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Resource management under endogenous risk of expropriation[☆]

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ABSTRACT

This paper explores how the dynamic management of a non-renewable resource is affected by an endogenous (i.e., mitigable) risk of expropriation. The time at risk increases with the value of the resource in the ground and decreases with the cost of expropriating the resource. When the risk of expropriation is internalized by the legitimate owner, in the absence of capacity constraints, the resource is depleted faster than it is socially optimal. Interestingly, a marginal improvement in the protection of property rights exacerbates the over-extraction of the resource. In the presence of endogenous capacity constraints, and when property rights are imperfectly protected, both under- and over-extraction are possible. If property rights are relatively strong the resource owner under-invests in extraction capacity and depletes the resource below the socially optimal rate. If property rights are relatively weak the owner over-invests and the resource is over-extracted.

1. Introduction

It is a well-known economic principle that the appropriate definition and enforcement of property rights is a necessary condition for efficiency. However, in many economic environments property rights are inadequately protected. For instance, in the oil and gas industry, the relationship between multinational firms and governments has been characterized by the persistence of weakly protected property rights.

In recent years, the commodity super-cycle and the political environment in Latin America, home of about one fifth of the world's oil reserves (BP, 2015), brought expropriations in the oil and gas industry—also known as resource nationalism—back to the headlines. Among the Latin American governments, Venezuela's has been portrayed as one of the most salient trespassers of private property.[1] An example of this, in the oil and gas industry, is the nationalization of ConocoPhillips and Exxon Mobil's operations, ordered by Hugo Chavez in 2007. ConocoPhillips' recount states that on June 11th, 2007—nine days before the nationalization was executed—the company declined the, allegedly unfair, compensation offered by the Venezuelan gov-

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[1] This is well reflected in Venezuela's dismal Ease of Doing Business rank for 2016, 186 out 189 (World Bank, 2016).

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ernment in exchange for its local operations. Upon the company's refusal to accept this deal, the government proceeded to inform that "the nationalization process was nonnegotiable and would move forward on the government's terms, with or without ConocoPhillips" (ICSID, 2013, p. 128). The International Centre for Settlement of Investment Disputes (ICSID) tribunal, arbitrating the case between ConocoPhillips and the Venezuelan government, ruled that the government "breached its obligation to negotiate in good faith for compensation for its taking of the ConocoPhillips assets" (ICSID, 2013, p. 131).

More recently, in April 2012, the Argentine government of Cristina Fernandez announced the seizure of 90% of Repsol's stake in YPF, a move to re-nationalize this oil and gas company (Forbes, 2012, April 17, 2013). At the time of the expropriation, Argentina faced an energy crisis, caused by a strict capping of energy prices, which significantly undermined the incentives to invest in the sector while increasing the demand for energy. Paradoxically, the government justified the expropriation of Repsol's assets on the grounds that Repsol's lack of investment was a main contributor to Argentina's trade deficit in fuel (Costamagna et al., 2015; Melgarejo et al., 2013). In the midst of the energy crisis, the expropriation of Repsol's YPF stake occurred only a few months after Repsol's announcement of the discovery of the Vaca Muerta basin; "[Vaca Muerta]is estimated to hold 16 billion barrels of shale oil and 308 trillion cubic feet (8.7 trillion cubic metres) of shale gas, which would give Argentina the world's fourth-largest reserves of shale oil and second-largest of shale gas." (The Economist, 2013, June 27, 2013). The discovery of Vaca Muerta presented itself as an obvious opportunity for the cash-strapped Argentine government to reach the goal of energy independence, and put YPF's re-nationalization under a thick cloud of suspicion.

These expropriations not only occurred at a time of high commodity prices; but, they also were carried out by governments with at best moderate constraints, from the legislature, to take action against private interests.[2] In the case of Venezuela, the lack of constraints on the executive occurred because the executive enjoyed special powers; while in Argentina, the parliament was largely controlled by the government's party. In other words, these expropriations occurred under what appeared to be favorable circumstances for the expropriator. Specifically, they took place in a context of: (i) increased value of the assets to be seized, because of the higher oil prices and the unexpectedly large size of the newly found basin; and, (ii) low cost of expropriation, because of the lack of political constraints on the executive.

These observations reveal the importance of incorporating the expropriation decisions as endogenous outcomes of a cost-benefit analysis in the study of resource management problems. The case for the economic motives behind expropriations is not only an intuitive or anecdotal one. Guriev et al. (2011) and Stroebel and van Benthem (2013) further substantiate this line of reasoning with evidence from nationalizations occurring after the 1960s. Both of these studies find that nationalizations in the oil sector have a higher probability of occurring when oil prices are high and in countries with low constraints on the executive.

This paper contributes to the literature on the dynamic management of a non-renewable resources by incorporating the notion that the decision to expropriate follows a cost-benefit analysis, and by exploring the effect of the endogenous risk of expropriation resulting from this decision making process. The theoretical analysis presented here rests on two main elements. First, it is assumed that expropriations only occur if the benefits of doing so outweigh the cost of expropriation. Second, the endogenous nature of the risk of expropriation is internalized by the resource owner. A direct implication of the combination of these elements is that the risk of expropriation vanishes endogenously in finite time when the stock of the resource reaches a certain threshold. If the owner is aware that the resource is at risk of being expropriated, her effective discount rate is higher than it would have been in the absence of the risk; as a consequence the resource is over-exploited. More interestingly, if on top of recognizing that there is a risk of expropriation the owner actually internalizes that this risk is endogenous, the over-exploitation of the resource is exacerbated: by reducing the size of the available stock the owner is protecting her property rights over the resource left in the ground.

From a broader perspective, this theoretical framework allows for a systematic analysis of the extraction of a non-renewable resource for the whole range of intermediate property rights regimes in between the two extremes commonly explored in the literature: perfectly protected property rights and fully exogenous risk of expropriation. From this analysis one can infer the effect of strengthening the property rights protection on the depletion of a non-renewable resource. When the risk of expropriation is treated as exogenous, it induces a higher effective discount rate, which in turn leads to the over-extraction of the resource relative what would be extracted under perfect property rights protection (e.g.,Bohn and Deacon, 2000; Long, 1975; Sinn, 2008). Interestingly, when the risk of expropriation is endogenous, marginally improving the protection of property rights (i.e., a marginal increase in the cost of expropriation) exacerbates the over-extraction problem. However, from the viewpoint of the resource owner, an improvement in the strength of property rights protection unambiguously increases the value of the resource in the ground.

Taking into account that complementary capital investments (e.g., demulsification and storage facilities) are needed to build-up a well's extraction capacity, the theoretical analysis is extended to allow for endogenous extraction capacity. Under endogenous capacity constraints, the risk of expropriation can be (strategically) internalized in one of two opposite ways. The owner can opt for reducing the value of the well, and the incentives to confiscate it, by running down the stock; this is achieved by installing extraction capacity above the efficient level. Alternatively, the resource owner may reduce the well's value by under-investing in the well's extraction capacity. Evidently, each of these two alternatives comes at a cost for the owner. Over-investing in extraction capacity is costly in the short run because of the higher installation costs,

[2] Another common characteristic is that the compensation offers, appear to have been well below the market value of the seized assets. For example, in November 2013 the Argentine government offered $5 billion for, the reportedly $10 billion worth, Repsol's stake in YPF.

and in the long run because there is less of the resource in the ground. In contrast, under-investing in capacity is costly because it constrains the owner's extraction in the short-run. Whether over-investing or under-investing emerges as the dominant strategy depends on the strength of property rights protection. When property rights are strong the level of under-investment required to avert an expropriation is not too low; therefore, the under-investing strategy is not as costly and emerges in equilibrium. When the protection of property rights is weak the owner is better off by over-investing.

The effect of weak property rights first got attention in the resource economics literature in the 1970s (e.g., Long, 1975) when the oil sector experienced a wave of nationalizations of foreign production activities (Kobrin, 1985). This early literature explores the dynamic effect of an exogenous risk of expropriation on the extraction of a non-renewable resource. By inducing a higher effective discount rate, a higher risk of expropriation leads to over-exploitation of the natural resource from the optimal perspective (e.g., Bohn and Deacon, 2000; Long, 1975; Sinn, 2008); this in turn, lowers the value of what is still in the ground.[3] In a related work, Olsen (1987) explores the effect of the exogenous risk of expropriation on extraction capacity finding that there is over-extraction if the resource is scarce. Konrad et al. (1994) study how the risks of losing access to the resource and to losing access to the savings from the resource exploitation may interact and actually cancel out leaving extraction unchanged. More recently, Bohn and Deacon (2000) find that, theoretically, a higher risk of expropriation has an ambiguous effect on the speed of depletion when one simultaneously accounts for extraction, investment in complementary capital, and exploration efforts. Their empirical results suggest that higher ownership security leads to more rapacious extraction.

Next to the resource economics view, the political economy of development literature offers an alternative perspective on the natural resource ownership problem. This literature commonly approaches the ownership problem assuming that the flow of rents from natural resources is exogenous, while the fight over these rents is endogenous. This literature usually contends that, in weakly institutionalized polities, rents from natural resources can have a negative impact on total output and welfare due to violent conflicts between rival factions, rent-seeking, and cronyism (see for instance, Acemoglu et al., 2004; Hodler, 2006; Mehlum et al., 2006; Torvik, 2002).

Recently, some literature aiming directly at filling the gap between the resource economics (exogenous expropriation) and the political economy (exogenous extraction) approaches, has emerged. The interplay between endogenous extraction and endogenous fight over resources has also been most commonly framed in the context of conflict between local factions (e.g., Janus, 2012; van der Ploeg, 2012; van der Ploeg and Rohner, 2012; Robinson et al., 2006; Sekeris, 2014). For instance, van der Ploeg (2012) and van der Ploeg and Rohner (2012) find a combination of the traditional results: on the one hand, the larger the stock in the ground, the more intense the conflict for power; on the other hand, because the conflict for power results in uncertainty about tenure of power and thus higher effective impatience, the resource is over-exploited. The fight over non-renewable resources has also been modeled in the form of the so-called resource wars between a resource abundant and a resource-less country (Acemoglu et al., 2012). These authors find that the prospect of invasion by the resource-less economy, together with the non-internalization of the incentives to invade, accelerates extraction today; as a consequence the resource becomes even scarcer, resulting in an earlier invasion. Also in the context of endogenous property rights and endogenous exploitation, Costello and Kaffine (2008) study the effect of uncertain renewal of exploitation rights of a renewable resource, where the likelihood of rights' renewal depends on the preservation of the resource. They find that the resource user has more incentives to preserve the resource, the longer the length of the exploitation rights and the higher the probability of renewal (i.e., the stronger the protection of property rights).

