Abstract

This paper studies the cycles of nationalization and privatization in resource-rich economies. It first discusses the available evidence on the drivers and consequences of privatization and nationalization, summarizing it into five stylized facts. The paper then develops a static and dynamic model of the choice between private and national regimes for the ownership of natural resources. In the model, this choice is driven by a basic equality-efficiency tradeoff: national ownership results in more redistribution of income and more equality but undermines incentives for effort. The resolution of the tradeoff depends on external and domestic conditions that affect the value of social welfare under each regime. This allows us to characterize how external variables—such as the commodity price—and domestic ones—such as the tax system—affect the choice of private vs. national regimes. The analysis therefore identifies the determinants of the observed cycles of privatization and nationalization and is consistent with the key stylized facts derived from the available literature.
1 Introduction

Why is the process of institutional innovation so volatile and often subject to reversion, particularly in developing countries? While the process of technological innovation generally follows a pattern of continuous progress, the process of institutional reform takes a more complex, cyclical pattern, especially in developing countries. Institutional reform tends to occur in times of crises but often, as social or economic conditions change, these reforms are reversed (Sturzenegger and Tommasi, 1998).

One of the most salient institutional reforms in the post-communist era has been the privatization of commercial enterprises all around the world (Chong and Lopez de Silanes, 2005). Lately, however, the benefits of privatization have been called into question, and many countries have moved to re-nationalize some of these enterprises (Manzano and Monaldi, 2008). In no area has this been more prevalent than in the exploitation of commodities in resource-rich economies (Kobrin, 1984; Rigobon, 2010). Looking back at the historical experience, it is evident that many of these economies have moved back and forth between private and national regimes (Chua, 1995; Minor 1994). Their behavior is a prime example of the instability of institutions, defined as the set of rules and norms under which the economy functions. Compared to these regime shifts, other issues surrounding the exploitation and administration of natural resources seem to be of secondary importance.

This paper studies the cycles of nationalization and privatization in resource-rich economies. These cycles occur mainly in countries with incipient institutional development and poor governance and, in turn, generate further institutional instability. The paper starts by presenting available evidence on the drivers and consequences of privatization and nationalization, obtained from both cross-country econometric studies and in-depth regional and country case studies. Five stylized facts emerge from this evidence. First, nationalizations and privatizations of

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1In the working paper version of the paper (Chang, Hevia, and Loayza, 2010) we present an analytical narrative of three illustrative case studies of repeated nationalization and privatization of a natural-resource industry (Bolivia and hydrocarbons, Venezuela and oil, and Zambia and copper). We focus on the periods before and after privatization and nationalization of the natural resource, with the objective of relating regime shifts to the behavior of the price of the commodity, its level of production and capital investment, the taxes and
tions are cyclical phenomena, which often come in waves common to several countries. Second, privatization - nationalization cycles tend to occur more often in the natural resources and utilities sectors. Third, nationalization of natural resource industries tends to happen when the price of the corresponding commodity is high. Fourth, contracts for the exploitation of natural resources between governments and private companies are such that commodity price windfalls are mostly appropriated by private firms. And, fifth, nationalization is more likely when inequality is endemic or worsens in the country.

These stylized facts motivate and provide a context for the main contribution of the paper, a dynamic model of the choice between private and national regimes for the exploitation of natural resources. The model is built around a basic tradeoff between equality and efficiency. Greater equality is obtained under public ownership of a natural resource, while more efficiency obtains when the ownership and administration of the resource are in private hands. The connection between ownership and the equality-efficiency tradeoff is given by the set of incentives for effort that each regime provides to economic agents. In the private regime, there is a differential compensation scheme that depends on observed productivity, thus encouraging agents to increase their efforts. Under the national regime, the government cannot credibly commit not to equalize income ex-post thus engendering equality but also minimal individual effort.

The resolution of the tradeoff depends on external and domestic conditions that affect national welfare under each regime. Hence our framework allow us to study how external variables –such as the price of the commodity in question– and domestic ones –such as the tax regime and government quality– affect the choice of private or national regimes. As external and domestic conditions fluctuate, cycles of privatization and nationalization emerge.

We argue that the theory is consistent with the stylized facts highlighted in our empirical review. Realistically, the model implies that privatization results in an increase of efficiency at other fiscal revenues derived from its exploitation, and the average income and degree of inequality of society at large.

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2 In the model, work effort is a proxy for all activities that are affected by economic incentives and that may have an impact on productivity. From a long run perspective, therefore, it does not only represent labor but also investment in human and physical capital, as well as managerial and entrepreneurial endeavors.

3 This assumption is similar in spirit to that of Perotti (1995), but our model and analysis are quite different.
the expense of consumption inequality. It also implies that privatization occurs when resource prices fall, while increases in resource prices eventually lead to nationalization. In addition, the model identifies several factors and parameters that determine the choice of nationalization vis-à-vis privatization. Increased risk aversion, for example, makes inequality more costly, and hence favors nationalization. This is reflected in the model in a decrease in the threshold price at which the country is better off by switching from a privatized regime to state ownership and, in the dynamic version of the model, an increase in the average duration of state ownership regimes. Similarly, in the dynamic model, an increase in the exogenous costs of nationalizing industries reduces not only the likelihood of nationalization but also makes it less likely that a nationalized sector be privatized. This is because privatization is not forever, and hence its value depends on the option to re-nationalize the industry, which falls with the aforementioned exogenous costs.

Our model stresses that observed cycles of privatization and nationalization may ultimately reflect the inability of a government to commit to a given policy, here restraining itself from redistributing income to home agents ex-post, when the domestic resource is under state ownership. This distortion generates realistic and complex strategic issues which are identified in our analysis. Under state ownership, home agents understand that the government will ultimately wipe away any relative gains from individual effort, which is unobservable, and hence they adjust effort accordingly. The outcome is inefficiently low effort under state ownership. Privatization can be seen as a partial solution in which the resource is sold to outsiders or foreign investors, who are profit oriented, do not care about redistribution, and hence are able to provide better incentives for effort. So private ownership enhances efficiency and, in fact, serves as a commitment device for the government. However, such a device comes at a cost, as the private regime results in more unequal consumption, relative to the state regime, for home agents. The cost also includes the profits appropriated by the investors if, as we assume, the welfare of the investors is not part of national welfare. The decision to privatize then depends on the relative merits of these benefits and costs, which in turn depend on the world price of
the resource. It is worth noting, finally, that the net benefits of privatization are themselves partly determined by the expectations of prospective buyers about future government actions. This is because, at the time of a privatization, prospective buyers correctly realize that the government may decide to re-nationalize the resource if its price increases sufficiently. This reduces the amount that the country can raise when the resource is privatized.

The model hence illustrates how political tensions about increased inequality and several associated conflicts emerge naturally as a by-product of the solution of the equity-efficiency problem. In contrast, our discussion assigns no direct role to other political characteristics, such as ideological preferences or historical colonization origins, which are sometimes stressed in the literature. This is not to suggest that these other political factors are unimportant but, rather, to emphasize the forces behind our theory which, we believe, are novel and can take us quite far.

The main policy implication of our theory is that breaking the cycles of privatization and nationalization requires addressing the causes of the key efficiency-equity trade off emphasized by our model. In particular, our analysis clarifies a sense in which “institutional reform” can end the cycles: reformed institutions can be effective in this regard if and only if they enhance the state’s ability not to renege on previous promises.

This paper is closely linked to the large literature on the “natural resource curse.” Following the seminal work by Sachs and Warner (1995), a vast array of papers has studied whether natural resource abundance contributes to slow economic growth and poor human development. The evidence provides a nuanced conclusion. Natural resource abundance can have a negative development impact if it is associated with irresponsible macroeconomic policies or poor governance. Manzano and Rigobon (2003) claim that natural resources have not had a direct impact on economic growth, rather, their negative effect has been the result of excessive indebtedness during high commodity prices followed by an inability to repay when commodity prices drop – a typical debt-overhang problem resulting from negligent macroeconomic policies (see also Atkinson and Hamilton, 2003). Bulte, Damania, and Deacon (2005) find that, while there is
some evidence of a direct impact of natural resources on human development, most of the negative effect works through a weakening of government institutions generated by natural resource abundance. To be precise, not all natural resources may lead to poor governance. According to Auty (2001a, 2001b) and Bulte, Damania, and Deacon (2005), it is "point" or concentrated resources such as oil fields and mineral mines which may lead to corruption and instability ("diffuse" resources such as those related to agriculture do not seem to have a similar effect). Our paper can be seen as one explanation for the mechanism through which concentrated natural resources are linked to regime instability and uneven production outcomes. Moreover, our work can show how these negative links are in turn exacerbated by financial imperfections and government weakness.

The rest of the paper proceeds as follows. Section 2 provides a review of the existing literature and describes the main facts surrounding the occurrence of privatization and nationalization. Sections 3 and 4 develop a model on the choice between private and national regimes. Section 3 discusses the static model, taking the regime choice as given. Section 4 introduces a dynamic version, where the possibility of regime choice and shifts arises. By calibrating and simulating the model, we explore and discuss the characteristics under which each of the regimes is more likely to be prevalent and the conditions that lead to more frequent regime changes. Finally, section 5 concludes, and the appendix provides the proofs of the main propositions in the body of the paper and a description of algorithms used to compute the equilibrium of the model.

