y (50%)	(3) Prod 35Y (50%)	(4) Prod 25Y (66%)	(5) Prod 30Y (66%)	(6) Prod 35Y (66%)	(7) Prod 25Y (75%)	(8) Prod 30Y (75%)	(9) Prod 35Y (75%)
Weak (Polity IV)	0.640	0.927*	1.147*	1.020**	1.271**	1.510**	1.059**	1.329**	1.579***
	(0.422)	(0.531)	(0.591)	(0.445)	(0.520)	(0.585)	(0.419)	(0.510)	(0.565)
N	2603	2616	2618	2603	2616	2618	2603	2616	2618
R-sq	0.16	0.21	0.24	0.18	0.25	0.30	0.19	0.28	0.33

	(1) Prod 25Y (50%)	(2) Prod 30Y (50%)	(3) Prod 35Y (50%)	(4) Prod 25Y (66%)	(5) Prod 30Y (66%)	(6) Prod 35Y (66%)	(7) Prod 25Y (75%)	(8) Prod 30Y (75%)	(9) Prod 35Y (75%)
Weak (OECD)	0.654	0.939*	1.137*	1.031**	1.298**	1.514**	1.079**	1.360**	1.588***
	(0.421)	(0.528)	(0.580)	(0.440)	(0.512)	(0.570)	(0.416)	(0.505)	(0.553)
N	2603	2616	2618	2603	2616	2618	2603	2616	2618
R-sq	0.16	0.21	0.24	0.18	0.25	0.30	0.20	0.28	0.33

Panel B: R&P

	(1) R&P 25Y (50%)	(2) R&P 30Y (50%)	(3) R&P 35Y (50%)	(4) R&P 25Y (66%)	(5) R&P 30Y (66%)	(6) R&P 35Y (66%)	(7) R&P 25Y (75%)	(8) R&P 30Y (75%)	(9) R&P 35Y (75%)
Weak (Polity IV)	0.352	0.622	1.103	0.684	1.007	1.567*	0.833	1.229	1.742*
	(0.547)	(0.706)	(0.828)	(0.577)	(0.722)	(0.865)	(0.571)	(0.727)	(0.849)
N	2029	2040	2042	2029	2040	2042	2029	2040	2042
R-sq	0.15	0.16	0.18	0.18	0.20	0.25	0.19	0.24	0.29

	(1) R&P 25Y (50%)	(2) R&P 30Y (50%)	(3) R&P 35Y (50%)	(4) R&P 25Y (66%)	(5) R&P 30Y (66%)	(6) R&P 35Y (66%)	(7) R&P 25Y (75%)	(8) R&P 30Y (75%)	(9) R&P 35Y (75%)
Weak (OECD)	0.471	0.761	1.257	0.809	1.168	1.724*	0.976	1.394*	1.929**
	(0.572)	(0.729)	(0.849)	(0.592)	(0.736)	(0.881)	(0.577)	(0.740)	(0.871)
N	2029	2040	2042	2029	2040	2042	2029	2040	2042
R-sq	0.15	0.16	0.18	0.18	0.21	0.25	0.19	0.24	0.29

Panel C: Government Take

	(1) GT 25Y (50%)	(2) GT 30Y (50%)	(3) GT 35Y (50%)	(4) GT 30Y (66%)	(5) GT 30Y (66%)	(6) GT 35Y (66%)	(7) GT 30Y (75%)	(8) GT 30Y (75%)	(9) GT 35Y (75%)
Weak (Polity IV)	0.573	0.812	1.171*	0.715*	1.030*	1.334**	0.861**	1.160**	1.374**
	(0.397)	(0.515)	(0.611)	(0.392)	(0.516)	(0.610)	(0.405)	(0.510)	(0.583)
N	2603	2614	2618	2603	2614	2618	2603	2614	2618
R-sq	0.17	0.18	0.19	0.20	0.22	0.26	0.22	0.26	0.31

	(1) GT 25Y (50%)	(2) GT 30Y (50%)	(3) GT 35Y (50%)	(4) GT 30Y (66%)	(5) GT 30Y (66%)	(6) GT 35Y (66%)	(7) GT 30Y (75%)	(8) GT 30Y (75%)	(9) GT 35Y (75%)
Weak (OECD)	0.590	0.855	1.200*	0.778*	1.106**	1.408**	0.922**	1.243**	1.456**
	(0.404)	(0.511)	(0.609)	(0.396)	(0.515)	(0.613)	(0.400)	(0.510)	(0.584)
N	2603	2614	2618	2603	2614	2618	2603	2614	2618
R-sq	0.17	0.18	0.19	0.20	0.23	0.26	0.22	0.26	0.31

Panel D: Investment (OPEX)

	(1) OPEX 25Y (50%)	(2) OPEX 30Y (50%)	(3) OPEX 35Y (50%)	(4) OPEX 25Y (66%)	(5) OPEX 30Y (66%)	(6) OPEX 35Y (66%)	(7) OPEX 25Y (75%)	(8) OPEX 30Y (75%)	(9) OPEX 35Y (75%)
Weak (Polity IV)	0.466	0.888	1.196	0.725	1.120	1.479*	0.857	1.270*	1.554**
	(0.527)	(0.668)	(0.754)	(0.515)	(0.669)	(0.775)	(0.509)	(0.629)	(0.745)
N	2603	2616	2618	2603	2616	2618	2603	2616	2618
R-sq	0.12	0.12	0.15	0.14	0.16	0.21	0.15	0.19	0.25

	(1) OPEX 25Y (50%)	(2) OPEX 30Y (50%)	(3) OPEX 35Y (50%)	(4) OPEX 25Y (66%)	(5) OPEX 30Y (66%)	(6) OPEX 35Y (66%)	(7) OPEX 25Y (75%)	(8) OPEX 30Y (75%)	(9) OPEX 35Y (75%)
Weak (OECD)	0.468	0.871	1.205	0.740	1.159*	1.561**	0.890*	1.354**	1.683**
	(0.532)	(0.665)	(0.736)	(0.509)	(0.652)	(0.748)	(0.503)	(0.613)	(0.726)
N	2603	2616	2618	2603	2616	2618	2603	2616	2618
R-sq	0.12	0.12	0.15	0.14	0.16	0.21	0.15	0.19	0.26

Panel E: Investment (CAPEX)

	(1) CAPEX 25Y (50%)	(2) CAPEX 30Y (50%)	(3) CAPEX 35Y (50%)	(4) CAPEX 25Y (66%)	(5) CAPEX 30Y (66%)	(6) CAPEX 35Y (66%)	(7) CAPEX 25Y (75%)	(8) CAPEX 30Y (75%)	(9) CAPEX 35Y (75%)
Weak (Polity IV)	2.644*	2.789*	3.854**	2.544*	3.117*	4.333**	2.636*	3.302**	4.309**
	(1.321)	(1.492)	(1.690)	(1.465)	(1.572)	(1.810)	(1.447)	(1.542)	(1.765)
N	1446	1456	1464	1446	1456	1464	1446	1456	1464
R-sq	0.16	0.12	0.16	0.14	0.13	0.19	0.12	0.13	0.20