The analysis presented in this paper belongs to the intersection of resource economics and political economy. Following the resource economics approach, this paper's main focus is on how the extraction path of a non-renewable resource is affected by an institutional imperfection, in this case the risk of expropriation. Next to this, it adds the political economy element of explicitly modeling the source of the expropriation risk; this is done by explicitly incorporating the expropriator's cost-benefit analysis into the model. As a result, the model generates some novel elements for the study of the management of non-renewable resources in presence of expropriation risk. First, it produces a systematic analysis of the effect of ill-defined property rights on the extraction of a non-renewable resource. In particular, the model serves to explore how depletion and extraction capacity react to changes in the strength of property rights, for the complete range of intermediate property rights regimes. Second, it decomposes the expropriation risk into two sources: the risk of a political shift, which is beyond the control of the resource owner; and the strength of property rights relative to size of the resource, which can be internalized by the resource owner.

The rest of this paper is organized as follows. Section 2 presents the basic setup: a model of extraction of a non-renewable resource under the endogenous risk of expropriation. Section 3 extends the basic framework by introducing the investment in extraction capacity as an additional variable under the control of the resource owner. This section explores how this investment is affected by the strength of property rights. Section 4 discusses how some alternative elements that characterize the relationship between firms exploiting non-renewable natural resources and potential expropriators, can be incorporated into the model. Finally, Section 5 is devoted to the concluding remarks.

[3] The poor definition of exploitation rights of a non-renewable resource has also been approached as a *common pool* problem: e.g., Kemp and Long (1984).

2. Basic framework

2.1. Setup

2.1.1. Endowments

The economy is initially endowed with a stock $S_0 > 0$ of a non-renewable resource, which is perfectly observable by all agents. Time is continuous and the planning horizon is of infinite length. The evolution of the resource over time depends on extraction $R(t)$: $dS/dt \equiv \dot{S}(t) = -R(t)$. The net instantaneous income generated by extraction is a concave function of the extracted amount R. Specifically, for $R(t)$ extracted units from the ground an income flow of $\theta(\theta - 1)^{-1} R(t)^{1-\frac{1}{\theta}}$ is generated, with $\theta > 1$. This assumption reflects that in the presence of geological constraints speeding-up extraction, by increasing the extractive pressure, lowers the quality and market value of the extracted resource (see Venables, 2011). Furthermore, the extraction cost is assumed to be zero and thus income and revenues from extraction are equivalent.

2.1.2. Agents and institutions

The political environment is characterized by two regimes: the incumbent's (business-friendly) regime *E* and the challenger's (business-hostile) regime *C*. By assumption the economy is initially in regime *E*. In this regime, the rights over the resource are granted to a third party (*F*). At every point in time during *E*'s regime there is an instantaneous and exogenous risk, $\pi > 0$, of a shift in the political regime. A regime shift is defined here as a change in the identity of the group in power, from *E* to *C*. The relevance of the regime shift is that it may undermine *F*'s property rights. Specifically, during *E*'s regime *F*'s property rights are secure, however upon a regime shift the new government *C* may seize *F*'s rights to exploit the resource by choosing to expropriate the remaining stock.[4] Yet, *C* may refrain from doing so because expropriating is costly. For instance, the new regime may face institutional constraints (e.g., constitutional dispositions, limited executive powers) that make expropriations hard to execute. The expropriation cost denoted by $\chi \geq 0$, is exogenous and reflects the extent to which the protection of property rights is independent of the identity of the group in power; in other words, it reflects how resilient property rights are to shifts in the private-ownership-stance of the government. As such, $\chi \to \infty$ implies perfectly protected property rights, and a regime shift will never threaten property rights; while, $\chi = 0$ implies that expropriation is certain whenever a political regime shift occurs. By assumption at most one political regime shift is possible.[5] Intuitively, χ mirrors the strength of property rights and not the technological constraints faced by the expropriator. In some polities, for instance, there are constitutional provisions deeming expropriation by the executive as illegal. Thus, if the executive wants to take control of the resource, it has to go through the costly process of convincing (or overruling) the legislature. This interpretation of χ is further corroborated by the negative association between the likelihood of nationalizations in the oil sector and the strength of the constraints on the executive (see, e.g., Guriev et al., 2011; Mahdavi, 2014; Stroebel and van Benthem, 2013). In their theoretical framework Guriev et al. (2011) and Stroebel and van Benthem (2013) also assume a fixed cost of expropriation and interpret it as institutional strength. However, in contrast to the present analysis, they do not explore the effect of this on the extraction/depletion decision.[6]

Expropriations are assumed to be permanent; that is upon expropriation *F* never regains access to the resource again.[7] In this economy all agents are risk neutral, and thus their objective is to maximize the net present value (NPV) of the income flow from exploiting the resource. Finally, the economy is small and open and therefore the interest rate *r* is exogenous and given by the international capital markets.

2.1.3. Timing

The timing of the instantaneous interactions is as follows:

1 All the agents observe whether a political regime shift occurs.
2 In case of a regime shift, *C* decides whether or not to expropriate the resource.
3 If there is no regime shift, or if the resource is not expropriated, *F* decides how much to extract in that period; otherwise the new owner (*C*) decides on extraction.
4 Extraction takes place and the revenues from extraction are accrued by the agent in control of the resource.

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[4] This feature is consistent with the evidence of a positive impact of a change in government on the probability of a nationalization (Guriev et al., 2011).

[5] This assumption just simplifies the exposition, but the results of this section remain unchanged if multiple regime changes are allowed. This is the case because under multiple regime shifts it is still true that the individual valuation of the resource is strictly increasing in the remaining stock, and that individuals discount time positively.

[6] An alternative interpretation of the cost of expropriation, is that upon expropriation the initial owner is nominally compensated, meaning that the compensation does not reflect to the value of what is still left in the ground. Also, an expropriation could entail a reputational cost, which manifests in lower foreign investment inflows or stricter conditions in the international credit markets (Mahdavi, 2014; Stroebel and van Benthem, 2013).

[7] In this sense, the terms expropriation and nationalization could be used interchangeably in this framework.

2.2. Analysis

2.2.1. The problem of the Challenger and the No Expropriation Constraint

Suppose that a regime shift occurs at time t, and that C gets a hold of the resource stock. The problem of C is then to maximize the NPV of the flow of revenues generated by the extraction of the resource as of t. This is

$$V^C(S(t)) = \max_{R(\tau)} \int_t^\infty e^{-r\tau}\frac{R(\tau)^{1-\frac{1}{\theta}}}{1-\frac{1}{\theta}}d\tau,$$

subject to the law of motion of the resource ($R(t) = -\dot{S}(t)$), the current value of the stock in the ground ($\int_t^\infty R(\tau)d\tau \leq S(t)$), and the non-negativity constraints ($S(t), R(t) \geq 0$ for all t); where $S(t)$ denotes the remaining stock of the resource in the ground, and $R(t)$ stands for the extraction of the resource at time t. Solving this cake-eating problem one gets extraction $R(t)$ as a function of the remaining stock $S(t)$[8]:

$$R(t) = \theta r S(t). \tag{1}$$

It is immediate from this expression that the depletion rate, defined as the extraction relative to the remaining stock (R/S), stays constant at θr. With no further political regime shifts after the challenger takes control over the resource C's property rights are perfectly protected. As a consequence, the extraction path described by (1) coincides with the socially optimal extraction path.

Definition 1. An extraction path is socially optimal if, using r as the discount rate, it maximizes the NPV of the flow of revenues from extraction ($\theta(\theta-1)^{-1}\int_t^\infty e^{-r\tau}R(\tau)^{1-\frac{1}{\theta}}d\tau$) subject to the law of motion of the resource ($R(t) = -\frac{\partial S}{\partial t} \equiv -\dot{S}(t)$), the remaining stock in the ground ($\int_t^\infty R(\tau)d\tau \leq S(t)$), and the non-negativity constraints ($S(t), R(t) \geq 0$ for all t). The socially optimal path is given by $\frac{\partial \ln R(t)}{\partial t} \equiv \hat{R}(t) = -\theta r$, and $\frac{R(t)}{S(t)} = \theta r$.

Using $R(\tau) = R(t)e^{-\theta r(\tau - t)}$ and (1) one can solve for the challenger's valuation of the remaining stock $S(t)$

$$V^C(S(t)) = \Theta r^{-\frac{1}{\theta}} S(t)^{1-\frac{1}{\theta}}, \tag{2}$$

with $\Theta \equiv \theta^{1-\frac{1}{\theta}}(\theta-1)^{-1}$.

According to the political economy structure of the model, expropriating is costly. As this cost is meant to reflect institutional (rather than technological) constraints, it does not depend on the size of the stock in the ground. As a result, and given that $V^C(S(t))$ is strictly increasing in $S(t)$, it is possible to define a threshold for the remaining stock, $\bar{S}$, below which the challenger is better off by not expropriating. In other words, as it is costly to confiscate the resource, only sufficiently valuable/large stocks are expropriated.[9] If the challenger expropriates the resource at time t, the continuation value is $U^C(S(t)|I(t) = f(t) = 1) = V^C(S(t)) - \chi$. Where U^C stands for the challenger's (net present) valuation of the resource, net of expropriation costs; $I(t) \in \{0, 1\}$ is a state variable that takes the value of 1 if political challenger is already in power at time t; and $f(t)$ takes the value of 1 if the challenger decides to expropriate the resource at time t, otherwise it is equal to 0.