2 Stylized Facts

We now present five key facts that motivate and guide our theoretical examination. These stylized facts are derived from both cross-country econometric studies and in-depth regional and country case studies. They are primarily focused on developing countries, where the cycles of nationalization and privatization have been most prevalent.
Fact 1: Nationalizations and privatizations are repeated, cyclical phenomena, which often come in waves common to several countries. Kobrin (1984) analyzed expropriations in 79 developing countries over the period 1960-79. He found that expropriations grew in the 1960s, peaked in the early 1970s and declined afterwards. Minor (1994) and Shafik (1996) extended Kobrin’s study to include the period up to 1993. They found that in the late 1980s and early 1990s, as many as 95 countries around the world experienced extensive privatization processes. Most recently, however, Manzano and Monaldi (2008) report the opposite trend in the last few years, albeit in a smaller group of countries, mostly in Latin America. For them, the current wave of nationalization is only the latest chapter of a repeating cycle, as they had previously experienced the nationalizations of the 1970s and the privatizations of the 1990s.

Chua (1995) is arguably the most comprehensive historical study of the privatization - nationalization cycle, with focus on Latin America and Southeast Asia. She found that, in spite of the differences between these two regions, there is an observable tendency of cycling back and forth between nationalization and privatization in both regions. In Latin America (most prominently, Argentina, Brazil, Chile, Mexico, Peru, and Venezuela), a first wave of privatization extended from the 1870s to the 1920s. Partly as reaction to the Great Depression, nationalizations became quite frequent and extensive in the 1930s. After World War II, a second tide of privatization occurred, only to be reversed under the populist regimes of the 1960s and 1970s. Two decades later, in the early 1990s, the pendulum fluctuated back to privatization, which, as mentioned above, occurred in a massive scale. In Southeast Asia (particularly, Malaysia, Pakistan, and Thailand), the cycle started later given their more recent history of independence. Initially, most of the economy was privately run. This changed in the late 1960s and early 1970s, when extensive nationalizations occurred. Also coinciding with the Latin American cycle, in the late 1980s and early 1990s, many state-owned companies were privatized in Southeast Asia.

Fact 2: Privatization - nationalization cycles tend to occur more often in the natural resources and utilities sectors. Kobrin (1984) documents that in the last five decades expropriations
ations encompassing large portions of the economy do occur, but they are less frequent than selective expropriations and have been mostly concentrated in a dozen of countries. In her historical account, Chua (1995) finds that in the majority of countries under analysis, utility and natural resource companies are significantly more prone to undergo the nationalization and privatization recurring cycle. Her account of the ownership swings of oil exploitation companies in Latin America is particularly revealing.

There is a large diversity within natural resources, and only a specific set has been subject to privatization and nationalization cycles. Kobrin (1984), Chua (1995), and Duncan (2006) single out the mineral and fuel sectors. What makes them different and prone to nationalizations? It is a combination of their geographic location and production technology. Auty (2001a, 2001b) differentiates between “point” resources such as oil fields and mineral mines and “diffuse” resources such as land, water, and others related to agriculture. “Point” resources have a concentrated geographic location and involve large, fixed, and specialized capital investment. This makes them particularly vulnerable to political control and potentially abuse, including expropriation. In turn, the abundance of “point” or concentrated natural resources tends to shape the quality of government, in terms of its proclivity towards corruption, rent-seeking, and populism, as documented by Bulte, Damanian, and Deacon (2005), among others.

**Fact 3:** Nationalization of natural resource industries tends to occur when the price of the corresponding commodity is high. Duncan (2006) investigated the causes of expropriation in the minerals sectors of developing country exporters. In this study, expropriation is defined as any act by which a government gains a greater income share than it was entitled to under the original contract with the foreign investor. The sample analyzed consists of the eight largest developing country exporters for seven major minerals (bauxite, cooper, lead, nickel, silver, tin and zinc). Covering the period 1960-2002, Duncan used probit regressions to estimate the effects of price booms and political and economic crises on the probability of expropriation. The results indicated that price booms are significantly positively correlated with the instances of expropriation. The paper concluded that a high real price for minerals is a stronger predictor
for state expropriation risk than political or economic crises are.

In a related study, Guriev, Kolotilin, and Sonin (2009) examined the determinants of nationalization in the oil sector, using panel data for 161 countries for the period 1960-2002. They run logit pooled regressions of nationalization events on oil price shocks and the quality of government institutions, controlling for country fixed effects and per capita GDP, among other variables. The regression results showed that governments are more likely to practice expropriations when the oil price is high and when government institutions are weak (although the latter result is controversial, as we discuss below).

**Fact 4:** *Contracts for the exploitation of natural resources between governments and private companies are such that commodity price windfalls are mostly appropriated by private firms.* This may explain why nationalizations tend to occur during commodity price booms. Manzano and Monaldi (2008) analyzed the recent trend of nationalization in the Latin American oil sector, pointing out to issues in the taxation system and political economy of this sector. The oil industry is in general characterized by considerable rents and sunk costs. This makes the industry very attractive for government expropriation when oil prices rise and the tax system is inadequate, in the sense of being regressive and lacking consideration for price contingencies. Accordingly, the authors argue that the new wave of nationalizations is induced largely by the increase in the international oil price.  

Likewise, in his study on expropriation in the mineral sector in major exporting countries, Duncan (2006) argues that a combination of high commodity prices and low profit sharing from private firms to host governments gave them large incentives to expropriate.

**Fact 5:** *Nationalization is more likely when inequality is endemic or worsens in the country.*

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4Rigobon (2010) studied oil production and profit-sharing contracts between governments and private companies. The simulation analysis of his model was directed at comparing two kinds of tax mechanisms – royalties and income taxes. His results showed that royalties can generate more stable tax revenues and lower agency costs. However, they may create more distortions in the production plan (because the quantity produced is more susceptible to price fluctuations when royalties increase). More controversially, Rigobon argued that under royalties, the probability that firms may earn large profits is higher, thereby stimulating government’s incentive for expropriation. By contrast, with income taxes, the volatility of private profits is lower, thus possibly mitigating expropriation risk. However, the variance of the tax revenue stream is higher and the potential losses due to agency problems are larger under income taxes.
try, and especially when the rents from natural resource or utility companies are perceived as benefiting only a minority. Chua (1995) concluded that nationalization in Latin America and Southeast Asia was promoted against not only foreigners but also domestic residents who were perceived as unfairly privileged. The private ownership and management of utility and natural resource companies was deemed to have worsened the inequality already present in these societies. Accordingly, differences across ethnic lines were a key factor to induce the ownership shifts in Southeast Asia, while an anti-elitist movement played a significant role in Latin America. The social pressure stemming from inequality is heightened and realized in times of government changes. This may explain why Duncan (2006) finds that mineral expropriations were more likely during the wave of independence of developing countries and also why Guriev, Kolotilin, and Sonin (2009) find that oil nationalizations tended to occur when government leadership was replaced.

Finally, we should remark that the relationship between the likelihood of nationalization and government regime type is rather ambiguous. While Duncan (2006) finds that mineral expropriations are more likely during democratic governments, Guriev, Kolotilin, and Sonin (2009) find that oil nationalizations tend to happen when democracy and constraints on the executive are weak. Moreover, as pointed out above, Duncan finds no connection between mineral nationalizations and political crises (except independence). It would seem that the underlying pressures of wealth and income inequality, observed high commodity prices, and perceived unfairness in the distribution of natural resource profits can lead to nationalizations in both democracies and dictatorships and under both political stability and political disruption.

3 A Single Period

This section and the next develop a model of an industry that can operate under either a private ownership regime or a state ownership regime. The economy is infinitely lived, but in this section we confine attention to one typical period given the ownership regime, and focus on
the determination of the net benefits of each regime. This hinges on a crucial efficiency-equity tradeoff derived from a moral hazard problem, together with the inability of the government to commit not to redistribute income under state ownership.

More specifically, we assume that the productivity of workers depends on unobservable effort.\footnote{As mentioned in the introduction, work effort in the model represents, in general, economic activities that are influenced by remuneration incentives and that may, in turn, affect production and productivity. They include not only labor input but also human and physical capital investment, as well as managerial and entrepreneurial behavior. As in the case of work effort in the model, these activities are subject to moral hazard in the sense that their compensation is tied to observed productivity and not only exercised input.} Efficient contracts would then prescribe that more productive workers be paid more than less productive ones, in order to elicit the right amount of effort. While this is possible under private ownership, the government cannot refrain from equalizing the incomes of workers ex-post under state ownership. But this destroys incentives for effort. The result is that private ownership is associated with more efficiency but less equality than state ownership, which is consistent with the stylized facts stressed in the previous section. Importantly, the result of the equity-efficiency tradeoff depends on a number of parameters, such as the degree of risk aversion, as well as other exogenous data including the price of the country’s resource.

\section{3.1 Workers}

We consider an economy that produces a commodity via an increasing and concave production function $F = F(L)$, where $L$ is labor input. Because technology is strictly concave, there is an implicit fixed factor of production that can be interpreted as land or capital.

The commodity is sold in the world market in exchange for world currency, which is taken as numeraire. The commodity price, denoted by $p$, is exogenous to the economy under analysis.

The economy is populated by a continuum of ex-ante identical workers of measure $N > 0$. The labor supply of worker $i \in [0, N]$, denoted by $l_i$, is a random variable whose distribution depends on worker $i$’s effort, $a_i$. One can interpret $l_i$ as the worker’s productivity for the job, which may be uncertain but is enhanced, on average, by effort spent on education or training. Crucially, labor supply is observable by everyone but effort is private information of
the worker. Because exerting effort is costly, the asymmetry of information introduces moral hazard problems into the model.

Naturally, exerting more effort is beneficial for productivity. For simplicity, assume that $l_i$ can be either high ($l_i = l_H$) or low ($l_i = l_L < l_H$), and that the probability of high productivity is an increasing and concave function of effort: $\Pr(l_i = l_H | a) = \pi(a)$, where $\pi(a), \pi'(a) > 0$ and $\pi''(a) < 0$. Given effort, the realization of labor productivity is i.i.d. across workers. We follow the standard assumption of imposing a law of large numbers so that if all workers spend effort $a$, the actual proportion of workers with high productivity equals $\pi(a)$.

