Expropriation, Extraction, and Evasion Decisions in the Design of Taxation Regimes for the Natural Resources Industries

Three models dealing with issues pertaining to the effects that taxation regimes have on the implementation and stability of foreign-owned natural resources projects

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Abstract

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This dissertation provides three models pertaining expropriation and production decisions in the natural resources industries.

The first two chapters are intertwined: in these, the government relies on two tools to capture the rents from privately-owned Natural Resources Companies, a corporate income tax and the possibility of expropriating the assets. A real options model is used to assess the effect that *progressiveness in taxation* has on the *political risk* of a natural resources project.

In the first chapter, we discover that under certain conditions for the underlying commodity: –low prices or forward curves in backwardation– the introduction of an equivalent but more progressive tax regime decreases the political risk and the corresponding deadweight loss. However, when initial prices are too high or initial futures curves are in strong contango, the introduction of a progressive tax regime ends up significantly increasing the risks.

In the second chapter, producers are able to foresee the risks of expropriation and thus change their behaviour: the results are mixed. As in the previous case, with lower prices and less tendency to expropriate, the scheduling of production allows for gains in the value of the operation for the firms. More progressive tax regimes end up being detrimental to the government, which in some cases can even result in a non-stable equilibrium with the producers and governments trying to outguess each other and end up *cycling* both the production and the expropriation probability in order to maximise their respective expected value for the operations. This has a detrimental effect for all parties involved.

Finally, the third chapter introduces the possibility that a government levies royalties over sales. The development of home-based institutions is going to affect the amount of tax evasion that a government will face and thus determine the appropriate combination of taxes that it must choose. We find that when the host country's tax and technological capacity are too low, a state has no incentives to improve its institutions and becomes trapped in a low tax, low revenue situation: what we call a *Royalty Trap*. We end up by showing the evolution of tax capture in Chile during the 20th century to illustrate how these concepts might be applied.

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An Introduction

Remota itaque iustitia quid sunt regna nisi magna latrocinia? Quia et latrocinia quid sunt nisi parva regna?

De Civitate Dei: Liber IV, 4

The Nature of the Problem

This dissertation presents three models that attempt to solve different aspects of how tax is collected in the natural resources industries. In every case, we see that there is a hold-up problem: extractive operations require upfront investment that needs to be recouped after years of operations; so, governments, having offered some attractive conditions to promote investing, have all the wrong incentives to renege on those promises once the investment is on the ground. Opp (2012) quotes Bernard Mommer, Venezuela's deputy oil minister saying the following in 2006:

> *"The Government can promise you whatever it wants –it is not binding."*

Of course, companies have known this from a very long time, and we can see how they plan ahead for such occurrences: in Chapter 3 we mention some of the measures taken by Kennecott to maximise the difficulties of having its mining assets grabbed by the Chilean government in the late 60s and early 70s.[1] Vernon (1983) provided an early extensive list of all the measures that a firm can take in order to minimise its political risk.[2]

[1] See Moran (1974) for a detailed description.

[2] Throughout this dissertation, 'political risk' is going to be tightly linked to the risk of governments taking expropriatory measures on foreign investment.

We could argue that the hold-up problem is unavoidable. Summers (2010) rightly points out that to the extent that natural resources projects entail a high risk, ex ante returns need to be sufficiently attractive. Afterwards, if oil or minerals are found, a substantial part of the geological risk disappears, making ex post returns to appear excessively high.

Thus, throughout this dissertation, we show the actions of governments and firms assuming the absence of strong, enforceable, norms that prevent the full compliance to a previously stated regulatory agreement.

Why this problem is relevant

Even though in absolute terms the extraction of oil, gas, and minerals constitutes a minor part of the world's economy, the influence of the natural resources extractive industries is disproportionately borne by least developed countries. When trying to assess the dependence of an economy on its natural resources, Hailu and Kipgen (2017) take into account, among others:

- The export revenue from oil, gas and minerals as a share of total export revenue.
- How little the country relies on export revenue from high-skill and technology intensive manufactures.
- The tax revenue from the extractive industries as a share of total fiscal revenue.

The resulting index, the Extractives Dependence Index (EDI), shows that those countries who are more dependent are usually among the least developed or are those who are in deep political instability.[3]

It is then the case that those countries that most require the revenues coming from the extractive industries are the same countries that are least able to attract foreign investment. Moreover, the volatility of these incomes can contribute to perpetuate instability and conflict.[4]

It is not clear, then, that even if resource-rich, a country can promote investment in the extraction of its natural resources. Doing so can be a first important step, as has been noted in a recent paper by Brock Smith (Smith, 2015), where he finds that after the appropriate controls, developing countries experience a positive impact on their GDP levels after extraction of natural resources starts:[5] evidence that goes against the idea of an all-encompassing Natural Resources Curse, at least in what respects to a one-off sustained

[3]The countries with highest EDI are: Iraq, Equatorial Guinea, Libya. Angola, and Congo.
[4]See, for example Collier and Hoeffler (2005) for an introduction on how resources can feed and sustain internal conflict.
[5]In Smith's paper, the criteria that divides developing from non-developing countries is OECD membership.

rise in GDP levels (and not taking into account any distributional problems that might arise with this new, higher, GDP).

This dissertation is in part concerned with promoting *that* initial investment, by stressing the potential pitfalls that a taxation regime might have and how the reaction of the producers is going to affect those risks even before operations begin. The third chapter is somewhat different in that it shows how progress from that first investment can be hampered by the specific characteristics of the host government: their ability to tax without risking massive evasion and their outside options if foreign companies leave or fail to invest.

Finally, this dissertation narrows the benefits of the extraction of natural resources only to the taxes that are collected. This is an oversimplification, but not an excessive oversimplification of reality when the investors are foreign multinationals. As Hidalgo, Klinger, Barabási and Hausmann (2007) show, when we study how the oil, gas, and mineral resources industries relate to the rest of the economy, we find them in the periphery of the *product space* of countries, weakly interacting with the rest of the productive sector. Furthermore, Hausmann and Hidalgo (2011) argue that as economies become more complex (i.e. as technology advances) this problem is only going to increase.[6] This has two consequences: on the one hand, the fact that natural resources extraction is weakly linked with the rest of the economy, puts additional responsibility to policymakers, they need to find the right combination of taxes that maximise tax collection without excessively deterring investment. On the other hand, this isolation in the product space makes us infer that most of the problems that originate in weak taxation design or in institutional flaws in the natural resources industries are not going to be self-correcting, and so they need to be addressed consciously.

We will now review a case that shows many of the pitfalls and issues that a developing country might face when trying to attract and retain investments in the natural resources industry, the case of Guinea's Simandou iron ore project.

A remote mountain range named Simandou

Guinea's Simandou iron ore project is a good example of the issues that governments and investing firms face when trying to implement or enforce an extractives legislation. Also, it shows us how a change in the political landscape and the ways in which information flows to the population can alter the legitimacy of an investing firm.

[6] For an overview of each country's product space, a good place to start is the *Atlas of Economic Complexity* by Hausmann, Hidalgo, Bustos, Coscia, Simoes and Yildirim (2014).

Dunn (1983) already mentioned the perils of dealing with autocratic governments: on the one hand, the autocratic regime might offer a friendly business environment on a fragile political basis; when a new regime arrives, it might view the previous deals as too generous, repudiating them, although if there is a continuing interest in the permanence of investors it might try to reassure them. The first case is what happened in Guinea, the second is more similar to what happened in South Africa:[7] the difference seems to be in the perceived fairness of the deal that was bargained between the multinational firms and the host government.

A brief timeline of the events

After realising that they were in possession of a 'tier-one' iron ore deposit in the Simandou mountain range, Guinea's government struck a deal with Rio Tinto, a multinational mining corporation, in 1997, where Rio Tinto was given exploration licences and extraction rights for the whole area.[8]

The government at that time, headed by the autocratic Lansana Conté, was eager to obtain fresh resources from this new mine, and the Guinean mining code of 1995 offered very generous terms to the natural resources firms. However, political instability and the existence of alternative iron sources for Rio Tinto (the Pibara mine in Western Australia), meant that eleven years later, in 2008, the Simandou iron ore deposit was still undeveloped.

We can see in figure I.1, that the moment where the generous terms were negotiated in 1997, coincided with the lowest real prices for iron ore since the 1940s, and that in 2008 the rapid and sudden increase in iron ore prices made that Rio Tinto's delay in beginning exploitation was especially onerous.

It is between 2006 and 2008, then, that Conté's government decided to renege on the agreement they had struck with Rio Tinto, stripping them of their licence to operate. Besides doing this, the government gave half of the deposits to Beny Steinmetz Group Resources (BSGR), a holding with no prior expertise in iron ore mining. In his investigation of what happened at that point in time, Keefe (2013) finds substantial evidence that this was the result of extensive bribing on the part of BSGR. We should not underscore, though, the fact that Rio Tinto had not developed the mine up until that date while its CEO boasted of having control of 'the top iron ore asset in the world.'

The rationale for BSGR of acquiring half of the rights of Simandou was quite simple, they could sell these for a good profit, and so they did a year later: they sold half of their exploration blocks to Vale, another

[7] See Velasco (2011) for the fiscal responsibility measures adopted by South Africa after the end of Apartheid.
[8] This timeline has been assembled mostly with the information gathered by Harvey (2014).

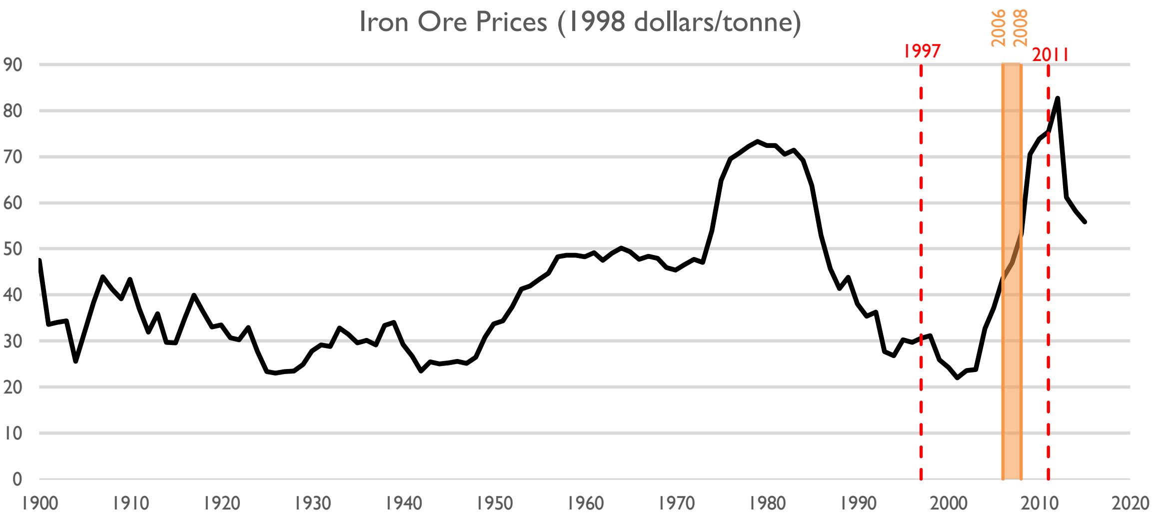

Figure I.1: Evolution of prices for Iron Ore (prices in 1998 dollars): the red lines represent the initial granting of exploration blocks in 1997 and the institution of the Guinean mining code in 2011. The orange area represents the period where Simandou's concession was partly transferred from Rio Tinto to BSGR. *Source: U.S. Geological Survey (2016).*

multinational mining corporation, for USD 2.5 billion. Of this amount the Guinean government did not receive any proceeds.