On the other hand, if the challenger decides not to expropriate, the continuation value is 0. This uses the fact that there is no better day than today to expropriate, which follows from the assumption that the resource is non-renewable; hence, even in the absence of extraction C's valuation of the resource is decreasing in the time of confiscation simply because of the positive time discount. The challenger therefore decides not to expropriate the resource if $U^C(S(t)|I(t) = f(t) = 1) \leq 0$, which is equivalent to

$$V^C(S(t)) \leq \chi. \tag{3}$$

As $V^C(S(t))$ is strictly increasing in $S(t)$, (3) generates a threshold for $S(t)$; if the remaining stock is below this threshold, the no expropriation constraint (NEC) (3) holds with strict inequality. Using (2) in (3) the NEC can be rewritten as

$$S(t) \leq \left(\chi\Theta^{-1}r^{\frac{1}{\theta}}\right)^{\frac{\theta}{\theta-1}} \equiv \bar{S}. \tag{4}$$

Evidently, the higher the cost of expropriation, χ, the less restrictive the NEC is.

2.2.2. The problem of the Owner

The initially rightful owner of resource F, hereafter just *the owner*, maximizes the NPV of revenues from the resource extraction, taking into account the risk of losing the resource to C. That is, the owner is fully forward looking. The risk of expropriation is composed by the combination of two elements: (i) the exogenous hazard of a political regime shift (i.e., the

[8] See Online Appendix A.1.

[9] Note that $\frac{\partial V^C}{\partial S} > \frac{\partial \chi}{\partial S}$ is sufficient for the existence and uniqueness of $\bar{S}$. That is, the results follow through with a non-constant cost of expropriation, as long as the cost is not too increasing in S.

instantaneous probability that E is replaced by C), represented by parameter $\pi > 0$; and, (ii) whether the NEC is fulfilled (i.e., whether $S(t) \leq \bar{S}$). Taking this into account, the expected NPV from the owner's viewpoint is

$$E\left[NPV^F(S_0)\right] = \int_0^\infty e^{-(r+\Pi(S(\tau)))} R(\tau)\, d\tau, \tag{5}$$

with

$$\Pi(S(t)) = \begin{cases} \pi & \text{if } S(t) > \bar{S} \\ 0 & \text{otherwise} \end{cases}.$$

The problem of the owner is then to maximize this expected NPV, subject to the law of motion of the resource ($R(t) = -\dot{S}(t)$), the endowment of the resource ($\int_0^\infty R(\tau)d\tau \leq S_0$), and the non-negativity constraints ($S(t)$, $R(t) \geq 0$) for all t.[10]

Definition 2. Let $\bar{t}$ denote the time period such that if $l(\bar{t}) = 0$ (i.e., if the incumbent remains in office at least until $\bar{t}$), then $S(\bar{t}) = \bar{S}$.

That is, $\bar{t}$ is the precise instant when the safe stock is reached. In the absence of a regime shift, by Definition 2 the cumulative extraction between an arbitrary $t < \bar{t}$ and $\bar{t}$ is equal to $S(t) - \bar{S}$: $\int_t^{\bar{t}} R(\tau)d\tau = S(t) - \bar{S}$. Taking this into account, the owner's problem is essentially an optimal switching time problem. When choosing how fast to extract, the owner is choosing how fast to reach the safety threshold $\bar{S}$; and this is equivalent to choosing $\bar{t}$. From the owner's perspective, running down the stock below $\bar{S}$ endogenously induces a regime shift (not to be confused with the political regime shift), in the sense that the effective discount rate jumps from $r+\pi$ to r (i.e., the risk of expropriation dissipates). The objective of the owner is to maximize the expected NPV of the revenue flows from extraction, which is given by[11]:

$$E\left[NPV^F(S_0)\right] = \int_0^{\bar{t}} e^{-(r+\pi)\tau} \frac{R(\tau)^{1-\frac{1}{\theta}}}{1-\frac{1}{\theta}} d\tau + e^{-(r+\pi)\bar{t}} \int_{\bar{t}}^\infty e^{-r(\tau-\bar{t})} \frac{R(\tau)^{1-\frac{1}{\theta}}}{1-\frac{1}{\theta}} d\tau.$$

The integral between 0 and $\bar{t}$ represents the sum of all the revenue flows, while the threat of expropriation is latent. During this time interval each flow is discounted by the interest rate and the survival probability of the incumbent's regime (i.e., $e^{-\pi t}$). The second integral is the sum of all the income flows after safety is reached ($t \geq \bar{t}$). These flows are received with certainty, conditional on the incumbent's regime surviving at least until $t = \bar{t}$; this occurs with probability $e^{-\pi\bar{t}}$. Moreover, this expected NPV takes into account that expropriation is full and permanent, and therefore the owner's continuation value upon expropriation is 0.

From $\bar{t}$ onwards F's problem is simply the risk-free problem (provided that F has retained the resource until $\bar{t}$). Under the assumption that the owner F has no technological (or market access) advantage over the challenger, the owner's valuation of the resource at $\bar{t}$ must be equal to χ, and so the last term of owner's NPV can be rewritten as $e^{-(r+\pi)\bar{t}}\chi$. Then, F's optimization problem between 0 and $\bar{t}$ can be represented by the following present value Hamiltonian:

$$\mathcal{H}^F(t) = e^{-(r+\pi)t} \frac{R(t)^{1-\frac{1}{\theta}}}{1-\frac{1}{\theta}} - \lambda(t) R(t),$$

where $\lambda(t)$ is the shadow value of the stock in the ground. Combining the FOCs of this problem with respect to the extraction ($\mathcal{H}_R^F = 0$) and the remaining stock ($\mathcal{H}_S^F = -\dot{\lambda}$) one obtains that the growth rate of extraction is constant and equal to $\hat{R}(t) = -\theta(r+\pi)$, and therefore

$$R(t_1) = e^{-\theta(r+\pi)(t_1-t_2)} R(t_2); \tag{6}$$

for any arbitrary pair $t_1 < t_2 < \bar{t}$, such that $l(t_2) = 0$. In order to pin down the exact extraction path between 0 and $\bar{t}$ one needs to establish the value of $R(t)$ at some t in that interval. For this, one can use the TVC of the problem at $\bar{t}$. As this is an optimal control problem, with a fixed end value of the state ($S(\bar{t}) = \bar{S}$) and a free end time ($\bar{t}$), the TVC at $\bar{t}$ is given by $\mathcal{H}^F\left(\bar{t}\right) + \frac{\partial\left(e^{-(r+\pi)\bar{t}} V^F(\bar{S})\right)}{\partial \bar{t}} = 0$, where $e^{-(r+\pi)\bar{t}} V^F\left(\bar{S}\right)$ is the net present value of reaching the safety threshold $\bar{S}$. This TVC simply

[10] In the context of environmental and resource economics other authors have also explored the role of stock-dependent (one-off) regime shifts For instance, Nkuiya (2015) and Nkuiya and Costello (2016) study regime shifts in pollution damages and preference respectively, where the probability of the shift depends on cumulative pollution. While, Miller and Nkuiya (2016) study regime shifts in the regeneration rate of a renewable stock, where the probability of the shift depends on the remaining stock.

[11] See Online Appendix A.2 for the formal derivation of this formulation.

establishes that when safety is reached, at $\bar{t}$, the value of remaining marginally longer at risk, $\mathcal{H}^F\left(\bar{t}\right)$, should be equal to the value of reaching safety marginally earlier, $-\frac{\partial\left(e^{-(r+\pi)\bar{t}}V^F\left(\bar{S}\right)\right)}{\partial\bar{t}}$. In the problem at hand the TVC reads[12]:

$$e^{-(r+\pi)\bar{t}}\frac{R\left(\bar{t}\right)^{1-\frac{1}{\theta}}}{1-\frac{1}{\theta}}-\lambda\left(\bar{t}\right)R\left(\bar{t}\right)=(r+\pi)e^{-(r+\pi)\bar{t}}\left(\frac{\Theta\bar{S}^{1-\frac{1}{\theta}}}{r^{\frac{1}{\theta}}}\right).$$

Using the FOC with respect to R, to get the co-state λ as a function of the control R, the TVC can be rewritten as

$$R\left(\bar{t}\right)=\left(1+\frac{\pi}{r}\right)^{\frac{1}{1-\frac{1}{\theta}}}\theta r\bar{S}. \tag{7}$$

Definition 3. *Let* $x>0$ be such that if $l(\bar{t})=0$, then $R(\bar{t})\equiv x\theta r\bar{S}$.

From this definition, x is the adjustment needed in R at time $\bar{t}$ for $R(\bar{t})$ to coincide with the social optimum (risk-free) level $\theta r\bar{S}$ (as a proportion of the social optimum extraction). Using (7) the optimal adjustment in the presence of expropriation risk is[13]: $x^*=\left(1+\frac{\pi}{r}\right)^{\frac{\theta}{\theta-1}}$. Note that with $\theta>1$ the optimal x is strictly larger than 1 and it is increasing in $\frac{\pi}{r}$. Thus, whenever the risk of expropriation is latent, the owner finds it optimal to extract in such a way that along a path in which a regime shift has not occurred, extraction must be discretely downsized at time $\bar{t}$.