Consider the decision problem of an individual worker. Regardless of the industry regime, the worker faces a labor market characterized by a wage schedule $\{y_H, y_L\}$, where $y_H$ and $y_L$ are the payments to a worker with high labor productivity and low labor productivity, respectively. Total income of a worker with productivity $l_i$ is $y_i + T$, where $T$ is a lump-sum transfer.

Denote the utility of income by $u(c)$ and the cost of effort by $\phi(a)$. We assume $u' > 0 > u''$, $\phi(0) = \phi'(0) = 0$ and $\phi', \phi'' > 0$ for all $a > 0$. Then, given the wage schedule $\{y_H, y_L\}$, the worker chooses $a$ to maximize her expected utility

$$\max_{a \geq 0} \pi(a) u(y_H^* + T) + (1 - \pi(a)) u(y_L^* + T) - \phi(a)$$

(1)

The first order necessary condition is

$$\pi'(a) [u(y_H^* + T) - u(y_L^* + T)] - \phi'(a) = 0$$

(2)

This has an obvious interpretation. $\phi'(a)$ is the cost of increasing effort by an infinitesimal unit; the gain is that, with increased probability, $\pi'(a)$, the agent gets to consume $y_H^* + T$ instead of $y_L^* + T$. Then, under our assumptions, $a > 0$ if and only if $y_H^* > y_L^*$: the worker will exert effort only if a more productive worker is paid more. Moreover, condition (2) implies that effort

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6The condition $\phi(0) = 0$ is an innocuous normalization and $\phi'(0) = 0$ is used to guarantee that positive effort is chosen whenever $y_H^* > y_L^*$. 

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increases in the wage differential.\footnote{To see this, let $\Delta = y_H^* - y_L^*$, and rewrite (2) as $u(\Delta + y_L^* + T) - u(y_L^* + T) = \gamma(a)$, where $\gamma(a) = \phi'(a)/\pi'(a)$. Differentiating this expression with respect to $\Delta$, and noting that $\gamma'(a) > 0$, gives $da/d\Delta > 0$.}

The wage structure, taxes, and industry ownership regime are taken as given to individual workers, but are endogenous from the viewpoint of the economy as a whole. We now turn to their determination.

### 3.2 State Ownership

Consider a period in which the industry is under state ownership. We make two assumptions about this regime:

- The government maximizes an equally weighted sum of the utilities of domestic workers.
- Under state ownership, the government chooses a wage schedule and taxes \textit{after} effort has been spent and individual productivity is observed.

The last assumption is crucial. It can be justified on the basis of political pressures. Any wage contract offered in advance of the choice of effort is assumed to be non-credible, as the state would always be able to renegotiate the terms of the contract. Alternatively, one may assume that the state can impose taxes and transfers to effectively undo any prior contract.

Under these assumptions, risk sharing motives lead the government to choose a wage schedule that equalizes consumption across agents: $y_H = y_L$. This is because, at the time the government chooses the wage schedule, effort and individual productivity are already given. Hence the wage schedule no longer distorts effort choice, and the government chooses it to prevent consumption inequality.

But, of course, if agents predict that their compensation does not depend on productivity, they will exert the minimum amount of effort; namely, $a_S = 0$. Labor input then falls to its minimum value.
More formally, and assuming (without loss of generality) that $T = 0$, given any probability of high productivity, $\pi$, the planner chooses $y_H$ and $y_L$ to maximize the sum of workers’ utilities:

$$ N [\pi u(y_H) + (1 - \pi) u(y_L)] $$

subject to the feasibility constraint

$$ N [\pi y_H + (1 - \pi) y_L] = pF(N (\pi l_H + (1 - \pi) l_L)) $$

The term on the left side is the total wage cost: a number $\pi N$ of workers are productive and are paid $y_H$ each, while $(1 - \pi)N$ workers are less productive and receive $y_L$. The right side is the value of production, noting that total labor input is the sum of $N\pi l_H$ from productive workers and $N(1 - \pi)l_L$ from the less productive ones. Note that, in this problem, the planner takes $\pi$ as given, since $\pi$ is determined by the prior effort choices of workers.

The first order conditions with respect to $y_H$ and $y_L$ are

$$ \pi u'(y_H) = \lambda \pi; \quad (1 - \pi) u'(y_L) = \lambda (1 - \pi); $$

where $\lambda$ denotes the Lagrange multiplier on the resource constraint. The optimal allocation implies $u'(y_H) = u'(y_L)$. Hence, given the strict concavity of the utility function, $y_H = y_L$.

Return now to the worker’s problem. As discussed above, $y_H = y_L$ implies that effort is zero, $a = 0$. Hence, aggregate labor supply is $L_S = N [\pi(0)l_H + (1 - \pi(0))l_L]$, which is the smallest possible labor supply.

We see, then, that state ownership results in perfect equity but inefficiently low effort choice. This is because the government cannot refrain from equalizing workers’ consumption ex-post, which destroys any incentives for exerting effort.
For future reference, note that the welfare of the typical worker under state ownership is

$$U_S = U_S(p) = u(pF(L_S)/N).$$

which is a function of the commodity price $p$.

### 3.3 Private Ownership

In periods in which the industry operates under private ownership, the key difference is that private owners can commit to pay different amounts to workers according to their productivity. This implies that private ownership will result in more efficient effort choice. But this comes at the expense of equity. For concreteness, it is convenient to think of private owners as foreign investors, although we only require that the government’s welfare function ignores the utility of investors.

We assume an industry structure in which private owners compete for workers. There is a continuum of firms of measure 1. Each firm produces domestic goods via the production function $F(L)$, sells the goods at the price $p$, and pays two taxes, a dividend tax $0 \leq \tau < 1$ and a sales tax $0 \leq \theta < 1$. The receipts from these taxes are rebated lump-sum to the workers.$^8$

Each firm takes as given a wage schedule $\{y_H^*, y_L^*\}$ of what highly productive and less productive workers are paid in the market. Given those market prices, each firm offers its own wage schedule $\{y_H, y_L\}$ and chooses the number of workers $n$ and a suggested effort level $a$ to maximize expected profits

$$\{p(1-\theta)F(n[\pi(a)y_H + (1-\pi(a))y_L]) - n[\pi(a)y_H + (1-\pi(a))y_L]\} (1-\tau)$$

$^8$An alternative approach is to assume a unique firm. A disadvantage of this approach, however, is that the firm will have monopsonistic power on the labor input it hires. This monopsonistic power together with the optimal contract under imperfect information delivers the extreme result that workers with low productivity are paid zero. With our industry structure, all workers have an outside option in the labor market and, therefore, wages will not be zero for low productivity workers. Although we consider more reasonable the multiple firms approach, all qualitative results hold if we assume an industry structure with a unique firm.
subject to

\[ u(y_H + T) - u(y_L + T) - \gamma(a) = 0 \quad (3) \]

\[ \pi(a)u(y_H + T) + (1 - \pi(a))u(y_L + T) - \phi(a) \geq U^*. \]

where \( \gamma(a) = \phi'(a) / \pi'(a) \).

The first constraint is the incentive compatibility (IC) constraint and requires the wage schedule \( \{y_H, y_L\} \) and suggested effort \( a \) to be consistent with the worker’s optimal effort choice. The second constraint is the participation or individual rationality (IR) constraint and requires the proposed contract to provide a level of utility at least as large as \( U^* \), the utility that a worker can get in the market, given by

\[ U^* = \pi(a^*)u(y_{H}^* + T) + (1 - \pi(a^*))u(y_{L}^* + T) - \phi(a^*). \]

Let \( \eta(1 - \tau) \) and \( \lambda(1 - \tau) \) denote the Lagrange multipliers on the IC and IR constraints.

The first order condition with respect to \( n \) is

\[ p(1 - \theta)F'(n\ell(a))\ell(a) = \pi(a)y_H + (1 - \pi(a))y_L, \quad (4) \]

where \( \ell(a) = \pi(a)l_H + (1 - \pi(a))l_L \) is the expected labor supply given effort \( a \). The intuition is simple. Since each worker is expected to supply \( \ell(a) \) units of labor, the left hand side is the expected increase in revenue to the firm of hiring one more worker. The wage cost of doing so will be \( y_H \) if the worker turns out to be productive, that is, with probability \( \pi(a) \), and \( y_L \) if the worker has low productivity. Hence the right hand side is the expected wage payment to the additional worker.

\[ ^9 \text{Using the worker’s first order condition as a constraint on the principal’s problem does not guarantee the optimality of the contract. This ‘first order approach’ is valid if the distribution function of labor endowment conditional on effort satisfies a monotone likelihood ratio condition and a convexity assumption (Rogerson, 1985). These two conditions are satisfied in our environment.} \]
The first order condition with respect to $y_H$ can be written as

$$\frac{n}{u'(y_H + T)} = \lambda + \frac{\eta}{\pi(a)}$$  \hspace{1cm} (5)$$

and the first order condition with respect to $y_L$, as

$$\frac{n}{u'(y_L + T)} = \lambda - \frac{\eta}{1 - \pi(a)}. \hspace{1cm} (6)$$

To interpret these two conditions, suppose (counterfactually) that $\eta$ were zero, that is, that the incentive compatibility constraint did not bind. In that case, the two conditions would collapse to $u'(y_H + T) = u'(y_L + T)$, that is, $y_H = y_L$. This means that the firm would pay the same amount to workers regardless of their productivity. This would be the case not because the firm cares about equity, but because it would be the cheapest way to pay workers their outside option of $U^*$. It is apparent, then, that the need to provide incentives for effort creates a wedge between $y_H$ and $y_L$ which is costly to the firm. In the first order conditions above, that wedge is induced by a positive multiplier $\eta$, which reduces $u'(y_H + T)$ relative to $u'(y_L + T)$, and hence increases $y_H$ over $y_L$. (See Propositions 2 and its corollary below.)