After a regime change, in 2010, the new government presided by Alpha Condé decided to review the conditions under which the licence to operate was given to BSGR, at the same time, a new mining code was drafted in 2011 (at the peak of iron ore prices, as can be seen in figure I.1), which established high royalties for extraction together with environmental provisions to guarantee the long-term sustainability of the operations.

This new mining code, and the evidence that Vale had compromised a payment of USD 2.5 billion for a 25% of the iron ore deposits while the prices for the commodity were lower, 'compelled' Rio Tinto to pay USD 700 million to reacquire half of the assets it was previously entitled to operate in Simandou.[9]

After all these negotiations, Simandou is still waiting to be developed as the logistics of the exploitation are exceedingly difficult, which implies that a substantial investment needs to be made in railways if only Simandou is going to be operated (according to Harvey (2014), USD 10 billion in building a railway to the capital, Conakry). Given that similar iron ore deposits are being prospected in neighbouring Liberia, the chances that the project is carried out as proposed by the Guinean government (i.e. connecting Simandou with Conakry) are slim.

[9] Harvey (2014) is clear to mention that there was no provision in the new mining code that forced Rio Tinto to do this, and that it looks more like as if the company was buying a 'social licence' to operate.

Some lessons from the Simandou Case

In her review of the new Guinean mining code, Bhatt (2013) shows us that sometimes one can find the proverbial low hanging fruit in what respects to improving a mineral tax code: one of the substantial modifications to the 1995 mining code in Guinea was to peg the price of the underlying commodities for tax purposes to international market prices (the LME's in this case). However, she does not explain how this new mining code has failed to materialise the necessary investment to proceed with the exploitation of the iron ore deposits.

As we will see in this dissertation, the timing of negotiation matters, and the fact that the mining code took the price conditions of 2011 made it especially fragile to an abrupt fall in prices of iron.

Moreover, Harvey (2014) argues that multinational firms favour the extension of an existing railway line from Liberia (the port of Buchanan) to Guinea's Simandou, which would have the added benefit of promoting the development of new Liberian iron ore mines. For Guinea, this makes the project more unappealing, as it introduces a new source of exogenous political risk (Liberia's) to the operation of the mine.

By relying on a railway through Liberia, not only Guinea, but Rio Tinto as well are at risk of having their rents being appropriated by a third party: installing an external control over production (like a railway on a foreign country) is a recipe for unwanted tensions.[10]

The findings of this dissertation and the tools that were used

This dissertation does not rely on cost opacity in the first two chapters[11] to force the agents to act against their best intentions; what it does is to introduce variability to the expected results for governments and firms using the price uncertainty of the commodities being extracted. This generates scenarios where governments are not able to resist grabbing the natural resource assets.

The third chapter, though, allows that the companies extract profits by means of the abuse of transfer pricing:

[10]Something similar happened during the government of Mobutu Sese Seko in Zaire: according to Bueno de Mesquita and Smith (2011), in Katanga he

> . . . famously replaced local electricity-generating capacity near Zaire's copper mines with a hydroelectric station that was more than 1,000 miles away. This empowered him to cut off electricity at the touch of a button, guaranteeing that he, and not some local entrepreneur, controlled the flow of copper wealth. It's worth noting that the power lines bypassed all the people along the way.

The extraction of rents is thus a real risk for Guinea if exports are dependent on the whims of a potentially unstable Liberian government.

[11]I am thinking here on the seminal papers by Osmundsen (Osmundsen, 1995; Osmundsen, 1998), or in the study of equilibria under no compromise done by Dixit in his book *Lawlessness and Economics (2004)*.

there are a number of solutions proposed in the literature for this asymmetry, limiting foreign ownership, for example, reduces the scope of tax evasion that is done through the masking of costs, something that is argued both in an early paper by Dasgupta and Sengupta (1995) and later by Karabay in two papers (Karabay, Pulverer and Weinmüller, 2009; Karabay, 2010). These measures are only going to affect the ability to evade taxes through transfer pricing, and so can be seen as an alternative way to improve the tax capacity (i.e. the participation of the state in a foreign firm's operations might be akin to improving the parameter χ of Chapter 3).

What follows is a brief description of what has been done in the three chapters that constitute this thesis, and the contribution that each one of them makes. Following the title of this dissertation:

> *Expropriation, Extraction, and Evasion Decisions in the Design of Taxation Regimes for the Natural Resources Industries*,

each one of the chapters deals with one specific issue that affects the design of taxation regimes for the natural resources industries; highlighting points where conventional wisdom fails, which can slow down the execution of extractive projects, as has happened –for example– with the Simandou iron ore deposit as was shown above.

First Chapter, Expropriation: Governments becoming predatory if renegotiating tax regimes under certain conditions

In the first chapter we test the notion that the introduction of more progressive taxation regimes can help to lower the risks that natural resources investments face. The results seem to validate this notion when renegotiation takes place in a low-price environment, or when forward curves expect a decrease of the price level. In other cases, we show that renegotiating tax regimes can promote early expropriation of the assets, leaving both parties: the government and the firms, in a worse position that if they had refrained from introducing the new tax regime.

This chapter makes use of **real options** as a method to construct an agent –the government– that is non-omniscient, but that can infer on whether it is convenient to expropriate assets or not. The innovation is to couple this methodology with the introduction of taxation regimes that are ex ante equivalent: this sort of tax regimes may be the result of an amicable negotiation where no party seems to be affected beforehand.

However, the skewness of the prospective tax payments for governments when prices are too high increases the risks in a non-symmetric way.

Second Chapter, Extraction: Companies adjusting to expropriation risks by changing its production function

In the second chapter, producers are able to respond to the threat of expropriation introduced previously. The intuition behind this is that more flexibility for the producer would always be desirable, as firms could abandon production when results of the operations are firmly on the negative side –and there are no prospects of improvement– and also because the firm could change its production schedule responding both to existing prices and to the threat of expropriation.

This chapter makes use of a **multiple real option** as the mechanism by which producers can allocate production more efficiently in presence of expropriation. To the model presented originally in Aleksandrov and Espinoza (2011) we added the possibility of producers to make a reasonable assessment of their risks (i.e. the firms can make an unbiased prediction, but cannot know for sure if or when they are going to be expropriated), and for the governments, we included the possibility to react to the expected best responses of firms. This iteration of best responses converged in the absence of high progressiveness in taxation, generating value to the firms and the governments over the baseline scenario (one with constant production), while when taxation was too progressive results could randomly favour either party or generate bad equilibria with substantial deadweight loss.

Third Chapter, Evasion: Governments getting stuck with less than optimal taxation regimes

In the third and final chapter, governments are no longer limited to choose from a variation of some kind of corporate income tax and so are able to choose between a combination of corporate income taxes and royalties. Also, governments have an outside option, given by their technological acumen; while their ability to prevent tax evasion is given by their tax capacity. The intuition is that a combination of corporate income taxes and royalties is not only going to maximise the revenue for the government but is also going to prevent governments from expropriating assets over a larger combination of tax capacity and technological development states.

This chapter makes use of **nonlinear optimisation** to find how the tax revenue proceeds in each case. And what we found was that there were cases where the combination of taxes and royalties could lock a country in a bad equilibrium, where any development in improving its tax capacity would be detrimental to its tax collection. Under some initial conditions this institutional trap could be sorted out by relying less on royalties, but there would still be cases where a country would have no marginal incentives to improve either its technological or its fiscal capacity.

Broadening the toolkit to analyse the Natural Resources Curse

This dissertation contains findings that broaden the toolkit that is available to governments and firms so that they can tackle more effectively issues related with the Natural Resources Curse.

The role of prices and of price models

The first one of these discoveries is that companies must take into account the peculiarities of the underlying commodity's price structure. As we can see in Chapter 1, different commodities have differences in behaviour –especially in what concerns the regression to the mean and the stochastic nature of volatility of price returns– that determine how a tax regime affects the perceived political risk of the operations.

Once the behaviour of the commodity's price is determined, then the nature of any tax deal that is being offered can be evaluated: both parties have the incentives to over or under sell a tax reform that introduces progressiveness, and a correct characterisation of the price structure is shown to be a necessary first step in order to achieve results that are convenient to all parties.

Taxes distort, but some distort more than others

Another finding was that the skewness of tax payments, that is, the number of scenarios where one party might have been favoured or adversely affected, matters a lot. The skewness of some progressive tax regimes may prompt early expropriation of operations, to which the firms can do little to minimise its effects.

The distribution of tax collection and its skewness –and not just the expected value– is something that governments should be very aware of when designing a tax regime for the Natural Resources industry.

The role of history: Bad starting points

Finally, we found that there can be traps that prevent the improvement of the fiscal capacity in governments when the starting point is sufficiently bad: governments can be in a position where it goes against their short-term interests to invest in building tax capacity.

The existence of these traps helps the case for exogenous intervention in the design and implementation of fiscal capacity, with the caveat that this is feasible when there are no great legitimacy risks for this intervention: in the Simandou case, it was Revenue Watch (now the Natural Resource Governance Institute), the one that made possible the revision of the 1995 mining code. As with Guinea, the results of the third paper can help organisations to narrow their focus on institution-building to those cases where the short-term interest of the host country advises otherwise.

Ideas for further research

In Maurer's (2013) *The Empire Trap*, the author argues that –in contrast to what is usually perceived– there has been no inefficiency in the use of retaliatory measures (such as the Hickenlooper amendment) taken by multinationals' governments against host countries that renege on their contracts. Resources literature from the 1970s and 1980s tells a different story,[12] which reveals that the time that took to recoup investments, according to Maurer, extended for a long period: long enough that it exceeded the scope of 1970s research. We can argue, however, that Maurer (2013) shows compelling evidence that the ability to coerce host governments is magnified when the world is unipolar (he looks at the U.S. as the sole enforcer of payments from rogue governments): this may cease to be the case. Kurlantzick (2016) and others see the emergence of sub-global countries that are sufficiently technologically-capable to implement extractive processes by themselves,[13] something that will necessarily increase the value of outside options for host countries and limit the power of global powers to exact compensations for expropriations. Even in the Cold War, when there was a credible outside option by aligning with one of the two superpowers, changing allegiance could be quite onerous: the current world, where extractive capabilities seem to multiply with the increasing number of National Resource Companies, will make the threats of expropriation more credible, something that this thesis assumes.