Note further that with $\theta>1$, x^* is decreasing in θ. Intuitively, how fast $\bar{S}$ is reached depends on how steep and how high the extraction path is. As θ increases the extraction path becomes steeper; thus, a high θ directly implies a low $\bar{t}$, and therefore the gain of inducing even more over-extraction through the jump x is lower. Using x^*, the maximized expected NPV of a given stock of the resource $S(t)$ is

$$V^F(S(t))=\begin{cases}\Theta\left((r+\pi)^{-\dfrac{1}{\theta-1}}(S(t)-\bar{S})+r^{-\dfrac{1}{\theta-1}}\bar{S}\right)^{\dfrac{\theta-1}{\theta}} & \text{if } S(t)>\bar{S}\\ \Theta r^{-\dfrac{1}{\theta}}S(t)^{1-\dfrac{1}{\theta}} & \text{otherwise}\end{cases}, \tag{8}$$

where $V^F(S(t))$ is increasing and continuous in $S(t)$ (See Online Appendix B.1). Furthermore, as shown by Proposition 3 below, $V^F(S(t))$ is increasing in χ, and therefore it is increasing in $\bar{S}$. By combining (6), (7), and the cumulative extraction between t and $\bar{t}$ one gets the full characterization of the extraction path as a function of $S(t)$ and parameters:

$$R(t)=\begin{cases}\theta\left((r+\pi)\left(S(t)-\bar{S}\right)+x^*r\bar{S}\right) & \text{if } S(t)>\bar{S}\\ \theta rS(t) & \text{otherwise}\end{cases}. \tag{9}$$

Given that $x^*r>r+\pi$, when the threat of expropriation is still latent, the rate of depletion (R/S) in (9) is higher than the one obtained under fully exogenous risk of expropriation (i.e., $\frac{R(t)}{S(t)}>r+\pi$ if $\bar{S}>0$); furthermore, this rate increases over time as the resource gets depleted. Overall, giving the owner the chance to protect her property rights over the resource by extracting fast enough exacerbates the over-extraction problem.

Proposition 1. *Under endogenous risk of expropriation there are two sources of distortion in the extraction path: 1. the exogenous risk of a regime shift (π); and, 2. the possibility of fully mitigating the risk of expropriation in finite time by reaching a safe stock of the resource. Both sources induce over-extraction of the resource with respect to the social optimum, and the distortion imposed by source 1. is constant while the one imposed by source 2. intensifies over time until the risk of expropriation endogenously vanishes when the safety threshold $\bar{S}$ is reached.*

Proof. Follows directly from the text. □

As summarized by Proposition 1, the endogenous risk of expropriation has two reinforcing effects that lead to a level of extraction that is too rapacious from the social perspective. First, the hazard of a political regime shift increases F's effective discount rate, and this homogeneously raises the "baseline" depletion rate from θr to $\theta(r+\pi)$. Second, the endogenous nature of the expropriation risk pushes the owner to further accelerate depletion as this reduces the time it takes to reach the safety threshold $\bar{S}$. That is, the fact that the risk of expropriation can be endogenously mitigated, exacerbates the over-extraction problem: depletion is even faster than under an exogenous risk of expropriation. Interestingly, the over-extraction induced

[12] For other applications of dynamic optimization problems with regime shifts, in resource economics, see for instance Polasky et al. (2011), de Zeeuw and Zemel (2012). The latter provides an explicit application of this TVC.
[13] Deriving x^* from the TVC, is in fact equivalent to explicitly solving for the optimal adjustment in extraction at $\bar{t}$.

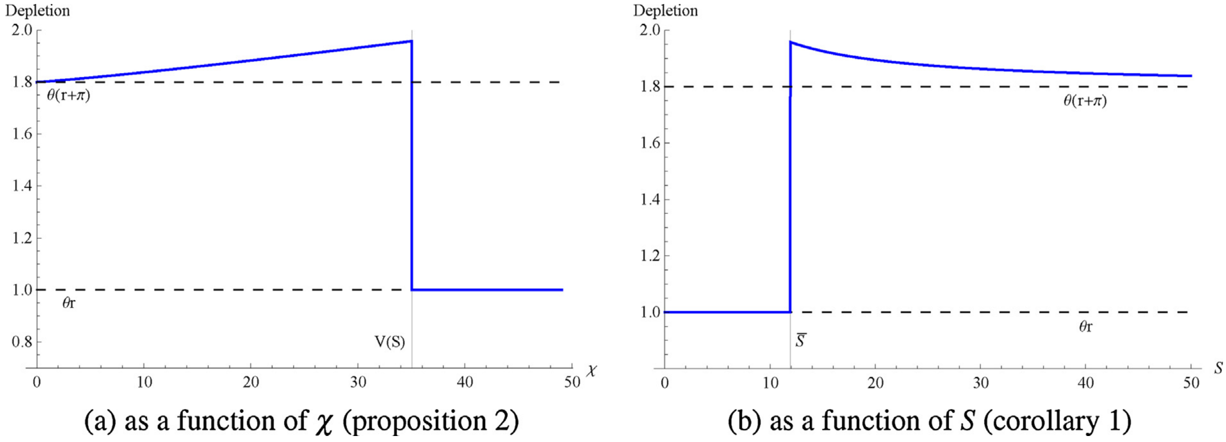


Fig. 1. Depletion rate.

by the mitigable nature of the risk of expropriation intensifies as $S(t)$ approaches $\bar{S}$. If the owner would be unable to mitigate the risk of expropriation, say if $\chi = \bar{S} = 0$, the rate of depletion would remain constant at $\theta(r+\pi)$. With an endogenous risk of expropriation however, the owner can fully mitigate the risk by reaching $\bar{S}$. Mitigation comes at the cost of distorting the extraction path. Taking into account that the owner's effective discount rate while at risk is $r+\pi$, the further away $\frac{R}{S}$ is from $\theta(r+\pi)$ the more distorted the path is from the owner's point of view; while at risk, the baseline level to evaluate the magnitude of the distortion and so the (marginal) cost of distorting the extraction path is equal to $\theta(r+\pi)$, and therefore it is independent of time. Yet, the (expected) marginal benefit of running down the stock does depend on time. Specifically, at time $t < \bar{t}$, the expected gain of marginally reducing the time at risk (marginally reducing $\bar{t} - t$) is: $(r+\pi)e^{-(r+\pi)(\bar{t}-t)}V^F\left(\bar{S}\right)$, which is decreasing in $\bar{t} - t$. That is, the closer the owner is to the safety threshold (i.e., the lower $\bar{t} - t$), the more there is to gain from speeding-up extraction. This is the case because, conditional on surviving until t, the probability of a political regime shift before reaching $\bar{S}$ is declining in t.

As mentioned above, in this framework, the cost of expropriation (χ), and not the risk of a political regime shift (π), measures how well defined property rights are (i.e., how resilient are property rights to the identity of the group in power). In particular, $\chi=\infty$ is equivalent to perfect protection of property rights, while permanent exposure to expropriation risk (i.e., non-mitigable risk) is implied by $\chi = 0$. Interestingly,

Proposition 2. *1. When the risk of expropriation is still latent, a marginal increase in property rights protection (i.e., an increase in χ), exacerbates the over-extraction problem. 2. Only a sufficiently high (discrete) improvement in protection, i.e., an increase in χ such that $\bar{S} \geq S(t)$, leads to a lower depletion $\frac{R}{S}$. In fact, such a piecewise improvement brings $\frac{R}{S}$ down to the socially optimal level θr.*

Proof. See Online Appendix B.2. □

This proposition has a striking implication: if property rights are sufficiently weak, a gradual improvement in the protection of property rights leads to more over-extraction in the short-run. This perverse effect of improving the strength of property rights follows from the interaction between the two sources of distortion: the exogenous risk of a regime shift and the possibility of endogenously avoiding expropriation. Proposition 2 is illustrated in panel (a) of Fig. 1[14]: when $\chi = 0$ (i.e., in a world with completely unprotected property rights) $\frac{R}{S}$ is equal to $\theta(r+\pi)$ as represented by the upper horizontal line, which constitutes the baseline depletion while at risk; initially the depletion rate increases with χ, up to the point where the NEC is met with equality (i.e., when χ is such that $\bar{S} = S(t)$), as represented by the vertical line. Note that if one interprets χ—instead of $1/\pi$—as "ownership security", these results are consistent with the (puzzling) evidence of Bohn and Deacon (2000) on the positive relationship between extraction and ownership security. In the current framework, this positive association is not due to complementary investment decisions, instead it is the outcome of using over-extraction as protection tool against expropriation. Once the NEC is fulfilled the risk of expropriation is no longer a concern; thus, $\frac{R}{S}$ jumps down to the optimal level θr (depicted by the lower horizontal line), and it does not change with further improvements in property rights protection. The flip side of Proposition 2 entails that:

Corollary 1. *For a given χ, such that $S_0 > \bar{S}$, in a path without a political regime shift the depletion rate ($\frac{R}{S}$) increases over time as the resource gets depleted while the resource remains at risk of being expropriated; once the safety threshold $\bar{S}$ is reached, the depletion rate jumps down to the optimal level θr and remains at that level.*

[14] In this figure $S(t) = 50$, and the values of the parameters are $r = \frac{1}{8}$, $\theta = 8$, and $\pi = \frac{1}{10}$.

Proof. Follows directly from Eq. (9) and $x^{*}r > r + \pi$. □

Panel (b) of Fig. 1 illustrates corollary 1. In this figure, again the upper horizontal line is the depletion rate under fully exogenous risk of expropriation ($\theta(r+\pi)$), the lower horizontal line is the socially optimal depletion rate (θr), and the vertical line depicts the safety threshold $\bar{S}$.

Regarding the value of the resource, despite the fact that an improvement in property rights exacerbates the over-extraction problem, from the owner's perspective stronger property rights unambiguously increase the value of the resource. While it is true that an improvement in the protection of property rights induces a higher distortion in the depletion rate, this improvement also leads to a shorter time at risk. In the end, the shorter time at risk more than compensates (in expected value) for the efficiency loss from over-exploiting the resource.[15] In sum, when it comes to the value of the resource,

Proposition 3. *Whenever the risk of expropriation is still latent, and for a given stock of the resource: 1. a marginal increase in property rights protection (i.e., an increase in χ), unambiguously increases the owner's expected NPV of the resource; 2. a marginal decrease in the risk of a regime shift unambiguously increases the owner's NPV of the resource.*

Proof. From (8) and $\theta > 1$ it follows that $\frac{\partial V^F(S(t))}{\partial \bar{S}} > 0$ and $\frac{\partial V^F(S(t))}{\partial \pi} < 0$. □

3. Installed capacity

Extracting and commercializing non-renewable natural resources typically requires complementary capital investments. In the case of oil for instance, extraction tends to be constrained by on-site storage and demulsification (i.e., separation of oil and water) capacities, which are needed to prepare the crude before shipping it through a pipeline. Capital investments in storage and demulsification facilities can be then interpreted as investments in extraction capacity. Due to the need for these complementary investments, oil extraction from an individual well, or field, occurs in three distinct phases: build-up, plateau, and decline. The build-up period is the time that it takes for the extraction capacity of the well to be installed. During the plateau phase, extraction is constrained by the well's extraction capacity and remains constant. Finally, during the decline phase, extraction smoothly decreases from the plateau level to the abandonment level, i.e., the minimum economically feasible extraction: 0 in the current setup.