Lastly, the first order condition with respect to effort, after using incentive compatibility, is

$$n\pi'(a) [p(1 - \theta)F'(n\ell(a)) (l_H - l_L) - (y_H - y_L)] = \eta \gamma'(a)$$  \hspace{1cm} (7)$$

The left hand side is the increase in expected profit of a marginal increase in $a$. The right hand side is the marginal cost of the incentive compatibility constraint: a small increase in $a$ implies that the difference between $u(y_H + T)$ and $u(y_L + T)$ must increase by $\gamma'(a)$. To obtain the associated cost, we multiply $\gamma'(a)$ by the shadow cost of the incentive constraint, $\eta$.

Some properties of the solution now emerge. First, the Karush-Kuhn-Tucker conditions imply that $\lambda \geq 0$. Intuitively, the marginal value on profits of increasing the reservation utility
U*, given by \(-\lambda\), cannot be positive. The next propositions characterize additional properties of the optimal contract.

**Proposition 1:** The IR constraint is binding.

**Proposition 2:** The IC constraint multiplier \(\eta > 0\).

Proofs of both Propositions are given in the Appendix.

**Corollary:** The optimal contract is monotone, that is, \(y_H > y_L\).

**Proof:** Rearranging (5) and (6), and using \(\eta > 0\) gives \(u'(y_H + T) < u'(y_L + T)\). The strict concavity of the utility function then implies \(y_H > y_L\).

We now consider the industry equilibrium. Because all firms are equal, in equilibrium \(n = N\) and \(\{y_H, y_L\} = \{y_H^*, y_L^*\}\). In addition, the government collects taxes and rebates them lump-sum to the workers. Thus, the government budget constraint is

\[
TN = \tau \{p(1 - \theta)F(N\ell(a)) - N[\pi(a)y_H^* + (1 - \pi(a))y_L^*]\} + \theta pF(N\ell(a))
\]

Collecting results, the system of six equations (3 - 8), with \(n = N\) and \(\{y_H, y_L\} = \{y_H^*, y_L^*\}\), determine the six \(\{y_H^*, y_L^*, a^*, T^*, \lambda, \eta\}\). The solution implies that the average worker has utility:

\[
U_P(p) = \pi(a^*)u(y_H^* + T^*) + (1 - \pi(a^*))u(y_L^* + T^*) - \phi(a^*)
\]

Note that, just like in the state ownership regime, \(U_P\) and the industry equilibrium under private ownership depend on the resource price \(p\), which affects the set of equations (3 - 8).

For future reference, we define the before-dividend-tax indirect return function of the firm, \(R(p) = p(1 - \theta)F(N\ell(a^*)) - N[\pi(a^*)y_H^* + (1 - \pi(a^*))y_L^*]\).
3.4 Efficiency and Welfare

Positive effort under private ownership (see proposition 2) implies that effective labor and production is greater than under state ownership. This also means that workers can have higher average consumption in a privatized regime. However, profits are partially appropriated by private owners and there is costly consumption inequality.

The constraint $\tau < 1$ is crucial to obtain a non-trivial tradeoff between the national and private regimes. In particular, if dividend taxes converge to 1 and sales taxes are set to zero, the government is able to attain the ex-ante constrained-efficient allocation under a private ownership regime—the allocation that a benevolent planner that is subject to the same information constraints as private firms would choose. In effect, the private regime acts as a commitment device which, together with the right taxes, implements the constrained-efficient allocation. This is summarized in the next proposition.

**Proposition 3:** A private-ownership regime with $\theta = 0$ and $\tau \to 1$ attains the ex-ante constrained-efficient allocation.

**Proof:** See Appendix.

For the rest of the paper we maintain the realistic assumption that dividend taxes are strictly below one. This is also the only sensible option, if only because in the full dynamic model no privatization would ever be possible if potential buyer know that they will pay a one hundred percent tax on their profits.

Under this assumption, there are two opposing forces at any price $p$. On the one hand, a state ownership regime induces perfect risk sharing across workers, but at the cost of low aggregate productivity. On the other hand, by providing incentives to exert effort, private firms are able to achieve higher labor productivity. This higher output together with the lump-sum transfers obtained from the taxation of sales and profits benefit not only high ability workers but also the low ability ones. However, because private owners appropriate a fraction of total profits—and the possible existence of distortionary sales taxes—the allocation under private ownership
regime is not constrained efficient creating a non trivial tradeoff between the private and state ownership regimes.

Our discussion thus identifies the key role of the assumption that the government cannot refrain from redistributing income \textit{ex-post} if able to. If the government could precommit not to do that, state ownership would clearly be preferred to private ownership, as the government would be able to elicit an efficient amount of effort without having to forgo the profits extracted by owners in a privatized regime. Then our analysis indicates that only state ownership would be observed, so we would have to search for a different explanation of the cycles we are concerned with.

The counterpart to the last observation is that privatization may be valuable to the country because it may serve as an imperfect commitment device. This would be reflected, in particular, by the fact that productivity is higher under private ownership than under state ownership. This is worth noting, because increased productivity has been often mentioned as an advantage of privatization, but for reasons that are quite different from ours. For instance, sometimes it is said that foreign owners would bring better know-how or organizational skills to privatized ventures. Such gains, however, are not only hard to document, but also unlikely to be significant in a world of fast dissemination of technology and knowledge. The assumption that a government may have a commitment problem, in contrast, is much easier to accept.

3.5 Numerical Explorations

Further insight on the properties of the model can be obtained by resorting to numerical methods. We view our numerical experiments as providing further insights into the working of the model and not as a realistic parametrization of any privatization - nationalization episode; our model is too stylized for that purpose. In any case, however, we will calibrate the model to obtain durations of privatization and nationalization regimes that resemble those observed in the hydrocarbon sector in Bolivia during the last decades.\footnote{In Chang, Hevia, and Loayza (2010) we present an analytical narrative of the case of Bolivia and hydrocarbons.}
detail when we describe the computation of the dynamic version of our model.

We make assumptions about functional forms and parameter values that generate predictions that are qualitatively consistent with the empirical regularities discussed in section 2. We then perturb these parameters and analyze how changes in the environment impact the equilibrium of the model.

We assume a utility of income of the constant absolute risk aversion form,

\[ u(c) = \frac{1 - e^{-\gamma c}}{\gamma}, \]

where \( \gamma > 0 \) is the coefficient of absolute risk aversion; a cost of effort function given by

\[ \phi(a) = \varphi a^2 / 2, \]

where \( \varphi > 0 \); a Cobb-Douglas production function,

\[ F(L) = AL^\alpha, \]

where \( A \) is the level of productivity and \( 0 < \alpha < 1 \); and a function transforming effort into probabilities of drawing high labor endowment given by

\[ Pr(l_i = l_H | a) = \pi(a) = 1 - \delta e^{-\nu a}, \]

where \( 0 < \delta < 1 \) measures the probability of low endowment when effort is zero and \( \nu > 0 \) measures the sensitivity of the probability to changes in effort.

In our baseline parameterization, the labor endowment of a worker that draws high productivity is \( l_H = 1 \), and that of a worker with low productivity is \( l_L = 0.1 \). That is, high labor endowment workers are ten times more productive that low labor endowment workers. The coefficient of absolute risk aversion is set at \( \gamma = 2.5 \), and the cost of effort parameter is \( \varphi = 1 \).
We assume that the probability of drawing low productivity if effort is zero is $\delta = 0.99$, and the sensitivity of this probability to changes in effort is $\nu = 2$. The level of technology is set at $A = 0.15$, total population is $N = 1$, and the exponent on labor in the production function is $\alpha = 0.66$. Finally, taxes are set at $\tau = 0.30$ and $\theta = 0.30$. Table 1 summarizes the baseline parametrization.

Given these assumptions, it is straightforward to solve for the outcome of the state ownership regime. The private ownership regime is a little more involved, as its solution is only given in implicit form by the system (3 - 8). The computation of equilibrium is described in the Appendix.

In all cases that we computed, we found two threshold prices $p_i << p^*$ that partition the set of prices $[0, \infty)$ so that, for all prices below $p_i$ and above $p^*$, welfare is larger under a state ownership regime, while for all prices between $p_i$ and $p^*$, welfare is larger in a private ownership regime. The threshold $p_i$, however, is always very close to zero (never greater than one) and disappears in the dynamic version of the model as soon as we introduce a cost of nationalizing the industry. For that reason, we focus only on the regions $(p_i, p^*)$ and $(p^*, \infty)$, which we refer to as the “low price” region and the “high price” region. Figure 1 displays a typical solution of the static model.

If $p$ is in the low price region, the private regime is worth more to the country than the national regime. The government would accept less risk sharing in exchange for the higher average labor productivity that prevails in a private ownership regime. On the other hand, if the commodity price is above $p^*$, the elimination of income inequality becomes more important, as more output is appropriated by private owners making concerns for efficiency less of an issue. In effect, higher commodity prices can be thought of as substituting for the low productivity in a state ownership regime. An implication is that pressures for national ownership are likely

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11At very low prices, those below $p_i$, private firms have few incentives to differentiate workers. In effect, as the price approaches zero, the optimal contract requires agents to exert zero effort. But if effort approaches zero, productivity under private ownership approaches productivity under state ownership. Therefore, state ownership becomes welfare superior for $p$ close to zero, as all production is distributed to the workers, while under private ownership firms take part of the profits.
to grow at large values of $p$, which is consistent with the facts described in section 2.