[12] See, for example Moran (1974), or Vernon (1983), or even as late as Moran (1998).
[13] Song and Wagner (2013) argue for China as the second country in this multipolar world.

Thus, there is scope for further research into how the emergence of multiple choices in the kind of extractive company that will operate in any given jurisdiction is going to affect the political risk of operations in less developed countries.

Additionally, this dissertation does not discuss the issue of fairness; the failure of which can provoke that agents act against a stated value maximisation: this is especially important where the introduction of a new taxation regime is seen as biased towards one party. Stated or implicit reference points are important, and the failure to comply with them might cause inefficiencies even when the letter of the contract is fully honoured.[14]

Finally, this dissertation just considers two agents: the governments, and the multinational companies; while in many cases it is necessary to introduce –even to this simple framework– the role of **workers** and/or **suppliers** in this 'rent-appropriation game'. The introduction of a third agent can generate a whole new set of dynamic interactions and alliances that would merit a research of its own.

[14] Hart (2009) and Hart and Moore (2008) discuss the rationale for underperformance when a contract is perceived to be unfair, while a general review on the concept of fairness can be seen in Young (1995).

Chapter 1

Renegotiating Taxes and Political Risk: The Effect of Introducing Progressive Tax Regimes

This chapter explores how the renegotiation of taxes in the Natural Resources Industry, especially the introduction of progressive taxation, *affects the* political risk *of the industry. Following the real options model developed by Schwartz and Trolle (2010), the political risk is reduced to an expropriation decision taken by the government modelled as the optimal exercise of an American-style option; whereas comparable progressiveness in taxation is achieved either using non-linear taxes or windfall taxes that are ex ante equivalent to a flat corporate profit tax. It was found that for an interval of initial market conditions –low spot commodity prices or futures contracts curves in backwardation– the introduction of an equivalent but more progressive tax regime decreased the political risk and the corresponding deadweight loss. However, when initial prices were too high or initial futures curves were in strong contango, the introduction of a progressive tax regime could significantly increase political risk. The model was calibrated with production data from the oil and copper industries for accuracy in the price dynamics.*

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Keywords: Non-renewable resources, political risk, expropriation risk, taxation, real options, progressive taxation, equivalent taxation.

1.1 Introduction

The extraction of petroleum and minerals are the single most important economic activities for many developing countries;[1] nevertheless, the positive externalities for the rest of the economy are limited given the fact that these activities are both capital intensive, usually located far from population centres, and, in the case of developing countries, with limited capability to source locally. Therefore, the social benefit for a country of having foreign owned firms involved in the extraction of non-renewables is mostly associated with the taxes governments can collect.

The importance of these extractive activities generates huge incentives for host governments to change the tax conditions once investments have been sunk. Governments and firms know this, and therefore there is going to be underinvestment in presence of weak ownership rights;[2] in these cases, governments can try to negotiate with incumbent firms a tax regime that will be inherently **more stable** without sacrificing expected income. This chapter shows the effect of the introduction of such equivalent tax regimes on the political risk, so that we are then able to know when a new and more progressive taxation regime can be of use in decreasing the perceived risk of investing in a given country.

What we find is that these efforts are successful in a limited number of cases: counterintuitively, a more progressive taxation regime can generate even more risks than the ones it was supposed to solve and so this chapter gives a note of caution about the price conditions of the underlying commodity when a tax deal is bargained.

It is necessary, at this moment to clarify two points, the first one is that this chapter will focus solely on the operations that involve the extraction of non-renewable natural resources, as a one of the assumptions is that the production function is finite, therefore the term 'natural resources' is restricted to its use as 'non-renewable natural resources.'

The second point is that in this chapter the political risk is restricted to the expropriatory actions taken by a government. By design of the model, once the new taxation regime has been agreed between the firms and the government this remains stable, and the only measure that the government takes to void the contract is by expropriating the assets. Thus, in this chapter, *political risk* and *risk of expropriation* mean the same.

[1] Cf. Boadway and Keen (2010) for a general review and Otto (2000) for the mining industry case.
[2] Cf. Bohn and Deacon (2000).

1.1.1 Motivation

This chapter thus wants to show how the incentives to renege from an existing tax regime in the natural resources industry can be modified by a new tax regime that can be mutually agreed by both the companies and the government. If that is the case, then it would be feasible to increase the overall social value of the natural resource operations by eliminating the deadweight loss associated with expropriations.

Dynamic inconsistency of taxes in the natural resources industry

Investment in the extraction of natural resources is characterised by a substantial upfront investment which then becomes largely immobilised at the site of operations. For this reason, the most important decisions for private firms are taken ex ante; as after the investment has been made they are left in a vulnerable position vis-à-vis the fiscal authority.

This chapter aims to tackle one of the issues that arise in the design and implementation of taxation regimes for the natural resources industry, namely, how governments can deal with their *inability to commit themselves* to a previously agreed taxation environment. This is a major issue both for the developing world and for natural resources companies: there is a deadweight loss associated with lack of commitment, which in its turn implies that a discretionary policy decreases the benefit coming from natural resources exploitation.

Governments are keen to attract foreign investment to develop new natural resources project. In cases where there is no reputation for good governance it is not uncommon for the same government to offer guarantees of intertemporal tax stability. Nevertheless, if there are abrupt changes in the prices of the underlying commodity these guarantees increase the risks that the government defaults on its promise and changes the supposedly stable tax regime. Investors can foresee this and will therefore demand higher rates of return in compensation.

Firms are therefore going to demand a higher rate of return to compensate for the increased perceived risk, thus altering the expected return of extractive operations for the host country. This is why in such situations the inability to commit lowers the social benefit of the natural resources industry relative to the scenario where the possibility of a government reneging to its tax regulation is lower.

Hypothesis: Less political risk with more progressive taxation

The **hypothesis to be tested** in this chapter is that in absence of taxation commitment a more robust and progressive taxation regime can be found without changing the total expected tax capture so that it significantly diminishes the risk of default from the state. The fact that these new tax regimes have the same expected discounted value would make firms indifferent between any of them ex ante in absence of political risk, so that any variation in the value of the operations that these different taxes generate can be attributed entirely to the effect of progressiveness in taxation.

The situation today

Stroebel and van Benthem (2013) analyse 2,466 oil contracts among different legislatures and find that tax capture is largely linear on the price of the commodity; that is, the tax rate is almost flat (i.e. not progressive). They argue that it might be the case that linear contracts are close to optimal, and therefore there are no incentives to deviate from the current taxation regime. Alternatively, they state that even in those cases where a more progressive taxation regime would be desirable, there might be signalling effects and cognitive costs that make transition into a more progressive tax regime too costly.

In this chapter we argue that changing from linear to progressive tax regimes does not necessarily need to be that costly; a reform that introduces progressiveness in taxation in such a way that it is equivalent ex ante to the previous tax regime should be accepted, in principle, by both governments and companies. For this reason, the introduction of a family of equivalent tax regimes might be considered as a proxy for negotiating under non-threatening conditions.

1.1.2 Literature review

The analysis of taxation within the extraction of non-renewables is conditioned by the unique characteristics of this activity, the most obvious of these –exhaustibility– was first dealt with in the seminal article by Hotelling (1931). Boadway and Keen (2010) provide a complete list of why taxation in the natural resources industry is of special concern, while Osmundsen (2010) provides reasons for society's low tolerance to profits in this industry.

Selecting a tax regime for this industry is hampered also by the asymmetry in available information; there is a problem of incentives which was analysed in an elegant two-stage model for efficient taxation of non-renewables by Osmundsen (1998). Nevertheless, that model assumes that governments are able to honour their tax promises; Engel and Fischer (2010) relax this assumption and build a closed model to optimise the taxation revenue from natural resources, assuming an exogenous 'expropriation function' to indicate when governments renege from their commitments, the optimal taxation regime thus obtained is similar to a resource rent taxation as introduced by Garnaut and Ross (1975), a very progressive taxation structure that extracts more of the rent in high commodity price scenarios. Rigobón (2010) goes a step further and models the production response from producers if facing an expropriating regime, albeit with an extremely simple and exogenous procedure to determine the expropriation decision.

A more elaborate model for an *endogenous* expropriation decision is considered by Schwartz and Trolle (2010), which constitutes the basis for the expropriation decision model used here. The use of real options for decision models in a non-renewables context as was used in that paper is taken from the work initiated by Cortázar and Schwartz (1998) and from the valuation of risk as a real option by Mahajan (1990) among others.

Finally, Stroebel and van Benthem (2013) analyse existing oil contracts in search of taxation regimes which vary with the underlying commodity price, only to discover that there is little evidence of tax regimes that try to capture additional rents when commodity prices increase. Both Stroebel and van Benthem (2013) and Johnston (2008) argue for the necessity to introduce 'progressive' elements to the taxation of natural resources: the effects that these same progressive elements have on the perceived political risk is what is going to be analysed in this chapter.

1.1.3 About the structure of this chapter

This chapter takes the expropriation decision model by Schwartz and Trolle (2010) and expands it to assess the effects on political risk (as faced by natural resources firms) of varying progressiveness in taxation. Thus, the main modifications/extensions to the original expropriation decision model that are implemented are:

- The introduction of a family of equivalent tax regimes, taxes that could be in principle agreed upon by both the government and the extraction companies as a replacement for the current tax regime, and then observe the effect of varying progressiveness on political risk.

- The adjustment of the dynamic pricing process, so that the no-arbitrage condition on the prices of futures contracts verifies at every moment.

- And finally, the use of additional dynamic price models to represent the behaviour of different commodities.

These models, that value political risk in the natural resources industry are detailed in **Section 1.2**; where the dynamic price models for crude oil and copper are introduced together with two types of equivalent taxation regimes of varying progressiveness, nonlinear and windfall. Finally, the section concludes with the introduction of a modified version of the expropriation decision model by Schwartz and Trolle (2010); which in this case allows for different tax regimes to be used. This section concludes with an outline of the methodology (the 'experimental setting') together with an overview of the most relevant results obtained, which is analysed in detail in the section that follows.

The results for the assessment of the expropriation risk for mines/oil fields under varying progressiveness are shown in **Section 1.3**. This section starts reviewing the initial conditions for each Monte Carlo simulation –which will determine decisively the price trajectory given the no-arbitrage condition– for both copper and crude oil prices as reviewed in this chapter. Then, results are shown for both commodities under nonlinear and windfall tax regimes. These results are finally analysed by the end of the section, where the departures from the initial hypothesis are explained.