	(1) CAPEX 25Y (50%)	(2) CAPEX 30Y (50%)	(3) CAPEX 35Y (50%)	(4) CAPEX 25Y (66%)	(5) CAPEX 30Y (66%)	(6) CAPEX 35Y (66%)	(7) CAPEX 25Y (75%)	(8) CAPEX 30Y (75%)	(9) CAPEX 35Y (75%)
Weak (OECD)	1.906	2.089	2.983	1.646	2.251	3.300*	1.741	2.333	3.210*
	(1.375)	(1.553)	(1.786)	(1.536)	(1.650)	(1.900)	(1.506)	(1.623)	(1.858)
N	1446	1456	1464	1446	1456	1464	1446	1456	1464
R-sq	0.14	0.11	0.14	0.12	0.11	0.17	0.10	0.11	0.18

Notes: Left hand side variable is capturing the number of years until 50%, 66% or 75% of the cumulative level of OPEX, Well CAPEX , production and tax payments after 25, 30 or 35 years is reached. Year of Start-Up FE and the life time of the asset are included in all regressions, identical to the results presented in the uneven columns of Table 2. Our baseline dummy $Weak_c(a)$ differentiates between countries with strong and weak institutions. SE in parenthesis is clustered by country and Start Up Year. * stands for statistical significance at the 10% level, ** at the 5% level and *** at the 1% percent level.

TABLE 5
ROBUSTNESS WITH CONTROLS

Panel A: Production (Physical)

	(1) Prod 25Y (50%)	(2) Prod 30Y (50%)	(3) Prod 35Y (50%)	(4) Prod 25Y (66%)	(5) Prod 30Y (66%)	(6) Prod 35Y (66%)	(7) Prod 25Y (75%)	(8) Prod 30Y (75%)	(9) Prod 35Y (75%)
Weak (Polity IV)	1.090***	1.720***	1.954***	1.228***	1.767***	2.034***	1.088***	1.627***	1.846***
	(0.350)	(0.418)	(0.491)	(0.410)	(0.467)	(0.542)	(0.388)	(0.471)	(0.526)
N	2599	2612	2614	2599	2612	2614	2599	2612	2614
R-sq	0.25	0.30	0.33	0.26	0.32	0.37	0.27	0.34	0.40

	(1) Prod 25Y (50%)	(2) Prod 30Y (50%)	(3) Prod 35Y (50%)	(4) Prod 25Y (66%)	(5) Prod 30Y (66%)	(6) Prod 35Y (66%)	(7) Prod 25Y (75%)	(8) Prod 30Y (75%)	(9) Prod 35Y (75%)
Weak (OECD)	1.233***	1.964***	2.169***	1.345***	2.029***	2.279***	1.194***	1.868***	2.038***
	(0.377)	(0.562)	(0.650)	(0.433)	(0.534)	(0.628)	(0.408)	(0.547)	(0.613)
N	2599	2612	2614	2599	2612	2614	2599	2612	2614
R-sq	0.25	0.30	0.33	0.26	0.32	0.37	0.27	0.35	0.40

Panel B: R&P

	(1) R&P 25Y (50%)	(2) R&P 30Y (50%)	(3) R&P 35Y (50%)	(4) R&P 25Y (66%)	(5) R&P 30Y (66%)	(6) R&P 35Y (66%)	(7) R&P 25Y (75%)	(8) R&P 30Y (75%)	(9) R&P 35Y (75%)
Weak (Polity IV)	0.553	1.011*	1.427**	0.844	1.285**	1.845**	0.891	1.420**	1.819**
	(0.464)	(0.520)	(0.674)	(0.531)	(0.609)	(0.856)	(0.539)	(0.675)	(0.871)
N	2025	2036	2038	2025	2036	2038	2025	2036	2038
R-sq	0.24	0.25	0.27	0.25	0.28	0.32	0.25	0.30	0.35

	(1) R&P 25Y (50%)	(2) R&P 30Y (50%)	(3) R&P 35Y (50%)	(4) R&P 25Y (66%)	(5) R&P 30Y (66%)	(6) R&P 35Y (66%)	(7) R&P 25Y (75%)	(8) R&P 30Y (75%)	(9) R&P 35Y (75%)
Weak (OECD)	0.758	1.407*	1.946*	1.088	1.756**	2.433**	1.188*	1.891**	2.417**
	(0.554)	(0.690)	(0.961)	(0.640)	(0.809)	(1.121)	(0.642)	(0.872)	(1.143)
N	2025	2036	2038	2025	2036	2038	2025	2036	2038
R-sq	0.24	0.25	0.27	0.26	0.28	0.32	0.25	0.30	0.35

Panel C: Government Take

	(1) GT 25Y (50%)	(2) GT 30Y (50%)	(3) GT 35Y (50%)	(4) GT 30Y (66%)	(5) GT 30Y (66%)	(6) GT 35Y (66%)	(7) GT 30Y (75%)	(8) GT 30Y (75%)	(9) GT 35Y (75%)
Weak (Polity IV)	0.741**	1.251***	1.654***	0.877**	1.401**	1.689**	0.947*	1.408**	1.577**
	(0.341)	(0.390)	(0.543)	(0.412)	(0.506)	(0.695)	(0.464)	(0.589)	(0.747)
N	2599	2610	2614	2599	2610	2614	2599	2610	2614
R-sq	0.25	0.26	0.27	0.27	0.28	0.32	0.28	0.31	0.36

	(1) GT 25Y (50%)	(2) GT 30Y (50%)	(3) GT 35Y (50%)	(4) GT 30Y (66%)	(5) GT 30Y (66%)	(6) GT 35Y (66%)	(7) GT 30Y (75%)	(8) GT 30Y (75%)	(9) GT 35Y (75%)
Weak (OECD)	0.911***	1.638***	2.082***	1.137***	1.870***	2.192**	1.230**	1.862**	2.056**
	(0.308)	(0.476)	(0.716)	(0.400)	(0.593)	(0.832)	(0.465)	(0.692)	(0.892)
N	2599	2610	2614	2599	2610	2614	2599	2610	2614
R-sq	0.25	0.26	0.28	0.27	0.29	0.33	0.28	0.31	0.36

Panel D: Investment (OPEX)

	(1) OPEX 25Y (50%)	(2) OPEX 30Y (50%)	(3) OPEX 35Y (50%)	(4) OPEX 25Y (66%)	(5) OPEX 30Y (66%)	(6) OPEX 35Y (66%)	(7) OPEX 25Y (75%)	(8) OPEX 30Y (75%)	(9) OPEX 35Y (75%)
Weak (Polity IV)	0.039	0.648	1.007	0.192	0.876	1.220	0.342	0.894*	1.125
	(0.525)	(0.555)	(0.676)	(0.489)	(0.527)	(0.735)	(0.441)	(0.522)	(0.707)
N	2599	2612	2614	2599	2612	2614	2599	2612	2614
R-sq	0.18	0.19	0.21	0.20	0.23	0.27	0.21	0.25	0.31