Taking this into account, and building on the framework developed above, this section incorporates an endogenous extraction capacity as a relevant element of the resource management problem. To include this, it assumed that in order to be able to extract at least K units of the resource at any time, an initial investment of $c(K)$ is required. This initial investment summarizes the build-up phase, where $c(K)$ is the net value of all the investment flows needed to build-up capacity K, calculated at the time when the capacity is fully available.[16] The installed extraction capacity of the well is then fixed over time and it determines the maximum level that can be extracted at any t, this constraint will be binding over some interval of time akin to the plateau phase. Eventually, as the resource gets depleted and the desired extraction decreases, the capacity constraint will stop being relevant, and extraction will decline over time.

This section explores how the two endogenous elements concerning the resource management, extraction and extraction capacity, are affected by the political economy uncertainty that creates an endogenous risk of expropriation. As a benchmark for this analysis, the case with no political risk (i.e., $\pi = 0$) is first presented, and then the case with political risk is developed.

3.1. No political risk

The case without expropriation risk is a standard exercise (e.g., Ghoddusi, 2010) that constitutes an useful benchmark for the analysis of the case with political risk. Following Definition 1 the results derived under no political risk constitute the social optimum in the presence of capacity constraints. Assuming that installing is costless (i.e., $c(K) = 0$), the NPV of owning the resource with an installed capacity K is given by[17]:

$$V_{NR}(S_0, K) = \begin{cases} \dfrac{K^{1-\frac{1}{\theta}}}{\left(1-\frac{1}{\theta}\right) r}\left(1 - e^{-rT}\left(1-\frac{1}{\theta}\right)\right) & \text{if } K \le r\theta S_0 \\ \Theta r^{-\frac{1}{\theta}} S_0^{1-\frac{1}{\theta}} & \text{if } K > r\theta S_0 \end{cases}; \tag{10}$$

[15] Online Appendix Fig. 7 presents the path of the owner's NPV (ln $\left(V^F\right)$ vs. t) compared to the path in case of no risk. There one can observe that the risk of expropriation has a permanent negative effect on V^F.

[16] The implicit assumption here is that during the build-up phase no extraction takes place, or alternatively that $c(K)$ is the cost of building up capacity net of the revenues from extraction during the build-up phase.

[17] See Online Appendix A.3.

where $V(S_0, K)$ denotes the maximum NPV of the resource taking S_0 and K as given, the subscript NR stands for "no risk" of expropriation, and T refers to the exact instant at which the capacity constraint becomes irrelevant, that is, the end of the plateau phase. Note further that $dV_{NR}/dK \geq 0$ and $d^2V_{NR}/dK^2 \leq 0$, with strict inequality if $T > 0$. The NPV thus reaches a maximum at $K = \theta r S_0$ (i.e., $T = 0$). Once the capacity is equal to $\theta r S_0$ further investments in capacity have no impact on the NPV of the resource. Now, assume that installing capacity is costly. Specifically, installing a capacity K costs $c(K)$, with $c' > 0$, $c'' \geq 0$, and $c(0) = 0$. Then, the optimal level of installed capacity K^*_{NR} is implicitly given by

$$\frac{K_{NR}^{*-\frac{1}{\theta}}}{r}\left(1-\frac{1+rT^*_{NR}}{e^{rT^*_{NR}}}\right)=c'\left(K^*_{NR}\right). \tag{11}$$

Because of the assumed properties of c, and given that V_{NR} is continuous, increasing, and strictly concave in K, K^*_{NR} exists and it is unique.

3.2. Political risk

The endogenous risk of expropriation creates a trade-off when choosing the level of installed capacity, and this may distort the owner's preferred level of K. This trade-off emerges from the possibility to mitigate the expropriation risk by reducing the gain from capturing the resource. On the one hand, a higher installed capacity allows for running down the stock at a faster pace, and so reaching the safety threshold $\bar{S}$ in less time. On the other hand, a lower installed capacity is more likely to bound the challenger's extraction in case of expropriation, and so it may increase the minimum size of the stock that the challenger finds worthy to seize. Which of these two forces dominates depends, among other things, on the exogenous risk of a political regime shift and on how costly it is for the challenger to build up capacity on top of the owner's initial investment. For simplicity, it is assumed that once the capacity of a well is installed, no further investments are possible; however, the results of the model remain qualitatively unchanged if the challenger can expand the installed capacity and c is strictly increasing in K.

3.2.1. The Challenger's problem and the No Expropriation Constraint

The problem of C depends on whether the capacity constraint is binding or not. In particular, we know that at time t the challenger decides not to expropriate the resource if $V^C(S(t), K) \leq \chi$. The exact form of the NEC depends on whether the challenger is constrained by the installed extraction capacity. Specifically, if the capacity constraint is irrelevant for the challenger ($K \geq \theta r S(t)$) the NEC remains as in (4); if the capacity constraint is binding at t ($K < \theta r S(t)$), the NEC can be rewritten as an upper bound for K, and this upper bound is a decreasing function of S:

$$NEC\left(S(t),\,K\right):\quad\begin{cases}\Theta r^{-\frac{1}{\theta}}S(t)^{1-\frac{1}{\theta}}\leq\chi\longleftarrow S(t)\leq\bar{S}\\[2ex]\dfrac{K^{1-\frac{1}{\theta}}}{\left(1-\frac{1}{\theta}\right)r}\left(1-e^{-r\left(\frac{S(t)}{K}-\frac{1}{\theta r}\right)\left(1-\frac{1}{\theta}\right)}\right)\leq\chi\longleftarrow K\leq\bar{K}\left(S(t)\right)\end{cases}. \tag{12}$$

When the capacity constraint is binding, the value of the resource is strictly increasing in S and K. Therefore, K's upper bound $\bar{K}(S(t))$—the iso-value curve when the NEC is exactly met—is strictly decreasing in $S(t)$; the intuition for this is straightforward: if the capacity constraint is binding, both $S(t)$ and K enter positively in the challenger's valuation of the resource; thus, the higher remaining stock the lower the maximum installed capacity that fulfills the NEC. This means that if the extraction capacity is binding, from the challenger's perspective, both the extraction rate and the extraction capacity are available tools in the owner's strategy to protect the resource against expropriation. From the challenger's unconstrained extraction path (1), one obtains that $\bar{K}\left(\bar{S}\right)=\theta r\bar{S}$, and therefore $\bar{K}\left(S(t)\right)<\theta rS(t)$ for any $S(t)>\bar{S}$. In other words, K has a strategic role if it constrains C's extraction at the time of a regime shift. Fig. 2 depicts the NEC. The combinations of S and K to the left and below the solid curve fulfill the NEC, the vertical segment corresponds to the NEC when the capacity constraint is irrelevant (i.e., if $K>\theta r\bar{S}$, the NEC is simply given by $S=\bar{S}$), and the decreasing segment corresponds to $K=\bar{K}\left(S(t)\right)$. As observed in the figure, the maximum K for which the NEC holds, given $S>\bar{S}$, lies below the challenger's and the owner's preferred extraction, R^C and R^F respectively.

3.2.2. The Owner's problem

With an endogenous capacity constraint, does the owner mitigate the risk of expropriation by depleting the resource at a fast pace or by installing a low extraction capacity? To answer this question one needs to obtain the owner's expected NPV as a function of K, S_0, and parameters. A systematic way to achieve this is by deriving the owner's expected NPV, maximized with respect to the extraction rate given K and S_0, over two different intervals of K (i.e., obtain $V^F(S_0, K)$). These intervals are defined by a combination of the strategic (i.e., fulfilling the NEC) and the constraining (i.e., limiting extraction) roles of K:

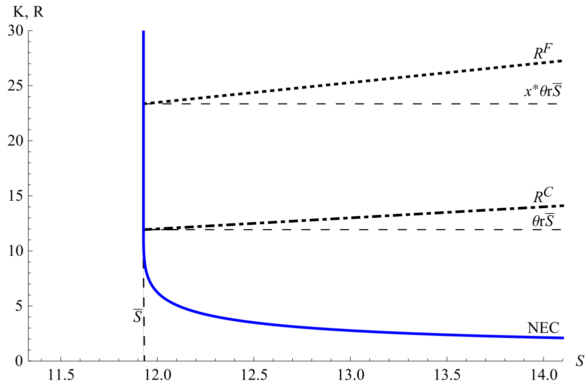


Fig. 2. Installed capacity and the NEC.

1 The NEC holds for some $S(t) > \bar{S}$: $K \leq \theta r\bar{S}$

When the installed capacity belongs to this first interval, the risk of expropriation can be fully mitigated before reaching the safety threshold $\bar{S}$. That is, K plays an active role protecting the resource against expropriation. Let us define t_1 as the first instant at which, in the absence of a regime shift, the NEC holds (i.e., $K \equiv \bar{K}(S(t_1))$ if $K > \bar{K}(S_0)$, or $t_1 = 0$ if $K \leq \bar{K}(S_0)$).[18] Using this the owner's expected NPV can be written as:

$$V_1^F(S_0,\ K,\ t_1) = \int_0^{t_1} \frac{K^{1-\frac{1}{\theta}}}{\left(1-\frac{1}{\theta}\right)} e^{-(r+\pi)\tau} d\tau + e^{-(r+\pi)t_1} V_{NR}^F(S(t_1),\ K) - c. \tag{13}$$

The first term to the right refers to the NPV of revenue flows while the risk of expropriation is latent and the capacity constraint is binding, and the second term represents the NPV of revenues once risk vanishes. Note that the effective discount of the latter accounts for the probability that a regime shift has not occurred before t_1. Using the definition of t_1 and $V_{NR}^F(S(t_1),\ K) = \chi$, the owner's expected NPV can be rewritten as a function of the initial stock S_0, the installed capacity K, and parameters: $V_1^F(S_0,\ K)$.[19] If $K \leq \bar{K}(S_0)$ the risk of expropriation is fully mitigated as of $t = 0$ and the expected NPV then corresponds to the no political risk benchmark presented above.