Finally, **Section 1.4** concludes; a set of recommendations to successfully negotiate change is introduced together with some suggestions to extend the model further.

The results in a nutshell

The hypothesis as it was defined –that a progressive taxation regime lowers the political risk of natural resources operations– was contrasted with the results obtained from different tax regimes and initial conditions, the main observations being the following:

Progressive taxation does not always help: When either the initial spot prices or the shape of the futures contracts curve is above a certain threshold, the introduction of progressiveness in taxation while keeping equivalence is counterproductive. Governments become impatient and increase the rate of expropriation, while the value of this same expropriation decision decreases initially as it is taken on worse terms than it was done without progressive taxes.

Windfall vs. Nonlinear taxation regimes: Nonlinear tax regimes are riskier than comparable windfall tax regimes if highly progressive; however, under some range of initial conditions, windfall tax regimes are subject to bigger discrete variations under modest changes in the progressiveness parameter.

The effect of different price models: Two different dynamic price models were used, one taken directly from Trolle and Schwartz (2009) to simulate oil prices, while the other was calibrated using copper price and futures data using the model by Cortázar and Schwartz (2003). Results from these models –both assume a no-arbitrage condition– showed different sensitivity to progressiveness; though in both cases under sufficiently adverse initial conditions, political risk increased with progressiveness.

1.2 Valuing political risk using real options

In this section we introduce the methodology that was employed to evaluate how political risk varied in presence of a mutually agreed renegotiation of the tax regime. First, we describe the basic assumptions behind the valuation model; then we introduce the concept of equivalence and progressiveness in a tax regime as a proxy for a mutually agreed tax reform in the natural resources industry. Finally, we describe the experimental setting and overview the results that are going to be detailed in the next section.

1.2.1 The basic framework

This chapter adapts the expropriation risk model by Schwartz and Trolle (2010), which employs a real options model to determine the dynamics of an expropriation decision in the natural resources industry as taken by a government. In this chapter, though, this model is extended to see how this risk evolves after a new tax regime has been introduced.

Like in the seminal paper by Mahajan (1990), the expropriation decision is modelled as the exercise of an American-style option, where the payoff is given by the balance between the gains and costs of expropriating at any given time, and the early exercise of this option represents the expropriation decision itself. The advantage of representing the political risk through an American-style option is that it considers the fact that it may be on the best interest of a government to withhold expropriation[3] –even if the payoff were positive at that time– due to a higher expected continuation value for the aforementioned option. However, unlike previous models, the resulting real option cannot be solved in a closed form, and therefore we use Monte Carlo methods to simulate price paths and value the exercise of this model. Numerical methods allow

[3] This is the quid of this and the following chapter: options allow agents to make a reasonable, but no omniscient, forecast of the future.

us to use dynamic price models that are more complex, and that attempt to represent better the reversion to the mean shown by commodity prices; different underlying price models can be compared without extensive modifications to the valuation framework introduced here.

The price models used in this chapter are presented in detail on the appendix; one of them is parameterised for crude oil while the other represents the copper market, the particular aspect of these models is that both generate stochastic spot prices and the *associated futures contracts curves for each generated spot price.* The common factor between these two models is that in both cases there is a no-arbitrage condition in the futures contracts market: futures contracts are unbiased indicators of the market's expectation for the price of the commodity, so that by construction we have the following equivalence,[4]

$$F(t_j, t_l) = E_{t_j}[S_{t_l}], \tag{1.1}$$

where $F(t_j, t_l)$ is the value at time t_j of the future contract maturing at time t_l, and $E_{t_j}[S_{t_l}]$ is the expectation at time t_j of the spot price of the commodity at time t_l.

To simulate crude oil spot and future prices, the data and parameters were taken from Trolle and Schwartz (2009) –the same price model used in the original expropriation risk model by Schwartz and Trolle (2010)– whereas for copper we used the model by Cortázar and Schwartz (2003), calibrating it with copper spot prices and futures from the year 2000 to 2010 with futures contracts expiring up to 120 months from the spot price date.[5]

As with any numerical simulation, prices vary discretely between each period; in this case the complete time horizon of the simulation is divided into N steps, so that the time corresponding to the j step can be described as t_j, where $j \in \{1, \dots, N\}$ and $t_N = T$, with T the time horizon of the extraction process, so that each period t_j has a length of $\triangle t_j = T/N$.

Therefore, for each commodity we produce a series of spot prices and futures contracts of the form: S_{i,t_j} and $F_i(t_l, t_j)$ respectively, where $i \in \{1, \dots, M\}$ is one of the M independent paths used in simulation.[6]

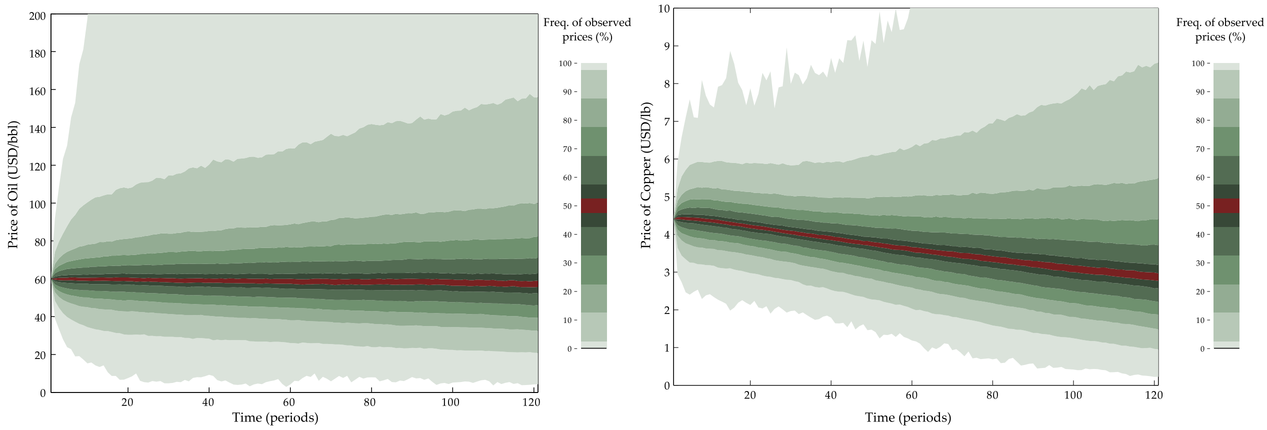
In figure 1.1 below we can see how the distribution of spot prices evolves throughout the life of the mine/oil field. In this figure, as in the rest of the chapter, we assume $T = 10\, years$ and $N = 120\, periods$.

As can be seen, both models show reversion to the mean: there is no exponential expansion of the distribution

[4]Taken from equation (1.48) on page 65.

[5]All this data was taken from Bloomberg.

[6]Throughout this chapter, and unless explicitly told otherwise, each Monte Carlo simulation was run using 10,000 paths with antithetic variate reduction, as suggested by Brandimarte (2006).



(a) Oil: $S_0 = 60\ USD/bbl$ and $x_0 = 0$

(b) Copper $S_0 = 4.4\ USD/lb$ and $\hat{v}_0 = 0$

Figure 1.1: Frequency of observed prices using the dynamic oil and copper price models. Colours represent the distribution of the different price paths when $M = 10,000$.

of prices, as it would be if we were simulating a typical random walk; this characteristic will later prove relevant for the conclusions of this model. We must not forget, either, that for each simulated spot price there will be a corresponding futures contracts curve with maturity up until the end of life for the mine or oil field.

In figure 1.2 we can see how we are going to proceed once these prices are generated; first we will estimate the total amount of tax that is going to be captured in a baseline case –a flat corporate profit tax as shown by Schwartz and Trolle (2010)– and then use that tax capture to construct a family of more progressive taxes that represent the outcome of an amicable negotiation. Finally, in section 1.3 we will assess the political risk of these new tax regimes and analyse the reasons behind the variations of it.

Figure 1.2: The flow of information in this chapter: stochastic price models, equivalent and progressive taxes, and the valuation model for political risk.

1.2.2 Tax negotiation: Introducing equivalent tax regimes

The initial tax structure that will serve as baseline for the operations of the mine or oilfield on which modifications are going to be introduced follows the structure presented by Schwartz and Trolle (2010): a simple flat tax rate on corporate profits, τ_{inc}; where corporate profits are defined according to the following equation:

$$OpIncome_{i,t_n} = (S_{i,t_n} - C_{firm}) \cdot Y_{t_n} \ , \tag{1.2}$$

where for each time period t_n, $n \in \{1, \ldots, N\}$, and each price path i where $i \in \{1, \ldots, M\}$, $OpIncome_{i,t_n}$ is the corporate profit, S_{i,t_n} is the price of the underlying commodity, C_{firm} is the operational cost per unit of production and Y_{t_n} is the production rate for the commodity at time t_n.

This is a simplified version of the framework used by Schwartz and Trolle (2010); however, it must be noted that in this chapter, to isolate the effect of progressiveness in the different tax regimes, we have decided not to include the royalty tax that is used there. For that reason, the total tax revenue at every price path i and time period t_n is going to be equal to:

$$Tax\ Revenue_{i,t_n} = \tau_{inc} \cdot OpIncome_{i,t_n} \ , \tag{1.3}$$

for each time period t_n and price path i; and where τ_{inc} is the corporate tax rate.

Given the no-arbitrage condition, at every moment the government and the extracting companies can make an unbiased –but not certain– prediction of the future prices of the commodity, and therefore, they can also predict the expected total tax revenue from the exploitation of the mine/oil field if there is no risk of expropriation at all and if the tax rate is **kept constant** at its original value τ_{inc}. The fiscal authority may then wish to follow the advice mentioned in some literature and choose to negotiate a new taxation regime that will be more progressive, in such a way that the perceived political risk decreases.

We can assume that in this case the industry and the government are able to negotiate a tax change that provides the same overall tax revenue for the government,[7] and can therefore be voluntarily accepted by both parties. The possible outcomes of these negotiations are going to be called *equivalent tax regimes* and will

[7]The initial debate for an appropriate level of taxation has been usually framed by this *ex ante* parity in tax revenue, as it is preferred that the companies voluntarily adopt the new regime, and that governments avoid costly arrangements afterwards (see Maurer (2013) for extensive evidence throughout the 20th century). An example of this can be seen in the 2004-2005 Chilean discussion about mining royalties, as summarised in Congreso Nacional de Chile (2005).

differ in the distribution of their payoffs as it is going to be described below. But, before this description, we need a proper definition of what are we going to understand by *equivalent tax regimes* and by *progressiveness in taxation.*

Definition 1. *We can define an **equivalent tax regime** as one which provides a tax revenue flow that has the same expected discounted value than the baseline case. In this chapter, this means any tax regime that provides –over the lifetime of the mine/oil field– a discounted value that is equivalent to the discounted tax revenue generated by a constant tax rate on profits,* τ_{inc}.