	(1) OPEX 25Y (50%)	(2) OPEX 30Y (50%)	(3) OPEX 35Y (50%)	(4) OPEX 25Y (66%)	(5) OPEX 30Y (66%)	(6) OPEX 35Y (66%)	(7) OPEX 25Y (75%)	(8) OPEX 30Y (75%)	(9) OPEX 35Y (75%)
Weak (OECD)	-0.147	0.491	0.947	0.022	0.802	1.241	0.234	0.932	1.251
	(0.554)	(0.664)	(0.830)	(0.540)	(0.674)	(0.907)	(0.526)	(0.691)	(0.901)
N	2599	2612	2614	2599	2612	2614	2599	2612	2614
R-sq	0.18	0.19	0.21	0.20	0.22	0.27	0.21	0.25	0.31

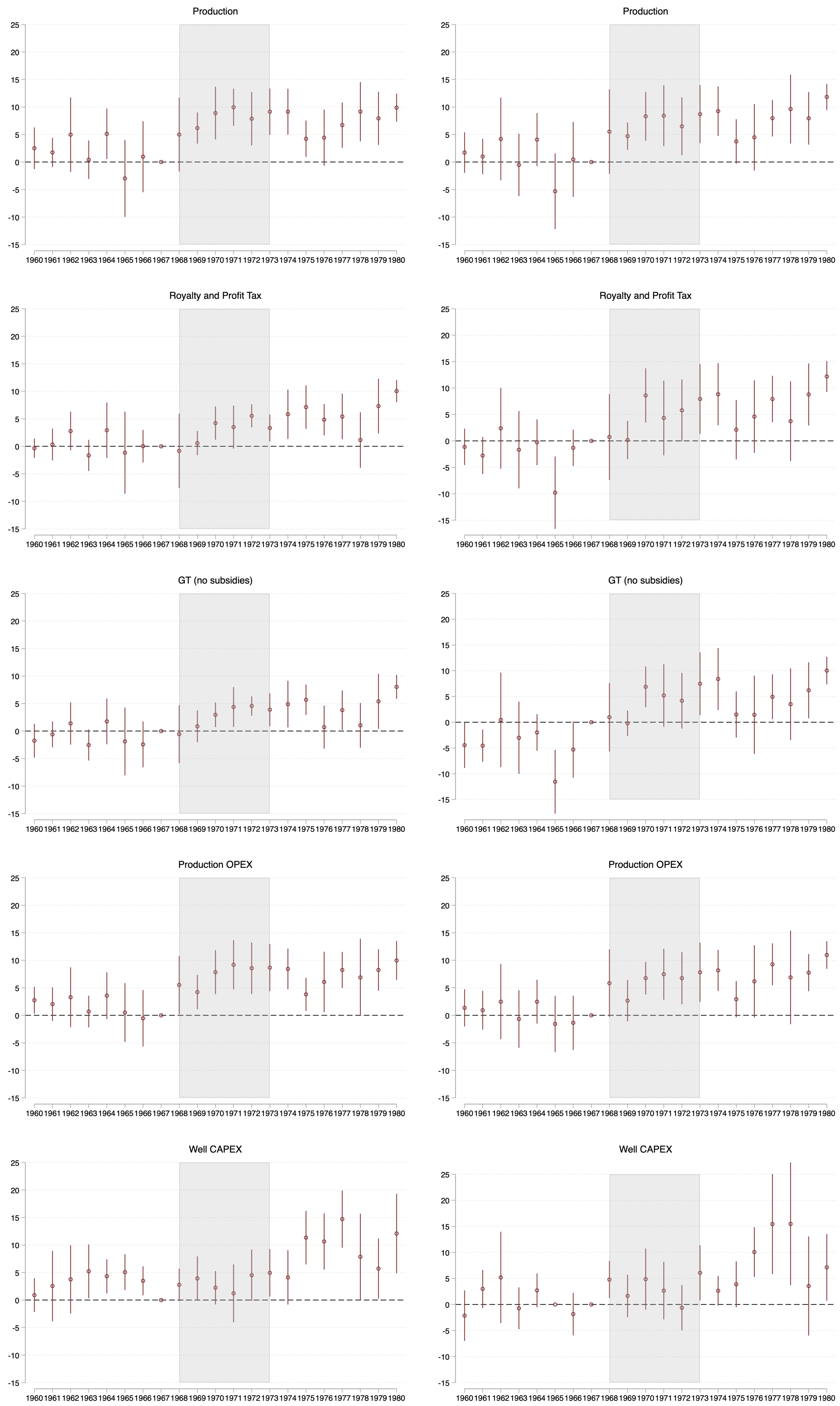
Panel E: Investment (CAPEX)

	(1) CAPEX 25Y (50%)	(2) CAPEX 30Y (50%)	(3) CAPEX 35Y (50%)	(4) CAPEX 25Y (66%)	(5) CAPEX 30Y (66%)	(6) CAPEX 35Y (66%)	(7) CAPEX 25Y (75%)	(8) CAPEX 30Y (75%)	(9) CAPEX 35Y (75%)
Weak (Polity IV)	0.877	0.593	1.525*	0.796	0.849	1.943**	0.756	0.982	1.958*
	(0.674)	(0.747)	(0.816)	(0.729)	(0.720)	(0.928)	(0.787)	(0.916)	(1.038)
N	1444	1454	1462	1444	1454	1462	1444	1454	1462
R-sq	0.49	0.48	0.49	0.48	0.47	0.49	0.45	0.45	0.46

	(1) CAPEX 25Y (50%)	(2) CAPEX 30Y (50%)	(3) CAPEX 35Y (50%)	(4) CAPEX 25Y (66%)	(5) CAPEX 30Y (66%)	(6) CAPEX 35Y (66%)	(7) CAPEX 25Y (75%)	(8) CAPEX 30Y (75%)	(9) CAPEX 35Y (75%)
Weak (OECD)	0.346	0.479	1.308	-0.034	0.447	1.373	0.047	0.300	1.084
	(0.791)	(0.862)	(1.033)	(0.831)	(0.872)	(1.161)	(0.854)	(1.011)	(1.206)
N	1444	1454	1462	1444	1454	1462	1444	1454	1462
R-sq	0.49	0.48	0.49	0.48	0.47	0.49	0.45	0.44	0.46