Table 2 reports exercises on comparative statics to analyze how the threshold $p^*$ changes as we change parameter values. The first row of the table reports the threshold price of the baseline parametrization. An inspection of the table reveals that all parameters have a monotonic relation with the privatization threshold $p^*$.\footnote{Table 2 does not report changes in $A$. The reason is that in the nationalization-privatization choice, only the product $Ap$ matters. Thus, an increase in $A$ immediately implies that $p^*$ declines.}

Consider first the impact of changes in the preference parameters $\gamma$ and $\varphi$. Table 2 shows that the threshold $p^*$ is *decreasing* in the risk aversion parameter $\gamma$. As workers become more risk averse, the welfare costs associated with the lack of risk sharing in a private ownership regime increase and, therefore, the set of prices for which a state ownership regime is superior than the private regime increases as well; that is, $p^*$ decreases. Likewise, $p^*$ is *decreasing* in the cost of effort parameter $\varphi$. Intuitively, as the cost of effort increases, firms need to increase the ‘punishment’ to workers with low labor endowment to induce them to exert effort. Hence, the lack of risk-sharing becomes more costly which reduces the nationalization threshold $p^*$.

Consider next the impact of changes in the probability of success parameters $\delta$ and $\nu$. The parameter $\delta$ measures the probability of drawing a low labor endowment when effort is zero. An increase in $\delta$ has two effects: first, it reduces the value of a state ownership regime because aggregate labor declines, and second, it increases the incentives to exert effort in a privatized regime because the probability of drawing high labor endowment when effort is low declines. Thus, firms are able to induce workers to exert the same amount of effort with a smaller dispersion in wages. Both effects imply that $p^*$ is *increasing* in $\delta$. Likewise, $p^*$ is *increasing* in the sensitivity parameter $\nu$. As $\nu$ increases, a marginal increase in effort induces a larger increase in the probability of success, which makes exerting effort more attractive to workers and, therefore, easier for firms to provide incentives. Thus, the benefits of a privatized regime increases with $\nu$.

We now consider the sensitivity of the threshold price $p^*$ to changes in the relative productivity of high and low productivity workers assuming that the average labor supply in a
state-owned regime—that is, when effort is zero—remains constant. Note that these changes do not affect welfare in a state-ownership regime but they do in a private ownership regime: an increase in the relative productivity of highly productive workers increases the efficiency gains of differentiating workers through a more unequal payment schedule. In other words, an increase in the spread of labor productivity makes a private ownership regime more efficient but also more unequal. Suppose now that high ability workers are five times more productive than low ability workers—that is, $l_H/l_L$ decreases from 10 to 5. The threshold price $p^*$ decreases from 40.1 to 27. In effect, firms in a privately owned regime have less incentives to differentiate workers—and, therefore, increase productivity relative to a state ownership regime—because the relative gain of doing so is now lower. Thus, $p^*$ declines.

The threshold price $p^*$ is increasing in the technology parameter $\alpha$. Intuitively, as $\alpha$ increases the technology becomes more ‘linear’ and, therefore, the degree of decreasing marginal product of labor decreases with $\alpha$. In other words, the benefits of inducing workers to exert effort increases with $\alpha$. Thus $p^*$ increases as well.

Finally, consider a change in the tax code, as summarized by changes in dividend and sales taxes. An increase in the dividend tax $\tau$ increases the lump-sum transfers to the workers in a private ownership regime. This increase in $T$ has two effects: first, more income is redistributed from the firms to the workers, and second, the differential in labor income between high and low ability workers becomes less important as their relative total income (including lump-sum transfers) becomes more equal. Thus, the welfare losses associated with consumption inequality in a private ownership regime decline, making private ownership more desirable, as reflected by a higher $p^*$.

Likewise, $p^*$ is increasing in the sales tax $\theta$. A change in the sales tax has a similar impact as an increase in $\tau$ in terms of the change in incentives through the increase in lump-sum transfers $T$. The change in $\theta$, however, has an additional impact on the firm’s behavior, since from a firm’s point of view, a higher $\theta$ is equivalent to a lower price $p$. Each firm must reduce wages ($y_H$ and $y_L$), which implies again that transfers are a higher share of

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13In contrast with a competitive industry, a change in $\tau$ does affect the decisions of firms because it modifies the incentive compatibility constraint of workers through a change in the lump-sum transfer $T$. 

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each workers’ income, reducing consumption inequality under private ownership.

4 The Dynamics of Privatization and Nationalization

4.1 Multiperiod Version of the Model

In this section we study the full dynamic version of the model. Time is discrete and denoted by $t = 0, 1, ..., \infty$. Workers are infinitely lived and discount future utilities with the discount factor $\beta$. Firms are also infinitely lived and discount future profits with the discount factor $1/(1 + r)$. To simplify the model, we assume that workers cannot borrow or save.

The price of the economy’s resource is now assumed to follow an exogenous Markov process, which is the only source of aggregate uncertainty. The timing of events is as follows. We say that the industry was privatized in period $t - 1$ if, at the end of that period, firms were privately owned. Otherwise, we say that the industry was in a state ownership regime. At the beginning of period $t$, the price $p_t$ is realized, and then the government decides whether to keep the regime the same or to switch to the other regime. After the privatization - nationalization decision is made, production and consumption take place.

As before, we assume that the government is benevolent in that it maximizes the welfare of the average worker. Here, though, the government’s regime choice is an intertemporal decision problem, in which the stochastic behavior of the price $p_t$ needs to be taken into consideration in relation with various costs and benefits.

Our results in the preceding section can now be regarded as the one-period equilibrium industry outcomes under either private ownership or state ownership. In particular, we showed how to compute the average worker’s payoffs under either regime, $U_P$ and $U_S$ respectively, and how those payoffs depend on the price $p_t$.

To complete the specification of the dynamic setting, we assume that changing regime entails a direct cost or benefit. To be precise, we assume that nationalizing the industry (switching from private ownership to state ownership) is associated with a one period loss of $c_S$ goods.
This cost is assumed to be exogenous and interpretable as the deadweight loss resulting from a political backlash or international sanctions following nationalization.

Likewise, privatizing the industry results in a temporary boost to government revenues due to the proceeds from selling state firms. We assume that the government makes a take-it or leave-it offer to a measure one of incumbent firms in exchange for the rights to operate in the industry. Competitive bidders drive the offer up to the firm’s value and, therefore, the government extracts all the rents. We assume that a fraction \(0 \leq \kappa \leq 1\) of these rents are transferred lump-sum to the current workers. The remaining fraction is a loss that can be interpreted as the cost of reorganizing the industry, selling the firms, corruption, and the like.

Under our assumptions, dynamic behavior is relatively easy to characterize in recursive form. Let \(V_P(p)\) denote the value for the government at the end of a period in which the price is \(p\) and the regime ends up being private ownership, and has been in private ownership for at least one period. Likewise, let \(V_P^0(p)\) denote the value for the government at the end of a period in which the industry is privatized (after having been state owned the previous period) and the price is \(p\). Similar definitions hold for \(V_S(p)\), the value in a state ownership regime, and \(V_S^0(p)\), the value in a period in which the industry is nationalized.

Then, the function \(V_P(p)\) satisfies the Bellman equation

\[
V_P(p) = U_P(p) + \beta \int \max \{V_P(p'), V_S^0(p')\} Q(p, dp')
\]  

(9)

where \(Q(p, B) = \Pr\{p_{t+1} \in B | p_t = p\}\) is the transition function governing the price process, and \(p'\) is next period’s price. The interpretation is straightforward: the value of a privatized regime is today’s payoff to the average worker, \(U_P(p)\), plus the discounted value of tomorrow’s option to continue in the privatized regime, \(V_P(p')\), or to nationalize the industry, \(V_S^0(p')\).

Similarly, the value in a state ownership regime \(V_S(p)\) satisfies

\[
V_S(p) = U_S(p) + \beta \int \max \{V_P^0(p'), V_S(p')\} Q(p, dp').
\]  

(10)
In periods of regime change, that is, when the industry is just privatized or just nationalized, the value functions are respectively given by

\[
V^0_P(p) = U^0_P(p) + \beta \int \max\{V^0_P(p'), V^0_S(p')\} Q(p, dp')
\]

(11)

\[
V^0_S(p) = U^0_S(p) + \beta \int \max\{V^0_P(p'), V^0_S(p')\} Q(p, dp'),
\]

(12)

where \(U^0_P(p)\) and \(U^0_S(p)\) denote the static payoffs in the privatization period and nationalization period respectively.

Because nationalization entails a cost \(c_S\), the payoff in a nationalization period is, simply,

\[
U^0_S(p) = u \left[ \frac{pF(L_S) - c_S}{N} \right]
\]

We now describe the payoff in a privatization period, \(U^0_P(p)\). To that end, let \(W^0(p)\) denote the value of a private firm in the privatization period, and let \(W(p)\) denote the value of the firm in subsequent periods. These functions are different because the additional lump-sum transfer at the privatization period modifies the incentives to exert effort.

The function \(W(p)\) satisfies the recursive equation

\[
W(p) = (1 - \tau)R(p) + \frac{1}{1 + \tau} \int_{\Omega} W(p')Q(dp', p),
\]

where \(\Omega = \{p' : V^0_P(p') \geq V^0_S(p')\}\) is the set of prices tomorrow for which the industry remains private, and \(R(p)\) is the firm’s before-dividend-tax profit function. In computing the present discounted value of the firm tomorrow, we are considering only those prices for which the firm will not be nationalized in the next period, \(\Omega\).

Likewise, the value of the firm in a privatization period is given by

\[
W^0(p) = (1 - \tau)R^0(p) + \frac{1}{1 + r} \int_{\Omega} W(p')Q(dp', p),
\]
where $R^0(p)$ is the firm’s before-dividend-tax profit function at the privatization period.