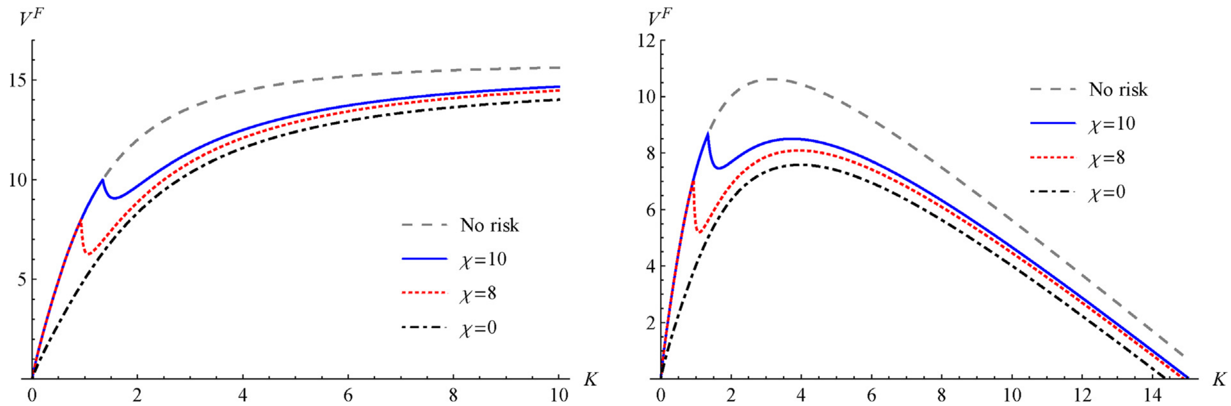
2 *K may* constrain the owner's extraction while the risk of expropriation is latent, but the NEC only holds if $S(t) \leq \bar{S}$: $K \geq \theta r\bar{S}$

In this second interval, K is high enough for the installed capacity is not necessarily relevant during the entire time at expropriation risk. In this case, K is too high to deter the challenger from expropriating before reaching $\bar{S}$; that is, the resource is expropriated unless $S(t) \leq \bar{S}$. Let us define t_2 as the instant at which, in the absence of a regime shift, the capacity constraint stops being binding for the owner, and $\bar{t} \geq t_2$ as the instant at which the safety threshold $\bar{S}$ is reached (recall Definition 2). Using these definitions, the owner's expected NPV can be written as:

$$V_2{}^F(S_0,\ K,\ t_2,\ \bar{t}) = \int_0^{t_2} \frac{K^{1-\frac{1}{\theta}}}{1-\frac{1}{\theta}} e^{-(r+\pi)\tau} d\tau + \int_{t_2}^{\bar{t}} \frac{\left(R(t_2) e^{-\theta(r+\pi)(\tau-t_2)}\right)^{1-\frac{1}{\theta}}}{1-\frac{1}{\theta}} e^{-(r+\pi)\tau} d\tau + e^{-(r+\pi)\bar{t}} V^F(\bar{S}) - c. \tag{14}$$

where the first term to the right represents the owner's expected NPV while the capacity constraint is binding ($t \leq t_2$) and the risk of expropriation is latent, the second term represents the NPV in the interval of time in which the capacity constraint is not binding but the risk of expropriation is still latent ($t \in \left(t_2,\ \bar{t}\right)$), and the last term is the owner's NPV once risk vanishes. Again the effective discount takes into account the probability that a regime shift has not occurred. Note that if $K \in (\theta r\bar{S},\ x^*\theta r\bar{S})$, then $t_2 = \bar{t}$ (i.e., the instant at which the constraint stops being binding for the owner, and the risk of expropriation vanishes is the same) and thus the right hand side expression then reduces to the first and third term. Using the definitions of t_2 and $\bar{t}$, and $V^F\left(\bar{S}\right) = \chi$, the owner's expected NPV can be expressed as a function of S_0, K, and parameters only: $V_2^F(S_0,\ K)$.[20]

[18] See Definition 4 in Online Appendix A.4.
[19] See Online Appendix A.4 for the derivation of this result.
[20] See Online Appendix A.5.



(a) $c(K) = 0$ (b) $c(K) = K$

Fig. 3. Expected NPV as a function of K for different χs.

This completes the picture of the owner's expected NPV of the resource for any K, given S_0. Concretely, if $S_0 < \bar{S}$, the owner's expected NPV of the flow of revenues from exploiting the resource is:

$$V^F(S_0, K) = \begin{cases} V_1^F(S_0, K) & \text{if } K \leq \theta r \bar{S} \\ V_2^F(S_0, K) & \text{otherwise} \end{cases}. \tag{15}$$

In case $S_0 \leq \bar{S}$, then $V^F(S_0, K)$ simply reduces to (10).

Lemma 1. *$V^F(S_0, K)$ is continuous in K, for any $K \geq 0$, and has a continuous first derivative in K for any $K > \bar{K}(S_0)$.*

Proof. See Online Appendix B.3. □

With the explicit formulation of $V^F(S_0, K)$ it is then possible to proceed to answer if the owner prefers to under-invest in K to keep the value of the resource low and deter the challenger from expropriating it; or, if on the contrary the owner over-invests in K to run down the stock as fast as possible to avoid expropriation.

3.2.3. The effect of the cost of expropriation (χ) on the owner's preferred level of K

Assuming $c(K) = 0$, in the absence of expropriation risk the owner's NPV is (10), with K^*_{NR} equal to any $K \geq \theta r S_0$. Under risk of expropriation the expected NPV is (15). Panel (a) of Fig. 3 depicts the owner's expected NPV of the resource given $S_0 > \bar{S}$ under different regimes of property rights protection (i.e., different values of χ), and costless installation of extraction capacity.[21] As expected, the owner's valuation of the resource is increasing in the strength of the property rights protection, χ. Furthermore, just as in the no-risk benchmark, when $c(K) = 0$ the owner strictly prefers to install enough capacity such that the constraint is never binding: $K = \theta\left((r + \pi)\left(S_0 - \bar{S}\right) + x^* r \bar{S}\right) > K^*_{NR}$.

When installing K is costly, $K = \theta\left((r + \pi)\left(S_0 - \bar{S}\right) + x^* r \bar{S}\right)$ is not necessarily the owner's preferred level of K. In this framework this occurs not only because of the direct effect of the installation cost, but also because K can play an active role in deterring expropriation. In fact, when $c(K) > 0$, the relationship between the owner's preferred K and χ is not necessarily monotonic, as shown in panel (b) of Fig. 3, where $c(K) = K$. The two extreme cases in terms of property rights strength, i.e., the "no risk" benchmark ($\pi = 0$) and exogenous expropriation risk ($\chi = 0$) are depicted by the upper-most curve and the lowest curve respectively. These two curves (i.e., no risk and exogenous risk) are hump-shaped, and have only one critical point, which in case of no risk is K^*_{NR}. Yet, the owner's preferred K does not follow a monotonic pattern between the two extremes.

As shown in panel (b) of Fig. 3, under intermediate strength of property rights protection, there are two potential candidates for a maximum: one with high installed capacity located at the top of the "hump"; and one with low installed capacity at the top of the fin-shaped kink. The "hump" is the consequence of $c(K) > 0$ and it is located at the point where the expected marginal benefit equalizes the marginal cost of installing K. The "fin", is exactly located at $\bar{K}(S_0)$ and results from the discrete jump in the discount rate following a marginal increase in K above $\bar{K}(S_0)$. When $K \leq \bar{K}(S_0)$ the length of the interval at expropriation risk is zero, which is why the curves with imperfect protection and the "no risk" curve overlap for $K < \bar{K}(S_0)$. Increasing K just above $\bar{K}(S_0)$ has a direct positive effect on the owner's NPV because of the less restrictive

[21] Fig. 3 uses $S_0 = 20$, $r = \frac{1}{8}$, $\theta = 8$, and $\pi = \frac{1}{10}$ as fixed parameters. The "no risk" benchmark is obtained by setting $\pi = 0$.

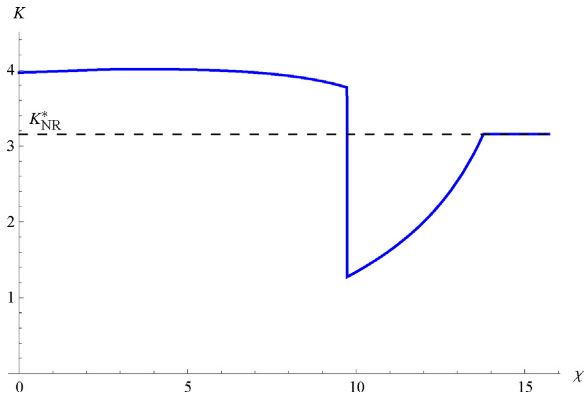


Fig. 4. Owner's preferred K for different χs $c\,K = K$.

capacity constraint. However, it exposes the resource to the risk expropriation: a marginal increase in K above $\bar{K}(S_0)$ leads to a discrete jump in the effective discount rate from r to $r+\pi$, which immediately reduces the expected NPV of future flows. Whenever this negative impact of marginally increasing K above $\bar{K}(S_0)$, running through the higher discount rate, dominates over the direct positive effect of a less demanding capacity constraint, the NPV will exhibit this fin-shaped kink, and thus there will be two candidates for a maximum.