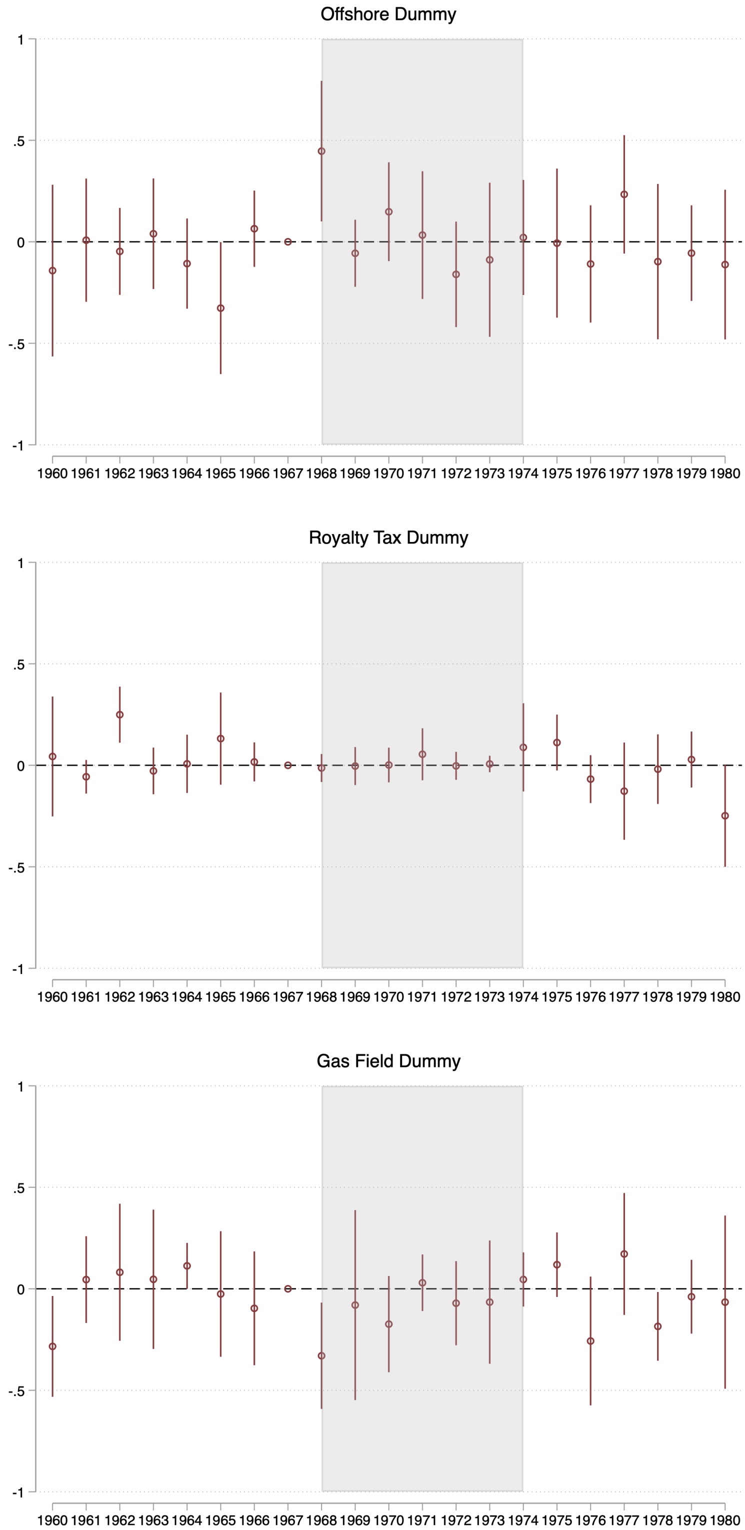
Notes: Notes: Left hand side variable is capturing the number of years until 50%, 66% or 75% of the cumulative level of OPEX, Well CAPEX , production and tax payments after 25, 30 or 35 years is reached. The fulls set of controls is included in all regressions, identical to the results presented in the even columns of Table 2. Our baseline dummy $Weak_c(a)$ differentiates between countries with strong and weak institutions. SE in parenthesis is clustered by country and Start Up Year. * stands for statistical significance at the 10% level, ** at the 5% level and *** at the 1% percent level.

Figure 15: NEW WORLD OIL ORDER WITHOUT OPEC



Notes: The dependent variable is the number of years until 66% of OPEX, CAPEX, production and tax payments over a 35 year period is reached. Year of Start Up, country FE and the life time of an asset are included in all regressions. In the graphs on the right, we additionally control for the full set of controls as used in the even columns of Table 2. The shaded area marks period of the transition to a new world order in which military force is not used to respond to expropriations. The plotted interaction terms are on the yearly level and the sample is limited to the period between 1960 and 1980, with 1967 being the baseline. SE are clustered by country and Start Up Year and on the graph we plot the 95% CI.

Figure 16: CONFOUNDERS



Notes: In the top panel, the left hand side is a dummy indicating offshore assets versus onshore assets, with the latter being coded as zero. In the middle panel, the left hand side variable is a dummy indicating the use of Concessions versus Production Sharing Agreements, with the latter being coded as zero. In the bottom panel the left hand side variable is a dummy indicating the extraction of natural gas as opposed to crude oil, with the latter being coded as zero. Year of Start Up and country FE and life time of the asset are included in all regressions. The plotted interaction terms are on the yearly level and the sample is limited to the period between 1959 and 1980, with 1967 being the baseline. SE are clustered by country and Start Up Year.

B Proofs of the model in Section 2

In this Appendix, we solve the stylized model presented in Section 2 and prove Propositions 1 and 2 and Lemma1.

Proof of Proposition 1

We start with describing the solution to the optimization problem stated in section 2. There are multiple equilibria in this infinitely repeated game including a trivial SPE with the default payoffs $(0, 0)$ received in each period. We focus on the SPE that lies on the Pareto optimal frontier and that maximizes the firm's profits at the start of the game.

We start by restating this Pareto optimization problem in a recursive form. Let V and U be the discounted values of the firm and the government, respectively. We need to find a decreasing concave function $U(V)$ (which describes the Pareto frontier in the (V, U) space as in Figure 3) for each V satisfying the firm's Bellman equation:

$$U(V) = \max_{I,\{V_p\},\{GT_p\}} \{-I + \mathbb{E}[r(I,p) - GT_p + \delta U(V_p)]\} \tag{7}$$

where the maximization is subject to the following constraints:
– the government's Bellman equation (GBE)

$$V = \mathbb{E}[GT_p + \delta V_p], \tag{8}$$

– the self-enforcing constraint (SE) for each p

$$\delta V_p \geq (1 - C)\,(r(I,p) - GT_p)\,, \tag{9}$$

– the feasibility constraint (F) for each p

$$0 \leq GT_p \leq r(I,p), \tag{10}$$

– the individual rationality constraint for the firm (IR)

$$U(V_p) \geq 0. \tag{11}$$

Here V_p is the government's discounted value calculated in the period after state p. The feasibility constraint means that there is no positive reward from the government to the firm and the government cannot take more than the firm has at the moment.

There are two possible states of nature. If a low price is realized, then $GT_0 = r(I, 0) = 0$, which implies that there is nothing for government to expropriate and the self-enforcing constraint (9) is slack. If a high price is realized, the feasibility constraint $GT_1 \leq r(I, 1)$ will not bind (otherwise the firm will incur losses since it needs to pay I and gets no output with probability $1/2$). These observations allow us to rewrite equations (7)–(11) as follows:

$$U(V) = \max_{I,V_0,V_1,GT_1} \left\{ -I + \frac{1}{2}\delta U(V_0) + \frac{1}{2}\left(4\sqrt{I} - GT_1 + \delta U(V_1)\right) \right\} \tag{12}$$

subject to

$$V = \frac{1}{2}\delta V_0 + \frac{1}{2}(GT_1 + \delta V_1), \tag{13}$$

$$\delta V_1 \geq (1 - C)\left(4\sqrt{I} - GT_1\right), \tag{14}$$

$$GT_1 \geq 0, \tag{15}$$

$$U(V_1) \geq 0[34]. \tag{16}$$

If there were no (SE) constraint (in particular, if $C = 1$ and institutions are characterized by perfect enforcement), the Pareto set would be that of the first-best:

$$U(V) = V^{\#} - V, \text{ where } V^{\#} = \frac{1}{1-\delta}, \quad I = I^* = 1. \tag{17}$$

Otherwise, the Pareto set would be smaller: $U(V) \leq V^{\#} - V$, $V \in [V_{\min}, V_{\max}]$. In what follows we characterize this Pareto set.