Definition 2. *A tax regime for a commodity is going to be **more progressive** than other if there is an underlying commodity price,* S^**, so that for every price* $S \geq S^*$ *the average tax rate in the **more progressive** tax regime is **higher** than in the less progressive one.*

Given these definitions, we can construct an unlimited number of tax regimes that are equivalent and more progressive than the baseline case. However, in this chapter we limit ourselves to the study of two tax structures: a nonlinear tax rate which is contingent on the commodity price, and a windfall tax. The first of these is akin to what is proposed by Stroebel and van Benthem (2013) and Johnston (2008); whereas the second is based on the results from Engel and Fischer (2010).

Both tax regimes replace the flat tax on the operational income, τ_{inc}, with a tax $Tax(S,k)$ where S is the underlying commodity price and k, a parameter that varies according to the progressiveness of the tax regime; so that each value of k will represent an equivalent tax regime of varying progressiveness, in such a way that the total tax revenue becomes

$$Tax\ Revenue_{i,t_n} = Tax(S_{i,t_n}, k) \cdot OpIncome_{i,t_n}\ , \tag{1.4}$$

and the corresponding income for the companies is

$$After\ Tax\ Income_{i,t_n} = (1 - Tax(S_{i,t_n}, k)) \cdot OpIncome_{i,t_n}\ , \tag{1.5}$$

for every simulated price path i at period t_n.

A nonlinear tax subject to commodity prices

The first one of these tax regimes is one where the tax rate varies in direct proportion to the price of the underlying commodity. As it was mentioned before τ_{inc} is replaced by a tax of the form $Tax(S,k)$, which in this case would be:

$$Tax(S,k) = Tax(S_{i,t_n}, \delta) = \delta S_{i,t_n} + \tau_{base}(\delta) \ . \tag{1.6}$$

The parameter k is represented by δ, which accounts for the progressiveness of the tax rate, as the expression $\delta \cdot S_{i,t_n}$ increases with the commodity price. To maintain the equivalence with the baseline case, a flat base tax, $\tau_{base}(\delta)$ is introduced; which is defined as a function of δ in such a way that for every value of δ there is a single value of τ_{base} that makes the tax rate equivalent. The value of $\tau_{base}(\delta)$ will be given by the following equation:

$$\tau_{base}(\delta) = \frac{\sum_{i=1}^{M} \sum_{n=1}^{N} e^{-r(t_n - t_0)}\, OpIncome_{i,t_n} (\tau_{inc} - \delta S_{i,t_n})}{\sum_{i=1}^{M} \sum_{n=1}^{N} e^{-r(t_n - t_0)}\, OpIncome_{i,t_n}} \ , \tag{1.7}$$

so that for a given value of δ it is possible to find a value for τ_{base} that keeps both the government and the companies *ex ante* indifferent to a change in the tax regime from the baseline, τ_{inc}, into the nonlinear model as stated in equation (1.6).

It is possible then to generate a set of paired $(\delta, \tau_{base}(\delta))$ parameters so that the effect of modifying the progressiveness of taxation regimes can be assessed while keeping taxes equivalent. We limit here the analysis to a family of taxes bounded by the case where $\delta_0 = 0$, implying that there is a flat tax equal to $\tau_{base}(\delta_0) = \tau_{inc}$, and on the other extreme the case where δ increases so much that $\tau_{base} = 0$, we name this upper bound for δ as δ_{max}. Therefore, for all cases $\tau_{base}(\delta) \geq 0$ [8], and by the definition of progressiveness $\delta \geq 0$,while the generated parameters $(\delta, \tau_{base}(\delta))$ will evolve as follows:

$$\begin{array}{ccll} \delta_0 & \tau_{base}(\delta_0) & \rightarrow & \delta_0 = 0, \text{ and } \tau_{base}(\delta_0) = \tau_{inc} \\ \delta_1 & \tau_{base}(\delta_1) & \rightarrow & \text{(more progressiveness, with } \delta \uparrow \text{ and } \tau_{base} \downarrow \text{)} \\ \vdots & \vdots & & \qquad\qquad \vdots \\ \delta_{max} & \tau_{base}(\delta_{max}) & \rightarrow & \delta_{max} \geq \delta_n \ \forall \ n, \text{ and } \tau_{base}(\delta_{max}) = 0 \ . \end{array} \tag{1.8}$$

[8] Thus avoiding situations where there would be a negative tax rate over operational income if the price were too low.

Where the value of the upper bound for δ, δ_{max}, is defined by the equation:

$$\delta_{max} = \frac{\sum_{i=1}^{M}\sum_{n=1}^{N} e^{-r(t_n-t_0)}\, OpIncome_{i,t_n}\cdot \tau_{inc}}{\sum_{i=1}^{M}\sum_{n=1}^{N} e^{-r(t_n-t_0)}\, OpIncome_{i,t_n}\cdot S_{i,t_n}}\ , \tag{1.9}$$

in such a way that $\tau_{base}(\delta_{max}) = 0$, so that in the limit case, taxes are completely dependent on the commodity price.

A windfall tax

An alternative way to define a more progressive taxation regime is with the institution of an equivalent windfall tax. The type of windfall tax assumed in this chapter is one where there is an initial flat tax rate τ_{wf} until the price of the underlying commodity reaches a windfall price S_{wf}. When the price of the commodity is higher than S_{wf}, then all the additional income is taxed, and therefore equation (1.5) is modified so that after-tax income becomes:

$$\mathit{After\ Tax\ Income}_{i,t_n}(\tau_{wf}, S_{wf}) = \begin{cases} (1-\tau_{wf})\cdot OpIncome_{i,t_n} & \text{if } S_{i,t_n} < S_{wf}\ , \\ \big((1-\tau_{wf})\cdot OpIncome_{i,t_n}\big) - (S_{i,t_n} - S_{wf}) & \text{if } S_{i,t_n} \geq S_{wf}\ . \end{cases} \tag{1.10}$$

We can also express the total tax capture using the expression $Tax(S,k)$ in equation (1.4), where the tax revenue is equal to[9]

$$\mathit{Tax\ Revenue}_{i,t_n} = Tax(S_{i,t_n}, k)\cdot OpIncome_{i,t_n}\ , \tag{1.11}$$

so that the windfall tax can be stated as:

$$Tax(S,k) = Tax(S_{i,t_n}, \tau_{wf}) = \tau_{wf} + \boldsymbol{I}_{[S_{i,t_n}\geq S_{wf}(\tau_{wf})]}\cdot\left(1 - \frac{S_{wf}(\tau_{wf}) - C_{firm}}{S_{i,t_n} - C_{firm}}\right)\cdot(1-\tau_{wf}). \tag{1.12}$$

Where $\boldsymbol{I}_{[S_{i,t_n}\geq S_{wf}(\tau_{wf})]}$ is an indicator variable that takes the value **1** when $S_{i,t_n} \geq S_{wf}(\tau_{wf})$ and zero otherwise, and where $S_{wf}(\tau_{wf})$ is the windfall price at the windfall tax τ_{wf}, and τ_{wf} by itself is the tax rate when prices are lower than the windfall commodity price.

To maintain the equivalence between this windfall tax and the baseline case, as the tax rate τ_{wf} decreases,

[9] Taken from equation (1.4) on page 22.

the windfall price should also lower to compensate for foregone income when prices are lower. Therefore, the windfall commodity price is obtained as a function of τ_{wf} using the following identity:

$$S_{wf}(\tau_{wf}) = \left(\sum_{i=1}^{M} \sum_{n=1}^{M} e^{-r(t_n - t_0)} \Big[\Big(\boldsymbol{I}_{[S_{i,t_n} \geq S_{wf}(\tau_{wf})]} \cdot S_{i,t_n}(1 - \tau_{wf}) \Big) + \Big(\big(S_{i,t_n} - C_{firm}\big)(\tau_{wf} - \tau_{inc}) \Big) \Big] \right) \cdot \left(\sum_{i=1}^{M} \sum_{n=1}^{M} e^{-r(t_n - t_0)} \boldsymbol{I}_{[S_{i,t_n} \geq S_{wf}(\tau_{wf})]} (1 - \tau_{wf}) \right)^{-1} . \quad (1.13)$$

It must be noted that this identity has to be solved numerically, as $S_{wf}(\tau_{wf})$ is present implicitly at the right hand side of the equation in the indicator $\boldsymbol{I}_{[S_{i,t_n} \geq S_{wf}(\tau_{wf})]}$. Thus, using this equation is it possible to find a windfall price S_{wf} for any given initial tax rate τ_{wf} where $0 \geq \tau_{wf} \geq \tau_{inc}$; in such a way that both parties –the government and the extracting companies– are indifferent *ex ante* on whether to use the windfall tax or the baseline case with a tax rate equal to τ_{inc}.

As with the nonlinear tax, it is possible to generate a set of paired $(\tau_{wf}, S_{wf}(\tau_{wf}))$ parameters to affect the progressiveness of the taxation regime while keeping taxes equivalent. The parameters are bounded by the initial case where $\tau_{wf0} = \tau_{inc}$, and therefore the tax is equivalent to the baseline case, up to the case where $\tau_{wf(min)} = 0$ and therefore $S_{wf}(\tau_{wf(min)})$ is the lowest value for the windfall spot price. The parameters that are generated according to this rule will be of the form:

$$\begin{array}{cccl} \tau_{wf0} & S_{wf}(\tau_{wf0}) & \rightarrow & \tau_{wf0} = \tau_{inc}, \text{ and } S_{wf}(\tau_{wf0}) = \infty \\ \tau_{wf1} & S_{wf}(\tau_{wf1}) & \rightarrow & (\text{more progressiveness, with } \tau_{wf} \downarrow \text{ and } S_{wf}(\tau_{wf}) \downarrow) \\ \vdots & \vdots & & \qquad\qquad \vdots \\ \tau_{wf(min)} & S_{wf}(\tau_{wf(min)}) & \rightarrow & \tau_{wf(min)} = 0, \text{ and } S_{wf} \text{ has its lowest value.} \end{array} \quad (1.14)$$

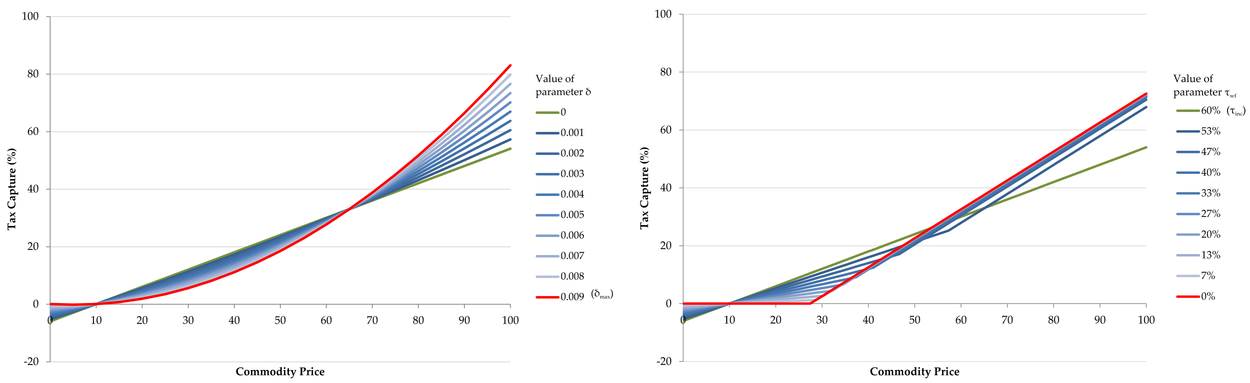
Thus, for the general case of a progressive equivalent tax regime we can state that

$$Tax(S,k) \Leftrightarrow Tax(S,\delta) \Leftrightarrow Tax(S,\tau_{wf}) \ . \quad (1.15)$$

In the following paragraph we will see the differences between these two progressive taxation regimes (non-linear and windfall). and how the tax capture evolves with the underlying commodity price.