Fig. 4 depicts the owner's preferred level of installed capacity as a function of χ. From it one can observe how χ affects the owner's choice of K through different channels.[22] The horizontal line corresponds to the owner's preferred K in the absence of political risk, K^*_{NR} (i.e., the social optimum level of K). The figure indicates that when the protection of property rights is relatively weak (i.e., when χ is relatively low), the owner prefers to over-invest in extraction capacity: install K above the social optimum K^*_{NR}. However, if the level of protection is sufficiently high, yet imperfect, the owner opts for using a limited extraction capacity to fully protect the resource against expropriation; that is, the owner's expected NPV is maximized at the "fin": $K = \bar{K}(S_0)$. Thus, when the protection of property rights is relatively strong, and if $\bar{K}(S_0) < K^*_{NR}$, the owner under-invests in extraction capacity. The reason for the shift in the preferred level of K from the "hump" to the "fin" can be explained by the relative cost of following each of these investment strategies. A low χ makes the under-investment strategy too costly to pursue. Achieving full protection under a low χ requires a very restrictive extraction capacity (i.e., $\bar{K}(S_0)$ is low): averting expropriation requires operating the well at a low capacity for a long period of time. On the contrary, when χ is high, under-investing is not that costly: $\bar{K}(S_0)$ is relatively high which means that fully protecting the resource is less costly in terms of a constrained extraction.

Furthermore, when the owner opts for under-investing in K, and as long as $\bar{K}(S_0) \le K^*_{NR}$, the preferred level of K increases towards the socially optimal level K^*_{NR} as the strength of property rights increases (i.e., $\bar{K}(S_0)$ is increasing in χ). When $\bar{K}(S_0) > K^*_{NR}$ the owner's preferred level of K is not distorted by the risk of expropriation, and therefore the level owner's preferred K becomes independent of χ; graphically this corresponds to the flat segment observed for high levels of χ in Fig. 4. However, when the owner opts for over-investing, the relationship between χ and the owner's preferred K is potentially non-monotonic. Given $\bar{K}(S_0) \le K^*_{NR}$, when the K maximizing V^F is located at the "hump", the owner's preferred strategy entails exposition to the risk of expropriation. Consequently, χ has two opposing effects on the incentives to install K. On the one hand, as shown in Section 2 the owner's preferred depletion increases with χ, and so a higher χ increases the marginal benefits from installing capacity. On the other hand, a higher χ also reduces the time at risk, and so it reduces the length of time for which it actually pays off to have an expanded capacity; the latter translates into a lower marginal benefit from increasing K. When the former (latter) dominates stronger property rights translate into a higher (lower) K.

Note that a necessary condition for under-extraction to occur is that the negative (effective discount) effect of increasing K just above $\bar{K}(S_0)$ dominates over the positive (higher capacity) effect, i.e., that the "fin" exists. This is the case for a universe of the (non-institutional) parameters θ, r, and S_0 (see Fig. 8 in Online Appendix C). However, the numerical results also suggest that the "fin" becomes less pronounced and even disappears as S_0 gets close $\bar{S}$, and as r increases (given π). Regarding the former, when S_0 is close to $\bar{S}$, the "longest" time at risk is by construction short, and thus the negative effect of increasing K just above $\bar{K}(S_0)$ (i.e., the higher discount during the time at risk) will be small in magnitude. As to the latter, when r is large relative to π, the discrete increase in the effective discount rate caused by marginally increasing K above $\bar{K}(S_0)$ becomes relatively less important because the discount rate is in any case high, and thus the negative impact of increasing the capacity just above $\bar{K}$ becomes dominated by the positive effect of relaxing the extraction capacity constraint.

[22] Note that for the set of parameters used here the risk of expropriation becomes irrelevant under relatively weaker property rights that in the case without capacity constraints. That is, with capacity constraints it is possible to obtain the socially optimal level of K (and extraction) even if $\chi < V(S_0) \approx 15.7$.

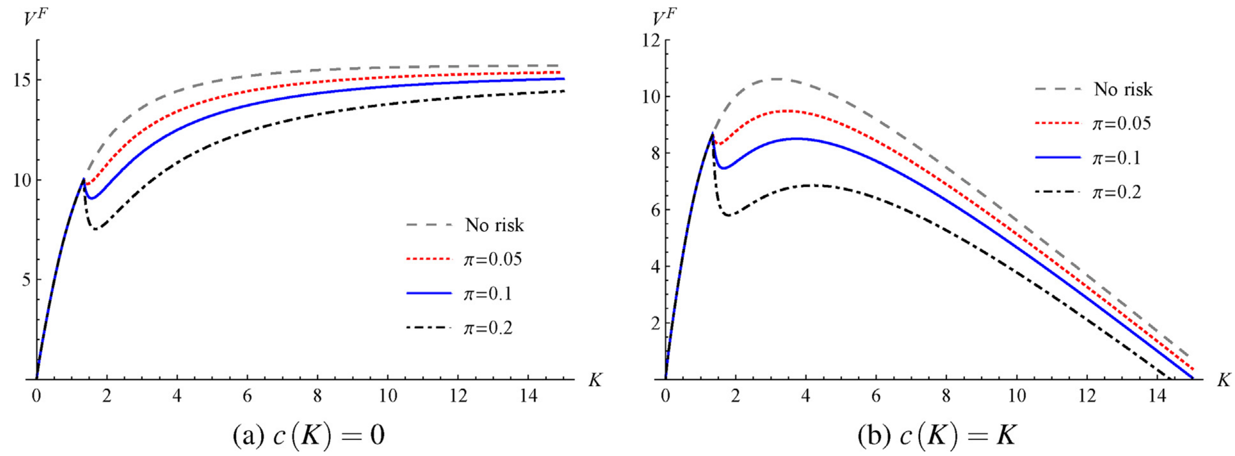


Fig. 5. Expected NPV as a function of K for different πs.

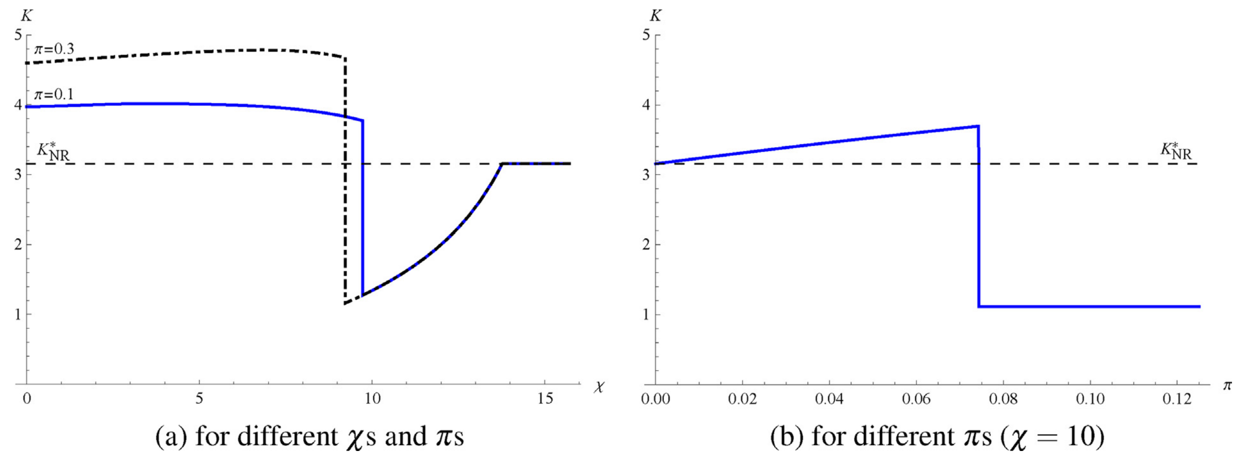


Fig. 6. Owner's preferred K c K = K .

3.2.4. The effect of a political regime shift (π) on the owner's preferred level of K

Regarding the second dimension of the expropriation risk, the risk of a political regime shift, Fig. 5 presents the owner's expected NPV as a function of K under different hazards of a regime shift.[23] In polities where shifts are more likely to occur (i.e., with a higher π) the valuation of the resource at risk is lower, for given values of S and K, because of the higher effective discount. Regarding whether the owner opts for under-extraction (i.e., full mitigation of the expropriation risk), one needs to note that the higher π the stronger the negative (effective discount) effect of increasing K just above $\bar{K}(S_0)$ (the discrete jump in the effective discount is larger). This is depicted in panel (b) of Fig. 5 where for high levels of π the owner's preferred K is more likely to be located at the "fin". Thus, higher uncertainty about the political environment results in a higher likelihood of the resource being initially under-exploited rather than over-exploited. Interestingly, the mechanism through which under-investment arises in this framework, and its exacerbation in a riskier environment, is not a typical hold-up of investment in risky environments (e.g. Bohn and Deacon, 2000). Instead, it follows from the strategic use of under-investment in extraction capacity as an alternative to fully mitigate the risk expropriation.

Overall, when it comes to installed capacity both over-investment and under-investment are possible outcomes, and which one dominates depends both on the strength of property rights χ and the risk of a political regime shift π. Panel (a) of Fig. 6 depicts the owner's preferred level of K for different combinations of the parameters describing the institutional environment: χ and π. As long as the risk of a shift is sufficiently high, under-investment is the owner's preferred strategy when the cost of expropriation is high, and over-investment when it is low. As mentioned above, this is the case because at high levels of χ, fully protecting the resource by under-investing is not too costly (i.e., $\bar{K}(S_0)$ is relatively high). Panel (b) of Fig. 6 also shows that whenever there is over-investment, the preferred level of K is increasing in π. After all, the reason for over-investing in K is to avoid losing the resource to the challenger by running it down fast enough; if a regime

[23] Fig. 5 uses $S_0 = 20$, $r = \frac{1}{8}$, $\theta = 8$, and $\chi = 10$ as fixed parameters.

shift becomes more likely, then the motive behind over-investment is reinforced. For intermediate levels of χ, however, the risk of a political regime shift, π, is crucial to determine whether the owner under or over-invests. Specifically, under a higher risk of a regime shift, the range of χ over which under-investment arises is wider: the minimum χ under which under-investment is chosen is decreasing in π. When the environment is too risky in terms of a potential regime shift, full protection of the resource becomes more desirable, and so the case for under-investing is strengthened.