We obtain the static payoff $U^0_P(p)$ and the profit function $R^0(p)$ by solving the static equilibrium with private ownership including the transfer from selling the firms. This static equilibrium is identical to the one described in section 3.3 except that here the government budget constraint (8) includes an additional source of funds, $\kappa W^0(p)$, raised from selling state firms:

\[ pF(N\ell(a_0)) [\tau(1 - \theta) + \theta] - \tau N [\pi(a_0)y_{H0} + (1 - \pi(a_0))y_{L0}] + \kappa W^0(p) = T_0N \]

Once we have the equilibrium allocation, we compute the static payoffs

\[ U^0_P(p) = \pi(a_0)u(y_{H0} + T_0) + (1 - \pi(a_0))u(y_{L0} + T_0) - \phi(a_0) \]

and

\[ R^0(p) = p(1 - \theta)F(N\ell(a_0)) - N[\pi(a_0)y_{H0} + (1 - \pi(a_0))y_{L0}]. \]

Given $U_P, U_S, U^0_P, U^0_S$, and the law of motion for $p$, the dynamic equilibrium is given by solutions $V_P, V_S, V^0_P$, and $V^0_S$ of the four functional equations (9), (10), (11), and (12). For an interesting range of parameters, the solution is illustrated in Figure 2. The functions $V_P$ and $V_S$ inherit the shapes of $U_P$ and $U_S$ respectively. The figure identifies a trigger price $p^*$ such that:

\[ V_P(p^*) = V^0_S(p^*) \]

From (9), $p^*$ is the price at which the government is indifferent between nationalizing a privately owned industry or leaving it in private hands. As long as the price is below $p^*$, the government refrains from nationalization, while nationalization occurs if the price jumps above $p^*$.

The figure also identifies another trigger price, $p^{**}$, such that

\[ V_S(p^{**}) = V^0_P(p^{**}) \]
From (10), \( p^* \) is the price at which the government is indifferent between privatizing a state owned sector or not. Hence, if the industry is under state ownership, it will remain in that regime as long as \( p_t \) is above \( p^* \). Privatization occurs, however, if \( p_t \) falls under \( p^* \).

In equilibria of the form just described, there is a range of prices \( p_t \in (p^*, p^*) \) for which the industry could be either in private ownership or state ownership regime depending on the previous history of prices. That is, this model features a form of hysteresis in the sense that the ownership regime in period \( t \) depends not only on the current price \( p_t \) but also on the history of prices \( p_0, p_1, ..., p_{t-1} \) leading to \( p_t \). This is a consequence of the gap in the value functions due to the nationalization costs and privatization benefits represented by \( c_S \) and \( \kappa \).

4.2 Dynamic Implications

In addition to the functional forms used in section 3.5, we assume the following stochastic process for the price,

\[
p_t = \bar{p}\exp(z_t),
\]

where \( z_t \) follows a stationary first order autoregressive process,

\[
z_t = \rho z_{t-1} + \varepsilon_t, \quad |\rho| < 1 \text{ and } \varepsilon_t \sim N(0, \sigma^2).
\]

Under this assumption, the price \( p_t \) is log-normal with a stationary distribution that has mean \( E(p_t) = \bar{p}\exp(\tilde{\sigma}^2/2) \) and variance \( VAR(p_t) = \bar{p}^2 \left( \exp(\tilde{\sigma}^2) - 1 \right) \exp\tilde{\sigma}^2 \), where \( \tilde{\sigma}^2 = \sigma^2 / (1 - \rho^2) \) is the variance of the stationary distribution of \( z_t \).

We interpret a period in the model to be one year, and set the parameters that determine the evolution of the price \( p_t \) by running a first order autoregression on the logarithm of real yearly crude oil prices\(^{14}\)  The point estimates of these regressions are \( \rho = 0.89 \), \( \sigma = 0.24 \), and \( \bar{p} = 54.6 \). Thus, the expected value and standard deviation of the invariant distribution of \( p_t \) are

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\(^{14}\)Oil prices are average annual prices per barrel of oil, in constant 2008 U.S. Dollars. Adjustment for inflation is obtained using the U.S. consumer price index. The spot oil price correspond to the West Texas Intermediate, as reported by Dow Jones & Company.
price $p_t$ are 62.8 and 35.5 respectively.

It remains to set the parameters $\beta$, $r$, $\kappa$, and $c_S$. We choose these parameters (and those common with the static model) to imply privatization and nationalization cycles of similar duration to those observed in the hydrocarbon sector in Bolivia—historically, a state ownership regime in Bolivia lasts between 20 and 25 years while private ownership, between 12 and 15 years. We assume a subjective discount factor of $\beta = 0.95$ and an interest rate of $r = 0.1$. We assume that 50 percent of the resources raised at the privatization period are redistributed to the workers, so that $\kappa = 0.5$. A reasonable value for the nationalization cost $c_S$ is more difficult to choose. Here we simply assume that the nationalization cost is such that if the commodity price is 30 percent of its long-run average value, namely $0.3E(p_t)$, consumption in a state ownership regime is zero. This implies $c_S = 0.3E(p_t)F(L_S)$. For our baseline calibration, the nationalization cost is $c_S = 0.64$, which represent about 31 percent of the value of production at the nationalization price $p^*$. These parameters are reported in Table 1.

Table 3 reports numerical experiments based on the dynamic model. The table displays the privatization and nationalization trigger prices $p^{**}$ and $p^*$, and the average duration of each regime. To be precise, we define the duration of a state ownership regime as the average number of years for the first time a price starting at $p_t = p^*$ reaches $p^{**}$. We note, however, that the proposed statistic is a lower bound on the duration of the regime, for the initial price could start at a value above $p^*$. Likewise, we define the duration of a privately owned regime as the average number of periods for the price to move from $p^{**}$ to $p^*$. These statistics are computed using Monte Carlo simulations and depend on the model parameters only through the invariant distribution of prices and the thresholds $p^*$ and $p^{**}$.\[^{15}\]

The first row of the table reports the thresholds prices and duration statistics of the baseline parametrization. In this economy, the industry is state-owned at all prices greater than $p^* = 60.4$ and privately-owned at all prices smaller than $p^{**} = 36.7$. The average duration of a state

\[^{15}\]We run 3000 simulations of length 50000, where the initial price is drawn randomly from the invariant distribution of prices. For each simulation we compute the average duration of each regime and next average the results across simulations.
ownership regime is 22 years and that of a private ownership regime is 14 years.

Consider an increase in risk aversion from the baseline $\gamma = 2.5$ to $\gamma = 3$. Both threshold prices decline, the average duration of a state ownership regime increases substantially and that of a privately ownership regime decreases slightly. The intuition for the change in the threshold prices is similar to that in the static model: an increase in risk aversion makes a state owned regime more appealing due to the larger costs associated with the lack of risk sharing in a privately owned regime. To understand the changes in the duration statistics, note that the stationary distribution of prices do not change but the threshold prices are now $p^{**} = 29.4$ and $p^* = 54.1$. Because prices are mean reverting, clearly the time it takes for the price to move from 29.4 to 54.1 will be substantially smaller than the time it will take to go from 54.1 to 29.4 for the simple reason that the average price is above both threshold prices.

The intuition for the changes in threshold prices due to changes in the parameters $\varphi, \delta, \nu, l_L/l_H, \alpha, \tau, \theta,$ and $A$ is similar to that discussed in the static model. These changes together with the observation that the invariant distribution of prices remains the same in all experiments provide intuition for the changes in the duration statistics. Consider, for example, a decrease in the ratio $l_H/l_L$ from 10 to 5 keeping the same average labor supply when effort is zero. This change implies a decline in both threshold prices, with the privatization threshold being just $p^{**} = 25.7$ and the nationalization threshold, $p^* = 51.7$. It is clear that it will take a long time for a mean reverting process with average value of 62.8 to move from 51.7 to 25.7. This observation explains that the average duration of a state-owned regime is about 53 years. On the other hand, the mean reverting property of the price process implies that the average duration of a private ownership regime is reduced to 13 years.

We now consider changes in the parameters that are specific to the dynamic model. Consider first an increase in the nationalization cost $c_S$ to 0.86. The nationalization threshold $p^*$ increases from 60.4 to 67.8 and the privatization threshold $p^{**}$ decreases from 36.7 to 36.2. It is clear why $p^*$ increases: given a higher nationalization cost, the welfare loss associated

$^{16}$The cost $c_S = 0.86$ implies that about 37 percent of the value of output is used to pay the costs associated with nationalizing the industry when the commodity price is $p_t = p^*$. 

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with the lack of risk sharing of a privately owned regime that justifies nationalizing the industry must be larger. This, in turn, implies that \( p^* \) increases. In addition, note that the privatization threshold \( p^{**} \) also changes even though the nationalization cost is paid only during the period of nationalization. The reason for this change is the indirect negative impact that an increase in \( c_S \) has on the value of a private ownership regime due to the possibility of future nationalizations of the industry. In any case, however, changes in \( c_S \) have a much larger impact on the nationalization threshold \( p^* \) than on the privatization threshold \( p^{**} \). In terms of duration, the increase in \( p^* \) and the decrease in \( p^{**} \) imply that each regime lasts longer. Indeed, the average duration of a state owned regime increases from 22 years to 24 years, and that of a state privately owned regime 14 to 18 years. Clearly, the duration of the private ownership regime increases substantially more than that of a state-owned regime.