Nonlinear vs. windfall

To illustrate the difference between the initial baseline case and the equivalent progressive tax regimes it is useful to see how the amount of tax collected varies when the underlying commodity price changes. In figure 1.3, the two equivalent tax regimes are shown –nonlinear and windfall tax– for identical initial conditions;[10] as progressiveness increases in both cases (a higher value of δ or a lower value for τ_{wf} in the case of windfall tax regime) the amount of collected tax increases with the higher price of the underlying commodity.



(a) Nonlinear tax (b) Windfall tax

Figure 1.3: Tax capture with varying progressiveness under different commodity prices: graphs made using the nonlinear and windfall equivalent taxes for the case of oil with initial spot price of $S_0 = 50$ and parameter $x_0 = 0$. The green line represents the baseline case, with a constant tax rate $\tau_{inc} = 60\%$, whereas the red line represents the maximum progressiveness for each tax regime.

These tax regime examples were built using the oil price model. As could be seen in equations (1.7) and (1.13), to calculate the new tax regimes parameters we require to know the values of the baseline tax rate, $\tau_{inc} = 0.60$, and the operational cost of the firm, $C_{firm} = 10\, USD/bbl$, which in this case are the values used in the following expropriation model as well as in the original version by Schwartz and Trolle (2010). For this reason we see that there is in effect a *negative tax* when prices are lower than $10\, USD/bbl$, where operational income is negative. This could be interpreted as a standard tax credit on losses, which does not affect results qualitatively.[11]

Finally, we might also add that these two taxes respect the vertical justice criteria.[12]

[10] As these tax regimes are equivalent, the value of the parameters for these new tax regimes will change if the initial conditions (basically, the spot price and the shape of the futures contracts curve) are different in such a way that the expected tax capture *ex ante* remains the same.

[11] In the last chapter of this dissertation we will explore the role that losses can have on the agent's behaviour.

[12] See Agostini (2013) for an extensive discussion on vertical and horizontal justice in tax regimes.

Now that the equivalent taxation regimes are properly defined, we can examine how the political risk is going to be valued. The details of the valuation model and of the experimental setting are detailed below.

1.2.3 The expropriation model by Schwartz and Trolle (2010)

Up until this point here all calculations have not considered their political risk implications. To value how equivalent taxation regimes of varying progressiveness affect this risk we use a modified version of the model presented by Schwartz and Trolle (2010) (the baseline model); which narrows the political risk of a natural resources project to the expropriation decision as taken by a *rational* and *risk-neutral* government. This expropriation decision is modelled as the optimal exercise of an American-style option, the payoff at the exercise of this real option would leave the government with the full income stream from the natural resources project, this is balanced with the fact that extraction costs will be higher and that the government should pay a compensation to incumbent operators after expropriating the assets as well as additional reputational costs that will not be transferred as compensation to former operators.

In the baseline model, Schwartz and Trolle (2010) show us that there is an *increased* risk of expropriation if the initial spot price of the commodity is *high* or if the futures curve of the same commodity is into a strong *contango* at the initial time t_0: both conditions imply the possibility of higher profits in the future, and therefore of a greater probability for the government to recoup the associated costs of exercising the option. As was mentioned before, the baseline case has a constant and flat corporate income tax equal to τ_{inc}, which is going to be contrasted with more progressive equivalent taxation regimes, so that it is possible to quantify the effect that a more progressive taxation can have in *reducing the expropriation risk* of natural resources operations. The *intuition* behind this is that when prices for a commodity are higher, a higher tax capture will leave the expropriation option as a less attractive alternative. As has been mentioned before, this fact has been acknowledged in the model by Engel and Fischer (2010), who proposes a version of a windfall tax to extract most of the economic rent from producers, thus eliminating an –exogenous– risk of expropriation by dramatically increasing the marginal tax rate; this chapter differs in that the risk of expropriation is endogenous, and that the amount of rent that can be extracted from producers is constrained by the fact that tax changes are equivalent to the baseline case as defined before.

The valuation model for political risk

According to this model, at each period t_j (with $t_j \in \{t_0 \dots t_N\}$), governments need to take a decision on whether to expropriate or not according to the perceived costs and gains of exercising an American-style real option on this decision to expropriate.

To value this option, the expected value of the operations is assessed using the spot prices and futures contracts of the underlying commodity: oil in the case of the dynamic price model by Trolle and Schwartz (2009) and copper in the case of the model by Cortázar and Schwartz (2003), these two dynamic price models are explained in detail in the appendix at the end of the chapter.

As before, S_{i,t_j} is going to be the spot price of the commodity at time t_j in the i simulated path, while $F_i(t_j, t_l)$ is going to be the price for futures contracts in simulated path i at time t_j and maturing in t_l. The constant interest rate is going to be r, and the operational income tax is going to be stated in the form $Tax(S_{i,t_j}, k)$, which is either defined as the nonlinear tax (in page 22) or as the windfall tax (in page 24). Finally, we must consider that at each moment the government only knows the *expected* future value of the spot price, and if we consider the identity,[13]

$$F(t_j, t_l) = E_{t_j}[S_{t_l}] \ , \tag{1.16}$$

used on the construction of the dynamic price models in the appendix on page 65, we can replace the operational income tax rate $Tax(S_{i,t_l}, k)$ with

$$Tax(F_i(t_j, t_l), k) \ , \tag{1.17}$$

for the value of the *expected* operational income tax rate at time t_l, that is, the future contracts are considered as unbiased predictors in a risk neutral setting. The cost of extracting one unit of the commodity is going to be C_{firm} for the firm and C_{gov} for the government; and it is assumed that $C_{firm} \leq C_{gov}$ so that expropriation increases the cost of production.[14] The other costs of expropriation are the compensation paid to producers, assumed to be equal to K_1 per year of remaining operational life of the mine or oil field, and a reputational cost K_2 if the expropriation decision is taken. Finally, the extraction rate (or the production rate) is going to be Y_{t_j} an exogenous production function for each period t_j.

[13] Taken from equation (1.48) on page 65.

[14] We will revisit this assumption in the last chapter, an assumption that is consistent with Opp's (2012) model and that is validated by the evidence provided by Titelman Goren (2007), Çakir-Melek (2011), and many others.

We can then estimate the value of futures contracts of different maturity at every moment for each simulated price path $i \in \{1, \dots, M\}$, where M is the total number of generated price paths. With these futures contracts we are able to estimate the instantaneous cost, $V_{cost}(i, t_j, k)$, and the gain, $V_{gain}(i, t_j)$, for the government of expropriating the operations in the price path i at time t_j, with a tax progressiveness given by factor k, according to equations (1.18) and (1.19).

$$V_{cost}(i,t_j,k) = \left[\sum_{n=j+1}^{N} e^{-r(t_n-t_j)} [(F_i(t_j,t_n) - C_{firm}) \cdot Tax(F_i(t_j,t_n),k)] Y_{t_n} \right] + K_1 \cdot (t_N - t_j) + K_2 \ , \quad (1.18)$$

$$V_{gain}(i,t_j) = \sum_{n=j+1}^{N} e^{-r(t_n-t_j)} (F_i(t_j,t_n) - C_{gov}) Y_{t_n} \ . \quad (1.19)$$

$V_{cost}(i, t_j, k)$ values the future tax income from the firm that is lost after the expropriation decision, as well as the reputational and compensation costs to be paid; while $V_{gain}(i, t_j)$ acknowledges the fact that after expropriation the government will receive the complete income stream from the operation. Thus, these two expressions are used to construct the payoff function for the exercise of the American-style expropriation option, this payoff should be:

$$\Pi(i,t_j,k) = \max(V_{gain}(i,t_j) - V_{cost}(i,t_j,k), 0) \ , \quad (1.20)$$

for path i at time t_j and tax progressiveness given by parameter k.

$\Pi(i, t_j, k)$ is a reasonable assumption for the government's payoff because the state can effectively fix future payments from the operations of the mine/oil field through future contracts, so that they become equivalent to an instantaneous payoff function.[15]

In order to evaluate an American-style real option with this payoff function for any given value of k, we used the least squares Monte Carlo method (the LSM method) proposed by Longstaff and Schwartz (2001), which calculates the continuation value of the option, $E_{t_j}[\Pi(i, t_{j+1}, k)]$ (the unbiased expectation at time t_j of the value of the option at time t_{j+1}), using a linear regression at each step.[16,17] What this means is

[15] See Moran (1973) for evidence of companies trying to fix future payments to deter expropriation.

[16] The option valuation algorithm was adapted from an American-style put option valuation that appears in Brandimarte (2006).

[17] At the period before operations cease, t_{N-1}, there's no uncertainty with respect to the value of the option –its continuation value is zero (i.e. the value of the option at t_n)– so at that moment the option is valued precisely at the value of the payoff function $\Pi(i, t_{N-1}, k)$.

that the owner of the option to expropriate (i.e. the government) tries to maximise its value by choosing an appropriate timing for its exercise.