Finally, note that if $c' > 0$, the social value of the resource (i.e., the value in the absence of expropriation risk: $V_{NR}(S_0, K) - c(K)$) is strictly concave in K. Therefore, if the owner over-invests in K (i.e., $K > K^*_{NR}$), further increasing K necessarily results in a reduction of the social value of the resource: $\frac{\partial V_{NR}(S_0, K)}{\partial K} - c' < 0$ for $K > K^*_{NR}$. In other words, when there is over-investment in extraction capacity, an improvement in the protection of property rights can reduce the social value of the resource by inducing further investment in installed capacity. On the contrary, an increase in χ is beneficial from the social perspective whenever the owner opts for an under-investment strategy.

4. Discussion

The theory developed here focuses on the roles of the cost of expropriation and political uncertainty in the relationship between the legitimate owner of the resource and the potential expropriator. Nevertheless, other elements like the expropriator's impatience due to an uncertain tenure, may play a role in the expropriation decision. This section discusses how, using the setup developed above, the model can be extended to incorporate multiple regime shifts and intermediate expropriation (taxation).

4.1. Multiple political regime shifts

One of the assumptions of the model is that there is at most one political regime shift. This assumption entails that C's expected tenure is of infinite length. Instead, one can assume that there are multiple political regime shifts; that is, once C is in power there is a risk π that a new challenger, C_2, takes power; C_2 faces the same risk of being replaced by a yet new challenger, C_3, and the uncertainty of the office holder continues *ad infinitum*. Assume that each incoming challenger is a replica of C: i.e., once C_m becomes the incumbent she has to decide whether to expropriate at a cost χ, or not to expropriate. Again, F is the original holder of the resource's property rights, which upon expropriation will pass to the expropriating incumbent, who then may lose these rights in the next political regime shift. Note that the assumption is still that expropriations are permanent; that is, once an agent loses the resource she loses it permanently. From the perspective of F the problem remains unchanged, she will lose the resource unless the remaining stock or the installed capacity are sufficiently low. The problem of C however, is slightly different. While it is the case that C only confiscates the resource if the expected NPV from exploiting it is higher than χ, C will not be free of expropriation risk unless the stock of the resource or the installed capacity are sufficiently low. This generates two fundamental changes. First, upon confiscating the resource from F, C behaves as F in the original model; this is so because C faces the risk of expropriation herself, and the risk can only be mitigated if the remaining stock is below certain level or if the installed capacity is too low. Second, being at risk of expropriation increases C's effective discount and unambiguously reduces C's valuation of the resource given S and K. This is in the end beneficial for the original owner F: a lower valuation by C makes expropriation easier to mitigate. Therefore, multiple regime shifts as described here entail higher $\bar{S}$ and $\bar{K}(S_0)$. Furthermore, upon expropriation extraction is not immediately in line with the social optimum as the threat of further expropriations remains latent.

4.2. Intermediate expropriation (taxation)

The model considers the expropriation decision as a dichotomous one: take all (e.g., nationalize) or nothing. Suppose instead that, upon coming to power, C has a third intermediate option: set a tax rate $\tau < 1$ on extraction, at a cost of $\kappa\chi$, with $\kappa \in (0, 1)$ reflecting the cost of partially infringing F's property rights.[24] One can think of this as a situation in which the business-friendly government (E) and the firm (F) agreed on a permanent tax (royalty) rate (which for simplicity, but without loss of generality, in this analysis it has been assumed to be 0). Then, the incoming business-hostile office holder (C) may decide to maintain the 0 tax rate, raise it to an intermediate level (i.e., partially expropriate), or fully expropriate the resource.

The question is, given S and K, which of the three alternatives would C opt for. To determine C's preferred option, two more critical levels of S (besides $\bar{S}$) need to be defined. The first one, $\bar{S}_1$, is the level of S such that C strictly prefers full expropriation over taxation (taxation over full expropriation) if $S > \bar{S}_1$ ($S < \bar{S}_1$). The second critical level, $\bar{S}_\tau$, is such that C strictly prefers taxation over upholding F's property rights (prefers to uphold C's over the taxation option) if $S > \bar{S}_\tau$ ($S < \bar{S}_\tau$).[25]

[24] Note that the assumption here is that τ is given and constant. The study of a dynamic (endogenous) tax rate, albeit interesting, goes beyond the scope of this discussion.

[25] Similarly, in the presence of endogenous capacity constraints, one can define three critical levels for K given S_0: $\bar{K}$, $\bar{K}_1$, and $\bar{K}_\tau$.

One can easily show that if $\kappa > \tau$ then $\bar{S}_1 < \bar{S} < \bar{S}_\tau$.[26] If this is the case then C's decision making remains unchanged with respect to the dichotomous choice model, in which partial expropriation is not possible. That is, from C's point of view the taxation alternative is strictly dominated by either full expropriation or by leaving the resource untouched and therefore partial expropriation does not arise in equilibrium, irrespective of the remaining level of S. In this case the only relevant critical value is $\bar{S}$. Instead, if $\kappa < \tau$ then $\bar{S}_\tau < \bar{S} < \bar{S}_1$. Therefore, in case of a political regime shift, and in the absence of capacity constraints, the resource is fully expropriated if the remaining stock is large ($S > \bar{S}_1$), it is taxed if the remaining stock is at an intermediate level ($S \in \left(\bar{S}_\tau, \bar{S}_1\right)$), and is left under F's control if the stock is small ($S \leq \bar{S}_\tau$). The owner then internalizes that by running the stock down to $\bar{S}_1$ (or installing $\bar{K}_1 > \bar{K}$) mitigates the risk of full expropriation, but the risk of partial expropriation remains latent; the latter is only fully mitigated once S is below $\bar{S}_\tau$ (or if the installed extraction capacity is at most $\bar{K}_\tau$, with $\bar{K}_\tau < \bar{K}$).

Nevertheless, the fundamental mechanisms distorting F's dynamic management of the resource remain at play. That is, the possibility of endogenously mitigating the risk of full (and partial) expropriation by running down the stock or by limiting the extraction capacity, distorts the owner's management of the resource. However, the presence of an intermediate possibility for C, will weaken F's incentives to over-extract. In the model developed above, the reward for crossing the safety threshold $\bar{S}$ is to *fully mitigate* the risk of *full* expropriation. In the alternative discussed here, the reward from crossing the $\bar{S}_1$ threshold is to *exchange* the risk of *full* expropriation for a risk of *partial* expropriation; while, crossing the $\bar{S}_\tau$ threshold *fully mitigates* the risk of *partial* expropriation. Whether, from the owner's perspective, a challenger with three alternatives is preferable than one with two depends on the values of κ and τ, and S_0. With $\kappa < \tau$, the possibility of taxation by C is good for the owner when the remaining stock is in $\left(\bar{S}, \bar{S}_1\right)$, but it is detrimental if $S \in \left(\bar{S}_\tau, \bar{S}\right)$.

5. Concluding remarks

Motivated by the long history of expropriations in the oil and gas sector, this paper explores how an endogenous risk of expropriation affects the management of a non-renewable resource. The endogeneity of the expropriation risk arises from a natural mechanism: the decision to expropriate is explicitly modeled as a cost-benefit analysis.

The main results of the theory presented here rest on the response of the resource owner to the endogenous risk of expropriation. Intuitively, the owner uses the tools at hand (i.e., extraction and investment in extraction capacity) to discourage the expropriator from seizing the remaining stock of the resource. In the absence of capacity constraints, the endogenous risk of expropriation leads the owner to engage in over-extraction. Interestingly, as long as the threat of expropriation remains latent, in the short-run the depletion rate is increasing in the strength of property rights. This occurs because in a more favorable institutional framework, the owner perceives a larger expected reward from protecting the resource by accelerating extraction. For the same reason, while the risk of expropriation is still latent, the depletion rate increases as the resource gets depleted. Furthermore, the mitigable risk of expropriation not only causes that the owner extracts the resource faster than under perfectly protected property rights, but also faster than with an exogenous risk of expropriation.

In the presence of capacity constraints, the owner can use the installed capacity as an additional tool to protect the resource against expropriation. That is, the owner can reduce the value of the resource, and thus the incentives to expropriate it, either by depleting the resource or by investing little in extraction capacity. When capacity constraints are taken into consideration both under- and over-extraction are possible in equilibrium. If property rights are relatively strong, the owner prefers to under-invest in extraction capacity. By doing so, she reduces the net present value of the resource to such a low level that the expropriator does not find it profitable to execute the expropriation. Instead, if property rights are relatively weak, there is over-extraction. Furthermore, when the owner over-invests in extraction capacity, a marginal improvement in the strength of property rights may actually reduce the social value of the resource.

These results add to the existing literature by providing a systematic analysis of the risk of expropriation on the dynamic management of non-renewable resources, for a continuum of property rights regimes. The rich set of dynamic implications regarding the effect of different property rights regimes on the resource management decisions, serve as motivation to explicitly include political economy elements in the models of expropriation risk. In this regard, the crossroads between resource economics and political economy branches of the economic literature appears as a natural starting point to analyze resource management problems in the context of imperfectly protected property rights.

Finally, the theoretical results derived in this paper suggest potential avenues for future empirical research on the impact of imperfectly protected property rights on the speed of depletion of non-renewable resources. First, the framework presented here generates a set of implications on the marginal effect of an improvement in the protection of property rights for a continuum of property rights regimes. Second, the model is structured in such a way that the risk of expropriation has two dimensions: the cost of expropriation (endogenous, and mitigable) and the risk of a political regime shift (exogenous and non-mitigable). Therefore, the results from this analysis highlight the relevance of exploring how different characteristics of a polity (e.g., the constraints faced by the executive, or the stability of the political regime) can have different impacts on the risk of expropriation, as perceived by the owner, and ultimately on the management of non-renewable resources.

[26] Remember that $V^C\left(\bar{S}\right) \equiv \chi$, and note that $V^C\left(\bar{S}_1\right) \equiv (1-\kappa)(1-\tau)^{-1}\chi$, and $V^C\left(\bar{S}_\tau\right) \equiv \kappa(\tau)^{-1}\chi$.

Appendix Supplementary material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.1016/j.reseneeco.2017.11.002.

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