We take the binding (13) to find an expression for GT_1:

$$GT_1 = 2V - \delta V_0 - \delta V_1, \tag{18}$$

Note that if V_1 increases, GT_1 will need to decrease to keep the utility V given to the government constant. Substituting (18) into (12), (14) and (15), the equations (12)–(16) are restated

[34] The additional (IR) constraint for $p = 0$: $U(V_0) \geq 0$ never binds.

as follows:

$$U(V) = \max_{I, V_0, V_1} \left\{ 2\sqrt{I} - I - V + \frac{\delta}{2} (V_0 + V_1 + U(V_0) + U(V_1)) \right\} \tag{19}$$

subject to

$$\delta V_1 - (1 - C) \left(4\sqrt{I} - 2V + \delta V_0 + \delta V_1 \right) \geq 0, \tag{20}$$

$$2V - \delta V_0 - \delta V_1 \geq 0, \tag{21}$$

$$U(V_1) \geq 0. \tag{22}$$

Note that (19) contains the firm's expected profit for one period: $2\sqrt{I} - I - \left(V - \delta \frac{V_0 + V_1}{2}\right)$ and the firm's expected profits of future periods: $\delta \frac{U(V_0) + U(V_1)}{2}$. Note that V is the government take over all periods so we need to subtract $\delta \frac{V_0 + V_1}{2}$ which is the discounted sum of all future government takes from tomorrow onwards.

We are now ready to solve this simplified problem. Let $\lambda, \mu, \nu \geq 0$ be the Lagrange multipliers for (20), (21) and (22), respectively. Then the first-order conditions for (19)–(22) are

$$I = (1 - 2\lambda(1 - C))^2, \tag{23}$$

$$U'(V_0) = -1 + 2\lambda(1 - C) + 2\mu, \tag{24}$$

$$U'(V_1) = \frac{-1 - 2\lambda C + 2\mu}{1 + 2\frac{\nu}{\delta}}. \tag{25}$$

Another condition follows from the envelope theorem applied to the problem (19)–(22):

$$U'(V) = -1 + 2\lambda(1 - C) + 2\mu = U'(V_0). \tag{26}$$

Thus, $-1 \leq U'(V) \leq 0$ for all relevant V.

The Pareto frontier $\{(V, U(V)) | V \in [V_{\min}, V_{\max}]\}$ can be divided into two parts: the first-best part ($V \in FB$) where the enforceability constraint (20) is not binding, and the second-best part ($V \in SB$) where it binds. We concentrate on the situation with non-empty FB (Case 1 in Thomas and Worrall (1994)) so $V_{\max} = V^{\#}$. Our parameter restriction

$$\delta < \frac{2 - 2C}{3 - 2C}$$

rules out the case where the FB is empty (Case 2 in Thomas and Worrall (1994)).

When $V \in SB$ then $\lambda > 0$, the investment level is suboptimal, $I < 1$, and

$$U'(V_0) = U'(V) > -1. \tag{27}$$

Assuming the function $U(\cdot)$ is strictly concave, it follows from (19)–(26) that $U'(V)$ is decreasing in V for $V \in SB$. Hence,

$$V_0 = V \leq V_1 \leq \frac{V}{\beta} \quad \text{where } \beta = \frac{\delta}{2-\delta}. \tag{28}$$

and the last inequality follows from (21) and the condition that $V_0 = V$. Moreover, note that $\mu = \nu = 0$ is impossible on the SB part of Pareto frontier as long as $C > 0$, since constraints (25) and (27) need to be satisfied (for $C = 0$ we can have additional multiple solutions). So, if $C > 0$ then either (21) or (22) must bind. If (22) is not binding, then $V_1 = V/\beta$. Otherwise, we have $V_1 = V^{\#}$. In contrast with Thomas and Worrall (1994), when there are formal institutions, even if very weak, there is a strict incentive to increase V_1 and that is why V_1 needs to be bounded by above. To see this, consider an increase in V_1. By (13), it will be accompanied by a decrease in GT_1 such that the government still gets V. When $C = 0$, an increase in V_1 does not affect the self-enforcing constraint in (20). On one hand, increasing future taxes relaxes the constraint but on the other hand, it decreases the current taxes thereby increasing the potential profits to be expropriated. Overall, both effects cancel out. However, when $C > 0$, because expropriation does not happen with probability 1, the benefit of increasing V_1 dominates.

When $V \in FB$, then $\lambda = 0$ and the first best level of investment is achieved $I = I^* = 1$. Due to (25), this implies that $\mu = \nu = 0$ (otherwise, the inequality $U'(V) \geq -1$ would not hold). Hence $U'(V) = U'(V_0) = U'(V_1) = -1$ and $U(V)$ is given by (17). Plugging (17) to the right-hand side of (19), we see that (17) indeed holds if (20)–(22) hold. There are multiple solutions[35] to the maximization problem (19)–(22). The set of solutions (V_0, V_1) for a given $V \in [\bar{V}, V^{\#}]$ is described by the following inequality system:

$$\begin{aligned} & V_1 - (1-C)(4 - 2V + \delta V_0 + \delta V_1) \geq 0, \\ & 2V - \delta V_0 - \delta V_1 \geq 0 \\ & V, V_0, V_1 \in [\bar{V}, V^{\#}]. \end{aligned} \tag{29}$$

[35] Note that $U'(V_0) = U'(V)$ regardless of which constraints bind. This does not imply $V_0 = V$ if $V \in FB$ because then $U'(V) = -1$ everywhere.

We solve for minimal V satisfying this condition in order to have the broadest set $[\bar{V}, V^{\#}]$ where investment is at the first best level. Notice that for such a minimal V the first inequality in (29) is more likely to hold for large V_1 and small V_0, so in solving for such minimal V we can set $V = V_0 = \bar{V}$. Recall that this, combined with (21) implies that $V_1 \leq \dfrac{V}{\beta}$. As a result, if $\bar{V} \geq \beta V^{\#}$ then then (21) binds in this optimization problem while (22) does not bind and the respective solution is to be found by setting highest possible $V_1 = V^{\#}$. If instead $\bar{V} < \beta V^{\#}$, then (22) binds while (21) does not bind and to solve (29) we need to take $V_1 = \dfrac{V}{\beta}$.