Once the real option model is solved using the LSM method, we know both the exercise time for every simulated path and the value of the option at time t_0. Then, for each price path i there is going to be a period $Z_i \in \{1, \ldots, N\}$ when the option is exercised; and if there is no exercise, $Z_i = N$, so that the time when the expropriation happens is going to be defined as t_{Z_i}. We can thus calculate the present value of the operations of the mine/oil field to the firm and to the government adjusted to the risk of expropriation:

$$V_{firm}^{exp}(t_0, k) = \frac{1}{M} \sum_{i=1}^{M} \left(\left[\sum_{n=1}^{Z_i} e^{-r(t_n - t_0)} (S_{i,t_n} - C_{firm})(1 - Tax(S_{i,t_n}, k)) Y_{t_n} \right] + e^{-r(t_{Z_i} - t_0)} K_1 \cdot (t_N - t_{Z_i}) \right), \quad (1.21)$$

$$V_{gov}^{exp}(t_0, k) = \frac{1}{M} \sum_{i=1}^{M} \left(\left[\sum_{n=1}^{Z_i} e^{-r(t_n - t_0)} \left[(S_{i,t_n} - C_{firm}) \cdot Tax(S_{i,t_n}, k) \right] Y_{t_n} \right] - e^{-r(t_{Z_i} - t_0)} (K_1 \cdot (t_N - t_{Z_i}) + K_2 \cdot \boldsymbol{I}_{[t_N > t_{Z_i}]}) + \sum_{n=Z_i+1}^{N} e^{-r(t_n - t_0)} (S_{i,t_n} - C_{gov}) Y_{t_n} \right). \quad (1.22)$$

Where for a given tax regime with progressiveness given by parameter k, $V_{firm}^{exp}(t_0, k)$ is the value of the operations for the firm in presence of expropriation, and $V_{gov}^{exp}(t_0, k)$ the corresponding value to the government; the indicator variable $\boldsymbol{I}_{[t_N > t_{Z_i}]}$ takes the value **1** if $t_N > t_{Z_i}$ and **zero** otherwise. The expressions in equations (1.21) and (1.22) should be compared to the value of the operations in absence of expropriation risk, V_{firm} and V_{gov} as defined below.

$$V_{firm}(t_0, k) = \frac{1}{M} \sum_{i=1}^{M} \left(\sum_{n=1}^{N} e^{-r(t_n - t_0)} (S_{i,t_n} - C_{firm}) (1 - Tax(S_{i,t_n}, k)) Y_{t_n} \right), \quad (1.23)$$

$$V_{gov}(t_0, k) = \frac{1}{M} \sum_{i=1}^{M} \left(\sum_{n=1}^{N} e^{-r(t_n - t_0)} \left[(S_{i,t_n} - C_{firm}) \cdot Tax(S_{i,t_n}, k) \right] Y_{t_n} \right). \quad (1.24)$$

Equations (1.23) and (1.24) are defined so that $V_{firm} = V_{firm}^{exp}$ and $V_{gov} = V_{gov}^{exp}$ in absence of expropriation risk, and $V_{firm} \geq V_{firm}^{exp}$ and $V_{gov} \leq V_{gov}^{exp}$ more generally. The presence of reputational costs, K_2, generates a deadweight loss, according to the following function:

$$DWL(t_0, k) = (V_{gov}(t_0, k) + V_{firm}(t_0, k)) - (V_{gov}^{exp}(t_0, k) + V_{firm}^{exp}(t_0, k)) \ . \tag{1.25}$$

It is also going to be of interest to look at the variation of the *value of the option to expropriate* at the initial time t_0, $P(t_0, k)$, this will be equal to the average of the sum of the value of discounted payoffs at the exercise time, so that the ex ante value of the option will be

$$P(t_0, k) = \frac{1}{M} \sum_{i=1}^{M} e^{-r(t_{Z_i})} \cdot (1 - \boldsymbol{I}_{[t_N > t_{Z_i}]}) \cdot \Pi(i, t_{Z_i}, k) \ , \tag{1.26}$$

where again, $\boldsymbol{I}_{[t_N > t_{Z_i}]}$ is an indicator variable that takes the value **1** if $t_N > t_{Z_i}$ and **zero** otherwise, and $\Pi(i, t_{Z_i}, k)$ is the value of the payoff function in equation (1.20).

Throughout this chapter we refer to the total probability of expropriation which is going to be valued as the total amount of expropriation decisions that take place with respect to the total number of simulated paths, so that we have the value:

$$\textit{Total Prob. of Expropriation} = \frac{1}{M} \sum_{i=1}^{M} \boldsymbol{I}_{[t_N > t_{Z_i}]} \ , \tag{1.27}$$

or the average number of times that the option is exercised, that is, whenever t_{Z_i} is smaller than the latest simulated period t_N. With these key indicators in mind we can now proceed to the actual implementation below.

1.2.4 Experimental setting

As explained on page 21, equivalent tax regimes of varying progressiveness were introduced to account for the effect of a negotiation that may be agreed by both parties on the political stability of the regulatory framework. These equivalent taxes, either nonlinear or windfall, were arranged to show increased progressiveness[18] so that the valuation of expropriation functions presented in the previous section can be of comparable nature.

Thus, while in Schwartz and Trolle (2010) the authors analysed how the political risk varied with different initial conditions for the dynamic price model for oil, or for static parameters such as K_1 or K_2, in this

[18] Using taxation of the form $Tax(S, k)$, the progressiveness parameter increases from $k = \delta_0 = 0$ to $k = \delta_{max}$ for nonlinear taxes and decreases from $\tau_{wf} = \tau_{inc}$ to $\tau_{wf} = 0$ in the case of the nonlinear tax.

chapter we focus on how the expropriation risk varies with a more progressive taxation regime, that is, how the variation of the parameter k affects the risk of the operations. The different initial conditions reviewed in this chapter are an extension of the ones presented in Schwartz and Trolle (2010) and are detailed below. In the original paper, the dynamics of the behaviour of commodity prices and of the related futures contracts are given by the single stochastic volatility model shown in Trolle and Schwartz (2009), it corresponds to a no-arbitrage model that considers an unspanned stochastic volatility and as such requires for its calibration the value of spot prices, futures curves and associated options from a complete options market. The calibration parameters found in table 1 of the paper by Trolle and Schwartz (2009)[19] were used here –requiring data of crude oil spot price, futures and options traded on NYMEX– so that the results that we show here for oil production are comparable with those obtained by Schwartz and Trolle (2010), with an equivalent baseline case ($k = \delta_0 = 0$ for nonlinear taxes or $k = \tau_{wf0} = \tau_{inc}$ for the windfall tax).

In addition to the dynamic price for oil used by Schwartz and Trolle (2010), a copper price model was introduced using the framework presented by Cortázar and Schwartz (2003), assuming spanned volatility and mean reversal for the long-term price of the commodity. This model was preferred over the one by Trolle and Schwartz (2009) for the copper case as it does not require a deep options market but can nevertheless represent the dynamics of both the spot price and of futures contracts. To calibrate the model, futures and spot prices were used; in this case we used data for copper prices available from Bloomberg (3,375 observations from 23 June 1997 to 17 November 2010) both for the spot price and for futures contracts of up to 10 years.[20]

Parameters

We also required to assign values for the multiple parameters in the expropriation valuation functions, such as the cost of exploitation by the incumbent company C_{firm} and the cost by the government C_{gov}. We relied, on the one hand, on the values used by Schwartz and Trolle (2010) for oil exploitation, while for the second set of simulations we relied on cost and operational data that was available from the Chilean copper commission (COCHILCO),[21] and for the tax rate, on the information provided by Otto (2000) for the Chilean case. A summary of the values assigned to production and expropriation parameters can be seen in table 1.1 below.

[19] These are shown again in the first column of table 1.5 on page 65.
[20] More information about setting these parameters is available on page 64 of the appendix.
[21] Cf. Titelman Goren (2007) for comparative data of the costs of private and public companies' extraction costs.

Table 1.1: Comparison of parameters used for the simulation of expropriation models.

Constant parameters in the expropriation model			
Trolle and Schwartz (2009) Crude oil		Cortázar and Schwartz (2003) Copper	
τ_{inc}	0.60	τ_{inc}	0.35
C_{firm}	10	C_{firm}	1
C_{gov}	15	C_{gov}	1.7
Y_{t_n}	10/12	Y_{t_n}	10/12
T	10	T	10
N	120	N	120
K_1	50	K_1	3
K_2	1,000	K_2	60

$\boldsymbol{Y_{t_n}}$, the production per period of time, $\boldsymbol{\Delta t = T/N}$, is assumed to be constant unless told otherwise. $\boldsymbol{T}$ is the time horizon for the operations (in years); $\boldsymbol{N}$ is the number of discrete steps in the simulation process; $\boldsymbol{K_1}$, is the yearly compensation over the remaining lifetime of mine/oil field paid to the producers if expropriated. Finally, $\boldsymbol{K_2}$ is the reputational cost that a country will endure if it exercises the expropriation option.

Initial Conditions

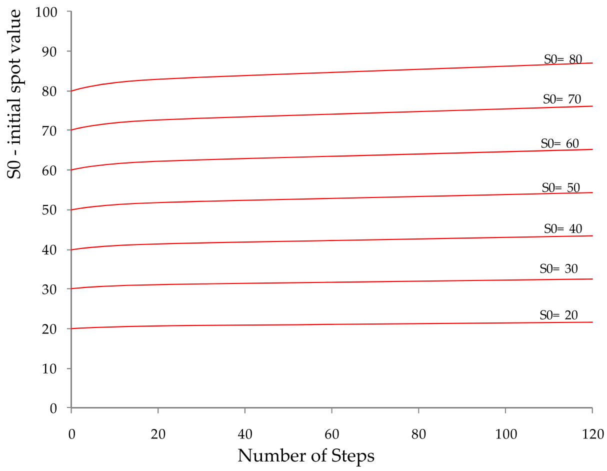
The construction of the dynamic price models for both oil and copper relied on the no-arbitrage condition, by which the unbiased expectation of the future spot price of the commodity at any given time is given by the price of the futures contract at that same moment, according to the identity,[22]

$$F(t_j, t_l) = E_{t_j}[S_{t_l}], \tag{1.28}$$

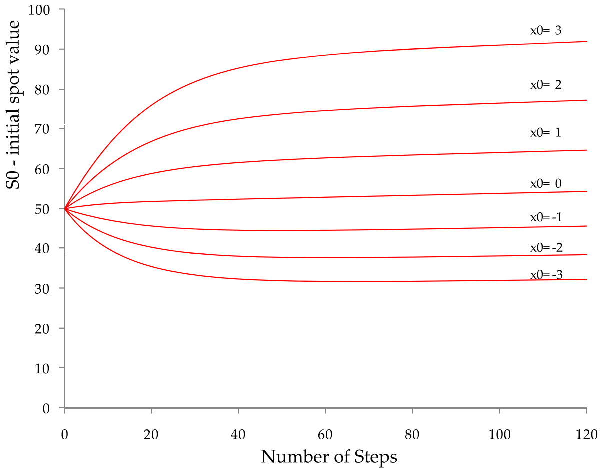
so that the expectation formed at time t_j of how prices are going to be at time t_l remains equivalent to the corresponding future contract valued at t_j and maturing at time t_l. Therefore, not only the initial spot prices, but also the shape of the futures contracts curve is going to determine the expectations that both governments and firms have. These are going to change from period to period as the futures contracts change, but nevertheless the price expectation that was formed at time t_0 remains unbiased due to the construction of the price model.