Consider next a change in the privatization benefit \( \kappa \). Assume that \( \kappa \) declines from 0.5 to 0.25, so that 75 percent of the benefits of privatizing the industry are lost or are used for purposes other than transfers. On a qualitative level, this change has the same impact as an increase in the nationalization cost \( c_S \) – both imply a higher loss of resources. The difference is that a drop in \( \kappa \) operates through a change in the value of a private ownership regime at the privatization period while an increase in \( c_S \) operates through a change in the value of a state ownership regime at the nationalization period. Thus, \( p^{**} \) decreases, \( p^* \) increases, and the average duration of each regime increases as well.

The last two experiments involve perturbing the persistence and the volatility of the stochastic process \( z_t \). Because these changes affect the invariant distribution of \( p_t \), the interpretation of the results must be taken with caution. In all cases, we adjust \( \bar{p} \) so that the invariant distribution of \( p_t \) has always the same mean of \( E(p_t) = 62.8 \). However, there are not enough parameters to simultaneously maintain the mean and standard deviation of \( p_t \) constant while changing the persistence of the process. Thus, keeping the mean constant, changes in the persistence parameter \( \rho \) necessarily involve changes in the volatility of \( p_t \).

Consider a mean preserving change in the persistence parameter \( \rho \). A decline in persistence
from 0.89 to 0.5 increases the privatization threshold $p^{**}$ from 36.7 to 40.5 and the nationalization threshold $p^{*}$ from 60.4 to 63.4.\footnote{Neither $p^{*}$ nor $p^{**}$, however, move monotonically with (mean preserving) changes in $\rho$.} The mean preserving decline in persistence leads to the somewhat counterintuitive result that the duration of each regime decreases. Intuition suggests that the less persistent the price, the more likely the price will cross the trigger prices. However, the standard deviation of the invariant distribution of prices decreases substantially as the persistence parameter $\rho$ decreases. This drop in the volatility in prices explains the increase in the duration of each regime.

The last experiment consists of a mean preserving spread of the price distribution. We increase the volatility $\sigma$ from 0.24 to 0.48 adjusting $\bar{p}$ so that the expected long-run price remains constant. Both threshold prices decline, the duration of state ownership regime declines substantially, and that of private ownership does not change. Intuition suggests that duration of a privately owned regime should decrease as well. In effect, if the model is calibrated on a monthly basis we do observe a decline of a few months in the duration of a privately owned regime. The yearly frequency of the model is too coarse to capture the shorter duration.

A related way to understand the propagation mechanism embedded in the model is to compare the stochastic properties of the endogenous variables with that of the price. Figure 3 illustrates this point by focusing on a simple measure of persistence. The left panel displays the ratio of the autocorrelation function of output to that of the price—the relative autocorrelation function—for the baseline parameterization of the model (solid circled line). The second (dashed) line corresponds to a model where the industry is always private and there is no possibility of changing regime.\footnote{We run 250 simulations of length 100000, where the initial price is drawn randomly from the invariant distribution of prices. We compute the sample autocorrelation function for each simulation and next average the results across simulations.} The right panel of the figure displays an analogous chart for effort. Lags for which the relative autocorrelation function is above (below) one are lags for which the corresponding endogenous variable displays more (less) persistence than the price. For example, output displays more persistence than the price at lags one through nine and less persistence than the price at longer lags. The difference is significant: while output is almost
three percentage points more persistent than the price at the third lag, it is almost eight per-
centage points less persistent than the price at the 30th lag. The difference is even starker if 
we focus on effort: at the 30th lag, effort is eleven percentage points less persistent than the 
price. Similar results hold for the rest of the endogenous variables.

The endogenous variables have different persistence than the price for two reasons. First, the 
model delivers policy functions that are non-linear functions of the price. Non-affine transfor-
mations of a stochastic process do not preserve the autocorrelation function. Second, and more 
importantly, the endogenous choice between private and national regimes induces more persis-
tence at shorter lags and less persistence at longer lags. To understand this point, compare the 
difference between the relative autocorrelation function of the baseline model with that of the 
model with only a private regime. The latter differs from 1 only due to the non-linearity of the 
policy functions. The difference between the models with and without regime change reflects 
the additional propagation mechanism induced by the privatization-nationalization choice.

The endogenous variable in the model with only private firms are less persistent than the 
price at all lags, while those in the model with regime change are more persistent than the 
price at short lags. The higher persistence at short lags in the model with regime change is 
due to the high persistence in the national regime. Effort, labor, and output are constant in 
the national regime. On the other hand, the model with only private firms is more persistent 
than the model with regime change at longer lags because the shifts in regime, whose likelihood 
increases with lag length, induce large changes in the endogenous variables. Moreover, note 
that the relative autocorrelation functions cross at the 14th lag, consistent with the observation 
that, on average, there are regime shifts every 14 years (from private to national) and every 22 
years (from national to private).

4.3 Discussion

It is worth stressing the ways in which the model is consistent with the five stylized facts 
identified in our empirical review in section 2.
As to Fact 1, the dynamic model clearly stresses the repeated, cyclical nature of privatization - nationalization episodes. In the model, the choice between state versus private ownership reflects an underlying equity-efficiency tradeoff, which is affected in a natural way by the price of the national resource. Also, while we have modeled a single country in isolation, note that because the resource price is presumably common to many producer countries, the model is clearly consistent with the observation that privatization episodes often involve multiple countries.

With respect to Fact 2, our analysis is not necessarily restricted to a specific sector, but it does focus on factors that are likely to be more prevalent in natural resource sectors than in alternative ones. The model, in particular, assigns a key role to the movements in the international price of the national resource. In the model, also, the exploitation of the resource is the main (indeed the only) productive activity of the domestic economy. These two features are typical of economies based on the exploitation and export of natural resources.

Fact 3 is reproduced by the model, as its calibrated versions easily imply that nationalizations happen when the price of the domestic resource is high. This occurs because, when prices are high, concerns about equity become relatively more pressing.

Privatizations occur in our model when prices fall below a threshold value. If prices subsequently increase, the resulting windfalls are appropriated, partly or wholly, by the private buyers, until the price increase triggers nationalization. In this sense, the model is consistent with Fact 4. But it also reveals more. The fact that private owners can benefit from price bonanzas in a privatized regime is necessary to justify the price they paid for the resource. By construction, in our model private owners do not appropriate supranormal profits, so that their profitability when prices are high is only compensating them for below market profits when prices are low.

In the model, nationalization occurs when inequality becomes relatively more important for social welfare. At the same time, nationalization happens as profits of the privately owned firm are at their highest. Hence, the model can explain Fact 5. But note, again, that in
the model private owners do make normal profits even after accounting for the possibility of expropriation. Indeed, the price at which the owners acquire the resource in the first place does take into account the fact that nationalization will occur when the price increases sufficiently.

Also, note that in our model inequality lowers social welfare because of risk aversion. Increases in the risk aversion coefficient may therefore capture a stronger concern for inequality. If this interpretation is valid, the model does deliver the correct prediction in that increased risk aversion makes state ownership and nationalizations more likely.

5 Concluding Remarks

We have argued that privatization - nationalization cycles can be usefully regarded as the resolution of an equity-efficiency tradeoff. In our model, that tradeoff is generated by a conventional moral hazard problem. Our theory has intuitive implications, both static and dynamic, and can be extended in several directions.

The theory suggests several policy implications, some direct, others less so. Our model highlights that cycles of nationalization and privatization are, ultimately, linked to the government’s inability, under a nationalized regime, not to redistribute income among domestic workers. In this sense, the model implies that institutional improvements may help eliminating privatization - nationalization cycles, but only to the extent that such reforms enhance the ability of the government to commit in advance to a (non-) redistributive policy. Institutional reforms to increase transparency and accountability, or to strengthen property rights, are examples in this regard. Conversely, our theory implies that other explanations of the cycles, such as political conflict, deserve less emphasis than hitherto.

A less obvious suggestion for policy concerns the possible impact of financial reform on privatization-nationalization cycles. An implicit assumption underlying our theory is that, in a privatized regime, workers cannot pool wage income risks among themselves. This is a natural assumption and is consistent with the view that countries that display privatization -
nationalization cycles are likely to suffer from financial frictions as well. In this regard, one can reinterpret our analysis of changes in risk aversion parameters as attempts to capture what would happen if financial imperfections were less binding. The theory would then say that financial reforms would reduce the incentives for nationalization.

Admittedly, though, more research appears to be warranted to flesh out these and other policy implications of the theory. It is likely that some of the elements that we have taken as exogenous in our model, such as the structure of capital markets or the costs of nationalization, are related to policy instruments and institutions. If so, the analysis of this paper could be reinterpreted as tracing the impact of changes in those policies and institutions. Clearly, however, making such a reinterpretation would require a more detailed specification of the fundamentals of the economy.
References


### Table 1. Baseline Parameters

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**Additional parameters of the dynamic model**

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Table 2: Static Model

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Figure 1. Optimal regime choice in static model

Figure 2. Value functions and optimal regime choice in dynamic model
Figure 3

Relative autocorrelation function of output

Relative autocorrelation function of effort

Model with regime change

Only private regime

ACF(output) / ACF(price)

ACF(effort) / ACF(price)
A Appendix

A.1 Proofs

Proposition 1: The IR constraint is binding.