As a result, this inequality system defines two subcases, jointly described as

$$\bar{V} = \max(\tilde{V}, V^*), \quad \tilde{V} = \frac{4(1-C)}{2-\delta}, \quad V^* = \frac{4(1-C)-(4-3C)\delta}{(1-C)(1-\delta)(2-\delta)}. \tag{30}$$

Case 1.1 takes place when $\delta \geq \dfrac{4-4C}{5-4C}$ and it implies $\bar{V} = \tilde{V}$. In this case, the first-best part of the Pareto frontier needs more than one step to cross from the left to the right. Then the segment of the Pareto set neighboring from the left to its first-best part is determined by equalizing (20) with $V_1 = V/\beta$, $V_0 = V$ and $U(V_1) = V^{\#} - V_1$. Solving (19) for $U(V)$, we obtain

$$U(V) = aV^2 + bV + c \tag{31}$$

where

$$a = -\frac{2-\delta}{8(1-C)^2}, \quad b = \frac{C}{1-C}, \quad c = \frac{\beta}{1-\delta}. \tag{32}$$

The level of investment is

$$I(V) = \left(\frac{2-\delta}{4(1-C)}V\right)^2 = \left(\frac{V}{\tilde{V}}\right)^2. \tag{33}$$

Equations (31)–(33) are valid $V \in [\beta\tilde{V}, \tilde{V}]$. To the right of this segment, that is for $V \in [\tilde{V}, V^{\#}]$, we have the solution in (17). The solution to the left of this segment, will be described later.

When $\dfrac{2-2C}{3-2C} \leq \delta < \dfrac{4-4C}{5-4C}$, we have Case 1.2 and hence $\bar{V} = V^*$. The first-best part of the Pareto frontier needs less than one step to be crossed. This means that there are points $(V, U(V))$ in the second-best part of the Pareto frontier (i.e. where $U(V) < V^{\#} - V$) such that the constraint (22) binds and we jump to $V_1 = V^{\#}$ following a high-price shock. Then the segment of the Pareto set neighboring from the left to its first-best part is determined by equalizing (20) with $V_1 = \min(V/\beta, V^{\#})$,[36] $V_0 = V$ and $U(V_1) = V^{\#} - V_1$. Solving (19) for $U(V)$, we obtain

$$U(V) = aV^2 + bV + c \tag{34}$$

where a, b, c are given by

$$a = -\frac{2-\delta}{8}, \quad b = -\frac{C}{4(1-C)}\frac{\delta}{1-\delta}, \quad c = \frac{\beta}{(1-C)(1-\delta)}\left(1 - \frac{\delta}{1-\delta}\frac{C^2}{8(1-C)}\right), \tag{35}$$

with the level of investment given by

$$I(V) = \left(\frac{C}{4(1-C)}\frac{\delta}{1-\delta} + \frac{2-\delta}{4}V\right)^2 \tag{36}$$

for $V \in [\beta V^{\#}, V^*]$ and by (32), with investment given by (33), for $V \in [\beta V^*, \beta V^{\#}]$.

For lower V (i.e. to the left of the segments considered above: to the left of $\beta\tilde{V}$ in case 1.1 and βV^* in case 1.2), both (20) and (21) bind. Then

$$V_1 = \frac{V}{\beta}, \quad I = \left(\frac{(2-\delta)V}{4(1-C)}\right)^2 \tag{37}$$

and the formula for $U(V)$ depends on k, the number of steps (made in high price periods) needed to reach the first best area, $k \geq 2$:

$$U(V) = a_k V^2 + b_k V + c_k \tag{38}$$

where a_k, b_k, c_k can be determined recursively from the Bellman equation (19):

$$a_k = \frac{a_{k-1}}{\beta} - \frac{2-\delta}{8(1-C)^2}, \quad b_k = b_{k-1} + \frac{1}{1-C}, \quad c_k = \beta c_{k-1}, \quad a_1 = a, \quad b_1 = b, \quad c_1 = c, \tag{39}$$

where a, b, c are defined in (32) or (35), depending on the case (1.1 or 1.2). This allows us to compute the coefficients a_k, b_k, c_k recursively

$$a_k = \beta^{1-k}a - \frac{\beta^{1-k}-1}{\beta^{-1}-1}\frac{2-\delta}{8(1-C)^2}, \quad b_k = b + \frac{k-1}{1-C}, \quad c_k = \beta^{k-1}c. \tag{40}$$

In order to compute these coefficients, we need to take the following steps. Take case 1.2, for

[36] We include V/β to get the full-length segment $[\beta V^*, V^*]$. Hence (21) binds and (22) is slack in the left part of the segment where $V \leq \beta V^{\#}$.

example. First, compute the segment to the left of $[\beta V^*, V^*]$. Using (37), the minimum V associated to the maximum $V_1 = \beta V^*$ is then $V = \beta^2 V^*$. Then take a V in $[\beta^2 V^*, \beta V^*]$ with associated $V_1 = \beta V$ and $U(V_1)$ defined by (34)–(35) and I as in (36) for $V \in [\beta V^{\#}, V^*]$ and, respectively, by (31)–(33), for $V \in [\beta V^*, \beta V^{\#}]$. Plug in this in (19) and find a_2, b_2, c_2. In general, k is given by

$$k = \left\lceil \frac{\ln\left(V_{\min}/\bar{V}\right)}{\ln \beta} \right\rceil \tag{41}$$

where (41) is determined by $\bar{V} = \tilde{V}$ for Case 1.1 and $\bar{V} = V^*$ for Case 1.2.

The left bound of the Pareto frontier $V_{\min}$ is reached at the maximum of $U(V)$, when $U'(V) = 0$ i.e.

$$V_{\min} = \frac{b_k}{-2a_k} \tag{42}$$

where k is such that $V_{\min}$ is between $\beta^k \bar{V}$ and $\beta^{k-1}\bar{V}$ where $\bar{V}$ depends on the case as before. Note that $V_{\min}$ is positive since $b_k > 0$. At this point, the firm gets the largest profits.

The Pareto optimal path for an initial $V_{\min}$ looks as follows: at the first $k-1$ periods where a high price is realized (low-price periods are not taken into account since the investment stays constant and $GT_0 = 0$), $GT_1 = 0$ and the investment increases exponentially at the rate $\frac{1}{\beta^2}$. Then the k-th high-price period follows. Case 1.1 has the same pattern as in previous $k-1$ periods, while in Case 1.2 the investment may grow at a decreased rate and some positive government take may occur. Finally, from period $k+1$ on the investment stabilizes at its maximal, first-best optimal level $I = 1$ and remains constant forever. The government take GT_1 is defined by (18) in all possible segments. It is zero up until the equilibrium path reaches the first best segment. Once the first best is reached, the evolution of GT is not uniquely defined; since the (20) constraint no longer binds, today's GT can be traded against tomorrow's value of V_1 as illustrated by equation (18). As a result, there are many possible paths for GT_1.

Proof of Lemma 1 For expositional clarity, we limit the analysis of this section and of Proof of Proposition 2 to Case 1.1. Most of the results of this section extend to Case 1.2 and the proofs are available on request. The only result that we could not establish for case 1.2 so far is the existence of an equilibrium with more backloading of government take under weaker institutions.

In this Lemma, we want to establish that k, the number periods with a high price realization needed to reach the first best part of Pareto frontier, is decreasing in C. The value of k is determined by the inequalities

$$\beta^k \le \frac{V_{\min}}{\tilde{V}} < \beta^{k-1}. \tag{43}$$

Remember that $V_{\min}$ is in (42), with a_k and b_k given by (40) and with a and b given by (32). As follows from these formulas, $V_{\min}$ is given by

$$V_{\min} = \frac{2(k-1+C)(1-C)(1-\beta^2)}{\beta(\beta^{-k}-1)} \text{ if } C_k \le C \le C_{k-1} \tag{44}$$

where

$$C_k = \sum_{i=0}^{k} \beta^i - k = \frac{1-\beta^{k+1}}{1-\beta} - k. \tag{45}$$

Here $[C_k, C_{k-1}]$ is the segment of C values satisfying $\beta^k\tilde{V} \le V_{\min} \le \beta^{k-1}\tilde{V}$.

Using (44)–(45), we obtain

$$\frac{V_{\min}}{\tilde{V}} = -\frac{(2-\delta)b_k}{8(1-C)a_k} = \frac{\beta^{-1}-1}{\beta^{-k}-1}(C+k-1) \tag{46}$$

We need to show that k as determined by conditions (43) and (46)

$$\beta^k \le \frac{\beta^{-1}-1}{\beta^{-k}-1}(C+k-1) < \beta^{k-1} \tag{47}$$

is decreasing in C.

Consider an auxiliary implicit equation defining a continuous variable $x \ge 0$ as a function of $C \in [0,1]$

$$\frac{\beta^{-1}-1}{\beta^{-x}-1}(C+x-1) - \beta^x = 0. \tag{48}$$

Note that this equation is a continuous version of the condition (47) which (step-wise) defines a natural number k as a function of C. Thus, if we can show that x is decreasing in C in equation (48), k is decreasing in C. Equation (47) can be rewritten as

$$\beta^x(\frac{\beta^{-1}-1}{1-\beta^x}(C+x-1)-1) = 0. \tag{49}$$

Define

$$F(C,x) \equiv \frac{\beta^{-1}-1}{1-\beta^x}(C+x-1),$$

then equation (48) is equivalent to

$$F(C,x) - 1 = 0. \tag{50}$$

Taking full derivative of this equation we get

$$\frac{dx}{dC} = -\frac{F_C(C,x)}{F_x(C,x)}$$

Partial derivatives of its LHS with respect to C and x are positive

$$F_C(C,x) = \partial \frac{\frac{\beta^{-1}-1}{1-\beta^x}(C+x-1)-1}{\partial C} = \frac{\beta^{-1}-1}{1-\beta^x} > 0$$

$$\begin{aligned} F_x(C,x) &= \partial \frac{\frac{\beta^{-1}-1}{1-\beta^x}(C+x-1)-1}{\partial x} \\ &= \frac{\beta^{-1}-1}{(\beta^x-1)^2}\left(C\beta^x \ln\beta - \beta^x \ln\beta - \beta^x + x\beta^x \ln\beta + 1\right) \\ &\geq \frac{\beta^{-1}-1}{(\beta^x-1)^2}\left(\beta^x \ln\beta - \beta^x \ln\beta - \beta^x + x\beta^x \ln\beta + 1\right) \\ &= \frac{\beta^{-1}-1}{(\beta^x-1)^2}\left(1 - \beta^x(1-\ln\beta^x)\right) \geq 0 \end{aligned}$$

as $\beta < 1$ and, thus, the maximum of the expression $\beta^x(1-\ln\beta^x)$ is achieved at $\beta^x = 1$ and is equal to 1. As a result, x is a decreasing function of C as defined by implicit equation (48), which completes the proof.

Proof of Proposition 2

Recall the definition of the cumulative share of investment/production/government take after n high-price periods as:

$$CS_n^I = \frac{\sum_{p=1}^{n} X_p}{\sum_{p=1}^{P} X_p} \tag{51}$$

where $n \in \{1,\dots,P\}$, P is exogenously given, and X may stand for investment I, production $r(I)$, or government take GT. The proof of this proposition is composed by three Lemmas.

Lemma 2. *Cumulative share of investment CS_n^I is increasing in C for any fixed n, P, and δ.*

Proof. Firstly note that if both the self-enforcing constraint (20) and the feasibility constraint (21) bind then the level of investment I is given by (33): $I = \left(V/\tilde{V}\right)^2$. This means that for all $V \in [0, V^{\#}]$

$$I = \min\left\{\left(V/\tilde{V}\right)^2, 1\right\}. \tag{52}$$

Consider the evolution of V starting from $V = V_{\min}$ where $V_{\min}$ is given by (42). If $p \leq k$ then the value of I is given by

$$I_p = \beta^{-2(p-1)}\left(V_{\min}/\tilde{V}\right)^2. \tag{53}$$

Hence the cumulative share of investment CS_n^I defined by (51) is given by

$$CS_n^I = \frac{e\left(V_{\min}/\tilde{V}\right)^2 + f}{\sum_{p=1}^{k}\beta^{-2(p-1)}\left(V_{\min}/\tilde{V}\right)^2 + P - k} \tag{54}$$

where

$$\begin{cases} e = \sum_{p=1}^{n}\beta^{-2(p-1)}, \ f = 0, & \text{if } n \leq k, \\ e = \sum_{p=1}^{k}\beta^{-2(p-1)}, \ f = n - k, & \text{if } n > k. \end{cases}$$

In both ranges of n,

$$e(P-k) > f\sum_{p=1}^{k}\beta^{-2(p-1)}$$

for all $n = 1, \ldots, P-1$, so CS_n^I is increasing in $V_{\min}/\tilde{V}$. □

Let's now prove that $V_{\min}/\tilde{V}$ is increasing in C. Recall from the proof of Lemma 1 that

$$\frac{V_{\min}}{\tilde{V}} = -\frac{(2-\delta)b_k}{8(1-C)a_k} = \frac{\beta^{-1}-1}{\beta^{-k}-1}(C+k-1) \text{ if } C_k \leq C \leq C_{k-1} \tag{55}$$

where

$$C_k = \sum_{i=0}^{k}\beta^i - k = \frac{1-\beta^{k+1}}{1-\beta} - k. \tag{56}$$

Here $[C_k, C_{k-1}]$ is the segment of C values satisfying $\beta^k\tilde{V} \leq V_{\min} \leq \beta^{k-1}\tilde{V}$. Note that $V_{\min}$ is continuous in C on each such segment.

From this expression it is easy to see that $V_{\min}/\tilde{V}$ is increasing in C for any particular k (or, equivalently, on each segment $[C_k, C_{k-1}]$). We are left to establish that $V_{\min}/\tilde{V}$ is continuous in C also at C_k for each k. As a result we would obtain that $V_{\min}/\tilde{V}$ is increasing in C, and, consequently, CS_n^I is increasing in C.