Proof: We proceed by contradiction. Suppose \( \{y_H^0, y_L^0, a^o, n^o\} \) is an optimal plan and

\[
\pi(a^o)u(y_H^0 + T) + (1 - \pi(a^o))u(y_L^0 + T) - \phi(a^o) > U^*.
\]

We propose a feasible plan that induces the worker to supply the same effort \( a^o \) but increases the firm’s profits. Because the proposed plan is incentive compatible, we can write the above inequality as

\[
\pi(a^o)\gamma(a^o) + u(y_L^* + T) - \phi(a^o) > U^*.
\]

Because \( u \) is continuous and increasing, there is an \( \hat{\epsilon} > 0 \) such that \( \pi(a^o)\gamma(a^o) + u(y_L^\hat{\epsilon} + T) - \phi(a^o) > U^* \). Consider now the plan \( \{\hat{y}_H, \hat{y}_L, a^o, n^o\} \), where \( \hat{y}_L = y_L^\hat{\epsilon} - \hat{\epsilon} \) and \( \hat{y}_H \) solves

\[
u(\hat{y}_H + T) = \nu(\hat{y}_L + T) + \gamma(a^o).
\]

Clearly, \( \hat{y}_L < y_L^\hat{\epsilon} \) and \( \hat{y}_H < y_H^\hat{\epsilon} \). The plan \( \{\hat{y}_H, \hat{y}_L, a^o, n^o\} \) is incentive compatible, satisfies the IR constraint, and increases the firm’s profits. Hence, \( \{y_H^0, y_L^0, a^o, n^o\} \) cannot be optimal and the IR must bind.

Proposition 2: The IC constraint multiplier \( \eta > 0 \).

Proof: This proof is a modified version of that in Holmstrom (1979). We proceed by contradiction. Suppose \( \eta \leq 0 \). Using \( \gamma'(a) > 0 \) and \( \eta\gamma'(a) \leq 0 \), the effort first order condition (7) implies

\[
n\pi'(a)[p(1 - \theta)F'(n\ell(a))(l_H - l_L) + y_L - y_H] \leq 0. \tag{A1}
\]

The first order conditions (5) and (6), together with \( \eta \leq 0 \) give

\[
\frac{n}{u'(y_H + T)} = \lambda + \frac{\eta}{\pi(a)} \leq \lambda - \frac{\eta}{1 - \pi(a)} = \frac{n}{u'(y_L + T)}.
\]

The concavity of \( u \) implies \( y_L \geq y_H \). Thus,

\[
n\pi'(a)[p(1 - \theta)F'(n\ell(a))(l_H - l_L) + y_L - y_H] \geq n\pi'(a)p(1 - \theta)F'(n\ell(a))(l_H - l_L) > 0.
\]

This result contradicts (A1). Therefore, \( \eta > 0 \).

Proposition 3: A private-ownership regime with \( \theta = 0 \) and \( \tau \to 1 \) attains the ex-ante constrained-efficient allocation.
Proof: The ex-ante constrained-efficient allocation solves
\[
\max_{a, y_H, y_L} N \left[ \pi(a) u(y_H) + (1 - \pi(a)) u(y_L) - \phi(a) \right]
\]
subject to the IR and IC constraints
\[
pF[N(p\ell(a) l_H + (1 - p\ell(a)) l_L)] - N[p\ell(a) y_H + (1 - p\ell(a)) y_L] = 0
\]
\[
u(y_H) - u(y_L) - \gamma(a) = 0
\]
Let \(N/\lambda\) and \(\eta N/\lambda\) denote the Lagrange multiplier on the IR and IC constraints respectively. Then, the first order conditions with respect to \(y_H, y_L,\) and \(a,\) can be written as
\[
\frac{N}{u'(y_H)} = \lambda + \frac{\eta}{\pi(a)}
\]
\[
\frac{N}{u'(y_L)} = \lambda - \frac{\eta}{1 - \pi(a)}
\]
\[
N\pi'(a) \{ pF'[N\ell(a)] (l_H - l_L) - (y_H - y_L) \} - \eta \gamma'(a) = 0,
\]
where the last condition uses the IC constraint. These conditions and the two constraints determine the constrained-efficient allocation \(\{y_H^e, y_L^e, a^e, \lambda^e, \eta^e\}.\)

Consider now the private ownership regime. Let \(\tilde{y}_H^* = y_H^* + T^*\) and \(\tilde{y}_L^* = y_L^* + T^*,\) set \(\theta = 0\) and \(\tau \to 1.\) Then, the equilibrium allocation of the private ownership regime solves
\[
u(\tilde{y}_H^*) - u(\tilde{y}_L^*) - \gamma(a^*) = 0
\]
\[
N/u'(\tilde{y}_H^*) - [\lambda^* + \eta^*/\pi(a^*)] = 0
\]
\[
N/u'(\tilde{y}_L^*) - [\lambda^* - \eta^*/(1 - \pi(a^*)]) = 0
\]
\[
N\pi'(a^*) \{ pF'(N\ell(a^*)) (l_H - l_L) - (\tilde{y}_H^* - \tilde{y}_L^*) \} - \eta^* \gamma'(a^*) = 0
\]
\[
pF(N\ell(a^*)) - N[\pi(a^*) \tilde{y}_H^* + (1 - \pi(a^*)) \tilde{y}_L^*] = 0
\]
\[
pF'(N\ell(a^*)) \ell(a^*) - [\pi(a^*) \tilde{y}_H^* + (1 - \pi(a^*)) \tilde{y}_L^*] + T^* = 0
\]
The first five equations coincide with those of the constrained-efficient allocation and the last condition pins down the equilibrium transfer \(T^*.\) Therefore, \(\{\tilde{y}_H^*, \tilde{y}_L^*, a^*\} = \{y_H^e, y_L^e, a^e\}.\)
A.2 Computation of the static equilibrium under private ownership

We simplify the system (3 - 8) as follows. We write the payments $y_H$ and $y_L$ as a function of $T$, $\lambda$, and $\eta$ by rewriting equations (5) and (6) as

$$y_H(T, \lambda, \eta) = (u')^{-1} \left[ \frac{N}{\lambda + \eta/\pi(a)} \right] - T$$

$$y_L(T, \lambda, \eta) = (u')^{-1} \left[ \frac{N}{\lambda - \eta/(1 - \pi(a))} \right] - T$$

Replacing these expressions into the remaining equations gives the following system of four equations in four unknowns,

$$u(y_H(T, \lambda, \eta) + T) - u(y_L(T, \lambda, \eta) + T) - \gamma(a) = 0$$

$$pF'(N\ell(a))\ell(a) - \pi(a)y_H(T, \lambda, \eta) - (1 - \pi(a))y_L(T, \lambda, \eta) = 0$$

$$N\pi'(a) [pF'(N\ell(a))(l_H - l_L) + y_L(T, \lambda, \eta) - y_H(T, \lambda, \eta))] - \eta\gamma'(a) = 0$$

$$pF(N\ell(a)) [\tau(1 - \theta) + \theta] - \tau N [\pi(a)y_H(T, \lambda, \eta) + (1 - \pi(a))y_L(T, \lambda, \eta)] - TN = 0$$

We solve this system of equations on a grid of prices \{p_1, p_2, ..., p_M\} using the Matlab routine fsolve.m.

A.3 Computation of the dynamic model

Because there is a one to one mapping between $p_t$ and $z_t$, we use $z_t$ as our state variable. We guess that the privatization region is an interval of the form $\Omega = (-\infty, z^*)$ and solve the model under this assumption. We then check that all our experiments satisfy this property.

We use the following algorithm to solve the model

1. Find the functions $U_P(z)$, $R(z)$, $U_S(z)$, and $U^0_S(z)$ on a grid of points and linearly interpolate their values at each $z$ not on the grid;

2. Choose a grid of points $Z = \{z_i\}_{i=1}^M$;

3. Choose initial guesses $V_P(z; 0)$, $V_S(z; 0)$, $V^0_P(z; 0)$, and $V^0_S(z; 0)$ for each $z \in Z$. For values of $z$ not in $Z$, we use linear interpolation. Set $j=0$.

   (a) Find the nationalization threshold $z^*$ that solves $V_P(z^*; j) = V^0_S(z^*; j)$.

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19Because $a$, $\eta$, $\lambda$, and $T$ are all positive, when solving the system of equations we define $a = e^{\tilde{a}}$, $\eta = e^{\tilde{\eta}}$, $\lambda = e^{\tilde{\lambda}}$, and $T = e^{\tilde{T}}$, and solve for the zero using the tilde variables.
(b) Given \( z^* \), iterate on the following functional equation to obtain the firm value \( W(z) \) at each grid point \( z \in \mathcal{Z} \)

\[
W(z) = (1 - \tau)R(z) + \frac{1}{1 + \tau} \int_{-\infty}^{z^*} W(z')Q(dz', z) \text{ for all } z \in \mathcal{Z}.
\]

We evaluate the integral using Gauss-Hermite quadrature.

(c) Given \( W(z) \), find \( U^0_P(z) \) and \( R^0(z) \) by solving the static equilibrium at the privatization period at each \( z \in \mathcal{Z} \).

(d) Given \( U^0_P(z) \), \( R^0(z) \), and the guesses \( V_P(z; j), V_S(z; j), V^0_P(z; j), \) and \( V^0_S(z; j) \), update the value functions at each grid point \( z \in \mathcal{Z} \) using the Bellman equations:

\[
\begin{align*}
V_P(z; j + 1) &= U_P(z) + \beta \int_{-\infty}^{+\infty} \max \{ V_P(z'; j); V^0_P(z'; j) \} Q(dz', z) \\
V_S(z; j + 1) &= U_S(z) + \beta \int_{-\infty}^{+\infty} \max \{ V^0_P(z'; j); V_S(z'; j) \} Q(dz', z) \\
V^0_P(z; j + 1) &= U^0_P(z) + \beta \int_{-\infty}^{+\infty} \max \{ V_P(z'; j); V^0_P(z'; j) \} Q(dz', z) \\
V^0_S(z; j + 1) &= U^0_S(z) + \beta \int_{-\infty}^{+\infty} \max \{ V^0_P(z'; j); V_S(z'; j) \} Q(dz', z)
\end{align*}
\]

We evaluate the integrals using Gauss-Hermite quadrature.

(e) If value functions are converged, stop; if they are not, set \( j = j + 1 \) and return to (a) using the obtained functions as the new guess.