Let's show that both the numerator and denominator of CS_n^I are continuous at the threshold C_k for any k. Start with the denominator, and show that the difference between the values of it to the left and to the right of C_k is zero

$$\begin{aligned}
&\left(\sum_{p=1}^{k+1} \beta^{-2(p-1)} \left(V_{\min}/\tilde{V}\right)^2 + P - k - 1\right) - \left(\sum_{p=1}^{k} \beta^{-2(p-1)} \left(V_{\min}/\tilde{V}\right)^2 + P - k\right) \\
= \;& \beta^{-2k} \left(V_{\min}/\tilde{V}\right)^2 - 1 = \beta^{-2k} \left(\frac{\beta^{-1} - 1}{\beta^{-k} - 1}(C_k + k - 1)\right)^2 - 1 \\
= \;& \beta^{-2k} \left(\frac{\beta^{-1} - 1}{\beta^{-k} - 1}\left(\frac{1 - \beta^{k+1}}{1 - \beta} - 1\right)\right)^2 - 1 = 0
\end{aligned}$$

Now turn to the numerator. If $n < k$, the difference between the values of the numerator to the left and to the right of C_k is trivially zero. If $n \geq k$, this difference is

$$\begin{aligned}
&\left(\sum_{p=1}^{k+1} \beta^{-2(p-1)} \left(V_{\min}/\tilde{V}\right)^2 + n - k - 1\right) - \left(\sum_{p=1}^{k} \beta^{-2(p-1)} \left(V_{\min}/\tilde{V}\right)^2 + n - k\right) \\
= \;& \beta^{-2k} \left(V_{\min}/\tilde{V}\right)^2 - 1 = 0
\end{aligned}$$

by the proof above. Thus we have proved that CS_n^I is continuous at C_k for any k, and that CS_n^I is increasing in C.

Lemma 3. *Cumulative share of production CS_n^r is increasing in C for any fixed n, P, and δ.*

Proof. The proof that CS_n^r is increasing in C for any fixed n, P, and δ closely parallels the one for the investment. Indeed, it is enough to note that $r(I, 1) = 4\sqrt{I}$, and $r(I, 0) = 0$. As a result, the cumulative share of production CS_n^r is given by

$$CS_n^r = \frac{\sum\limits_{p=1}^{n} r_p}{\sum\limits_{p=1}^{P} r_p} = \frac{\sum\limits_{p=1}^{n} 4\sqrt{I_p}}{\sum\limits_{p=1}^{P} 4\sqrt{I_p}} = \frac{\widetilde{e}\left(V_{\min}/\tilde{V}\right) + f}{\sum\limits_{p=1}^{k} \beta^{-(p-1)} \left(V_{\min}/\tilde{V}\right) + P - k} \tag{57}$$

where

$$\begin{cases} \widetilde{e} = \sum_{p=1}^{n} \beta^{-(p-1)},\ f = 0, & \text{if } n \le k, \\ \widetilde{e} = \sum_{p=1}^{k} \beta^{-(p-1)},\ f = n-k, & \text{if } n > k. \end{cases}$$

Just as above, $\widetilde{e}(P-k) > f \sum_{p=1}^{k} \beta^{-(p-1)}$ for all $n = 1, \ldots, P-1$, so CS_n^r is increasing in $V_{\min}/\tilde{V}$ for any k, and we have proved above that $V_{\min}/\tilde{V}$ is increasing in C.

It is left is to prove the continuity of CS_n^r in C. We show that both the numerator and denominator of CS_n^I are continuous at the threshold C_k for any k. We start with the denominator, and show that the difference between the values of it to the left and to the right of C_k is zero

$$\begin{aligned} &\left(\sum_{p=1}^{k+1} \beta^{-(p-1)} \left(V_{\min}/\tilde{V}\right) + P - k - 1\right) - \left(\sum_{p=1}^{k} \beta^{-(p-1)} \left(V_{\min}/\tilde{V}\right) + P - k\right) \\ = \;& \beta^{-k} \left(V_{\min}/\tilde{V}\right) - 1 = \beta^{-k} \left(\frac{\beta^{-1}-1}{\beta^{-k}-1}(C_k + k - 1)\right) - 1 = 0 \end{aligned}$$

The result for the numerator follows in the similar fashion. Thus we have proved that CS_n^r is continuous at C_k for any k, and that CS_n^r is increasing in C.

□

Lemma 4. *(a) The number of periods with zero government take is decreasing in C.*

(b) Cumulative share of government take CS_n^{GT} may be increasing in C for any fixed n, P, and δ.

Proof. Result (a) follows from the proof of Lemma 1. Let us establish result (b). As discussed earlier, unlike investment or production, the government take schedule may depend on the choice among multiple solutions in the first-best segment. To be specific, let us consider the equilibrium where V reaches efficient frontier at some point between $\tilde{V}$ and $\tilde{V}/\beta$, then jumps to $\tilde{V}/\beta$ and stays there stationary. Then GT_p is zero in periods $p \le k$, it is

$$GT_k = (2-\delta)V_k - \delta\frac{\tilde{V}}{\beta}$$

at $p = k+1$, and for $p > k+1$ it is given by

$$GT_k = 2(1-\delta)\frac{\tilde{V}}{\beta}.$$

As a result, $CS_n^{GT} = 0$ if $n \leq k$, while for $n > k$ it is given by

$$CS_n^{GT} = \frac{(2-\delta)V_k - \delta\frac{\tilde{V}}{\beta} + (n-k+1)2(1-\delta)\frac{\tilde{V}}{\beta}}{(2-\delta)V_k - \delta\frac{\tilde{V}}{\beta} + (P-k+1)2(1-\delta)\frac{\tilde{V}}{\beta}} \tag{58}$$

$$= \frac{(2-\delta)\beta^{-k}V_{\min} - \delta\frac{\tilde{V}}{\beta} + (n-k+1)2(1-\delta)\frac{\tilde{V}}{\beta}}{(2-\delta)\beta^{-k}V_{\min} - \delta\frac{\tilde{V}}{\beta} + (P-k+1)2(1-\delta)\frac{\tilde{V}}{\beta}} \tag{59}$$

$$= \frac{\beta^{-k}\left(V_{\min}/\tilde{V}\right) - 1 + \frac{2(1-\delta)}{\delta}(n-k+1)}{\beta^{-k}\left(V_{\min}/\tilde{V}\right) - 1 + \frac{2(1-\delta)}{\delta}(P-k+1)} \tag{60}$$

Since $-1 + \frac{2(1-\delta)}{\delta}(P-k+1) > -1 + \frac{2(1-\delta)}{\delta}(n-k+1)$ for $k \leq n < P$, CS_n^{GT} is increasing in C or δ for a given k as so is $\left(V_{\min}/\tilde{V}\right)$.

What is left to prove that the CS_n^{GT} is increasing in C on the entire domain is that CS_n^{GT} is continuous in C. We follow exactly the same steps as above, and do it for denominator first:

$$\begin{aligned}
& \beta^{-k-1}\left(V_{\min}/\tilde{V}\right) - 1 + \frac{2(1-\delta)}{\delta}(P-k) - \beta^{-k}\left(V_{\min}/\tilde{V}\right) + 1 - \frac{2(1-\delta)}{\delta}(P-k+1) \\
= \; & \beta^{-k-1}(1-\beta)V_{\min}/\tilde{V} - \frac{2(1-\delta)}{\delta} = \beta^{-k-1}(1-\beta)\beta^k - \frac{2(1-\delta)}{\delta} = \\
= \; & \frac{1-\beta}{\beta} - -\frac{2(1-\delta)}{\delta} = \frac{2(1-\delta)}{\delta} - \frac{2(1-\delta)}{\delta} = 0
\end{aligned}$$

Same argument works for the denominator, which completes the proof.[37] □

[37] Note that this result may depend on equilibrium selection