For this reason, we follow the methodology employed by Schwartz and Trolle (2010), that is, how the political risk –as defined by the previous valuation equations– changes given a set of initial conditions, as well as how

[22] Taken from equation (1.48) on page 65.



(a) Varying S_0, keeping x_0 constant



(b) Varying x_0, keeping S_0 constant

Figure 1.4: Futures curves for oil prices at time t_0 using the Trolle and Schwartz (2009) model, varying price parameters S_0 and x_0; each step represents a period t_j measured in months.

it responds to a variation on the tax structure by modifying the tax progressiveness parameters. The changes to the initial conditions are detailed below.

The case of Oil Price: In the Schwartz and Trolle (2010) paper, both the initial spot price S_0 and the shape of the initial futures contracts curve were modified. We used the same approach in this chapter to see how the effect of the initial conditions influenced political risk in presence of more progressive taxes, so that either the shape of the futures contracts curve was left unmodified, by setting the parameter $x_0 = 0$,[23] while changing the initial spot price of oil.[24] Additionally, the effect of the shape of the futures contracts curve was determined by keeping the initial spot price, S_0 constant at 50 USD/bbl and modifying the value of the parameter x_0. How these initial conditions vary is shown in figure 1.4.

Copper values: Initial conditions for the dynamic price model of copper were set analogously to the case of oil. First, the initial spot price, S_0, was changed leaving the futures contracts curve without modifications. Then, this curve was modified changing the parameter $\hat{v}_0$ in the model by Cortázar and Schwartz (2003).[25] Finally, and considering that the Chilean Budgetary Commission[26] forecasts a

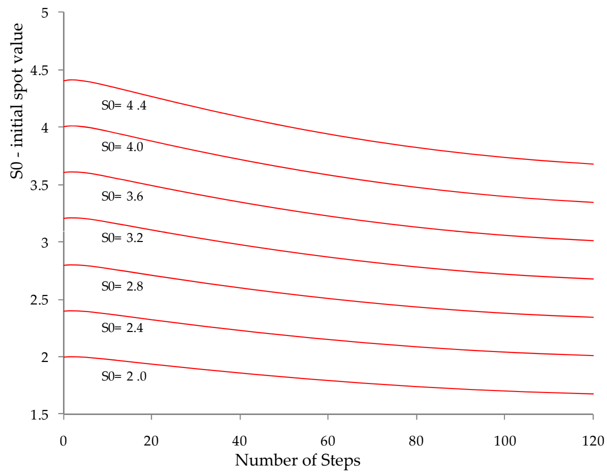
[23]The parameter x_0 defines the shape of the futures contracts curve in the Trolle and Schwartz (2009) dynamic price model, a positive value of x_0 implies a curve in strong contango while a negative value implies backwardation, as seen in figure 1.4b.

[24]The prices of oil selected for the dynamic price model in this chapter are on the vicinity of 50 USD/bbl, to acknowledge the real prices used in the calibration of the model as shown in Trolle and Schwartz (2009).

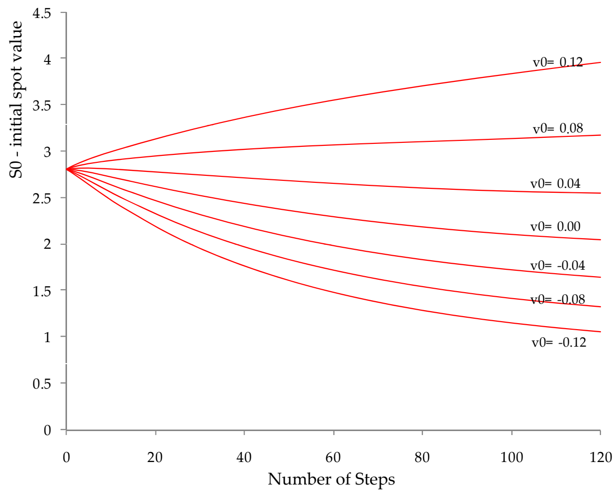
[25]As with x_0 in the oil price model, a negative value implies backwardation while a large positive $\hat{v}_0$ means that the futures contracts curve is in contango.

[26]This is the *Dirección de Presupuestos*, DIPRES, Chile's budgetary office depending from the Ministry of Finance.

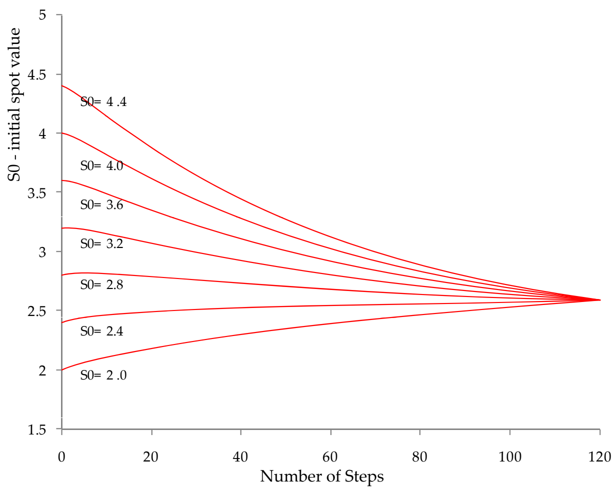
long-term price for copper (DIPRES, 2010), a third series of futures curves were created with different initial spot prices S_0 so that the long-term price, after 10 years, was of 2.59 USD/lb, the long-term outlook. All these initial conditions are shown in figure 1.5.



(a) Varying S_0 from 2.0 to 4.4 dollars per pound



(b) Varying $\hat{v}_0$ from -0.12 to 0.12



(c) S_T at 2.59 dollars per pound

Figure 1.5: Futures curves for copper prices using the Cortázar and Schwartz (2003) model, varying price parameters S_0, $\hat{v}_0$ and finally varying both in order to make S_T equivalent to long-term price of copper of 2.59 dollars per pound; each step represents a period t_j measured in months.

An overview of the results is presented below while the complete results are available in Section 1.3.

An overview of the findings

After running the political risk valuation model under different initial conditions and tax regimes, the results were compared with the 'intuition', the prior assumptions that motivated this research, and then an analysis was made to explain the resulting differences; below we can see a summary of what is covered in detail in the following section.

The intuition: The working hypothesis made before the model was implemented was that a more progressive taxation regime would decrease the political risk of a natural resources operation for an equivalent tax regime. With progressiveness in taxation as defined before in page 22, and with political risk defined solely as the exercise of the government's decision to expropriate the extractive operations.

Results: The intuition was confirmed to some extent: if the initial prices of the underlying commodity are low or if the futures curve is in strong backwardation we see that every single measure of risk decreases with the introduction of a more progressive tax regime; this is a Pareto optimum solution, as both the firm and the government see the value of their operations increase as the deadweight loss from expropriation recedes. Nevertheless, if prices are high enough, or if the futures curve is in strong contango we can see that the introduction of a more progressive taxation regime actually *increases* the risk of expropriation, in some cases reaching an almost certain and immediate take over by the government as soon as the new, more progressive, taxation regime is introduced.

Moreover, there were differences in the response to progressiveness in taxation between the different tax regimes: on the one hand, the introduction of a nonlinear tax showed that under unfavourable initial conditions political risk increased gradually and jointly with progressiveness; whereas in the case of windfall taxes, there was a jump in risk with the introduction of progressiveness that could be eliminated if the degree of progressiveness increased.

Finally, when comparing oil and copper price models; there was an increase in the overall risk of expropriation for both commodities if the initial price was high enough or if the futures curve was in strong contango. However, the effect was more pronounced in the case of the oil price model than in the copper case. It is conjectured that the higher sensitivity to the progressiveness shown by the oil price model can be attributed to the stronger reversion to the mean of the copper price model together with the differences in volatility between both price models.

Analysis: The results are analysed in detail at the end of next section; where the *timing* of the expropriation decisions is considered. One example is figure 1.17 on page 52, which shows us the difference between the timing of expropriation that takes place on low risk environments –most expropriation taking place on the second or third year of operations– with the surge in expropriation that takes place in riskier environments as progressiveness in tax increases, with almost all the expropriation decisions taken immediately. The increase on the expropriation risk when progressiveness is higher is counterintuitive in the sense that the value of the total payoff function, $\Pi(i, t_j, k)$,[27] decreases as predicted initially (and intuitively), however the expropriation decision is taken anyway because there are fewer prospects of expropriating profitably in the future.

Therefore, governments expropriate with higher progressiveness if prices are sufficiently large due to the fact that a decrease in the payoff function decreases the ability of the government to wait for further price increases; in such a way that governments become more *impatient* and for that reason the expropriation decision is taken in less favourable conditions. This is clearly shown when we see the evolution of an impatience coefficient at the end of next section: governments expropriate a higher proportion of positive payoff functions when tax progressiveness increases.

1.3 Results, political risk and tax structure

In this section we present the results obtained from running the expropriation model with the two sets of equivalent taxation regimes defined previously, together with an analysis of the reasons behind the departure from the 'intuition' that motivated this research.

1.3.1 The parameters for the initial conditions

As has been mentioned before, in order to see how tax progressiveness affected the political risk of a natural resources project we changed the initial price and futures contracts conditions. A summary of the analysed cases can be seen in table 1.2 below, where every initial condition is identified with a letter from **A** to **K**. Thus, for every commodity and every equivalent tax regime there is going to be a variation both in the initial spot price, S_0, and in the shape of the futures contracts curve. As the equivalent windfall tax regime

[27] As defined on page 29.

Table 1.2: Summary of modified price model parameters to generate sets of initial conditions for simulation.

	Trolle and Schwartz (2009) Crude oil				Cortázar and Schwartz (2003) Copper			
	# †	Varying	Range	Keeping Constant	# †	Varying	Range	Keeping Constant
Nonlinear	**A**	S_0	47 to 60	$x_0 = 0$	**C**	S_0	2.0 to 4.4	$\hat{v}_0 = 0$
	B	x_0	-0.5 to 1.5	$S_0 = 50$	**D**	$\hat{v}_0$	-0.12 to 0.12	$S_0 = 2.8$
					E	S_0	2.0 to 4.4	$S_T = 2.59$
Windfall	**F**	S_0	47 to 60	$x_0 = 0$	**I**	S_0	2.0 to 4.4	$\hat{v}_0 = 0$
	G ‡	S_0	61 to 74	$x_0 = 0$	**J**	$\hat{v}_0$	-0.12 to 0.12	$S_0 = 2.8$
	H	x_0	-0.5 to 2.0	$S_0 = 50$	**K**	S_0	2.0 to 4.4	$S_T = 2.59$

† Identification code for each simulated initial condition.
‡ There is an additional run with an increased initial spot price, S_0, given the robustness shown by the windfall tax regime.

proved to be more robust, we had to analyse an extended range of initial spot prices to see how the results from the two tax regimes were comparable.

1.3.2 Intuition and results: Nonlinear progressive taxes

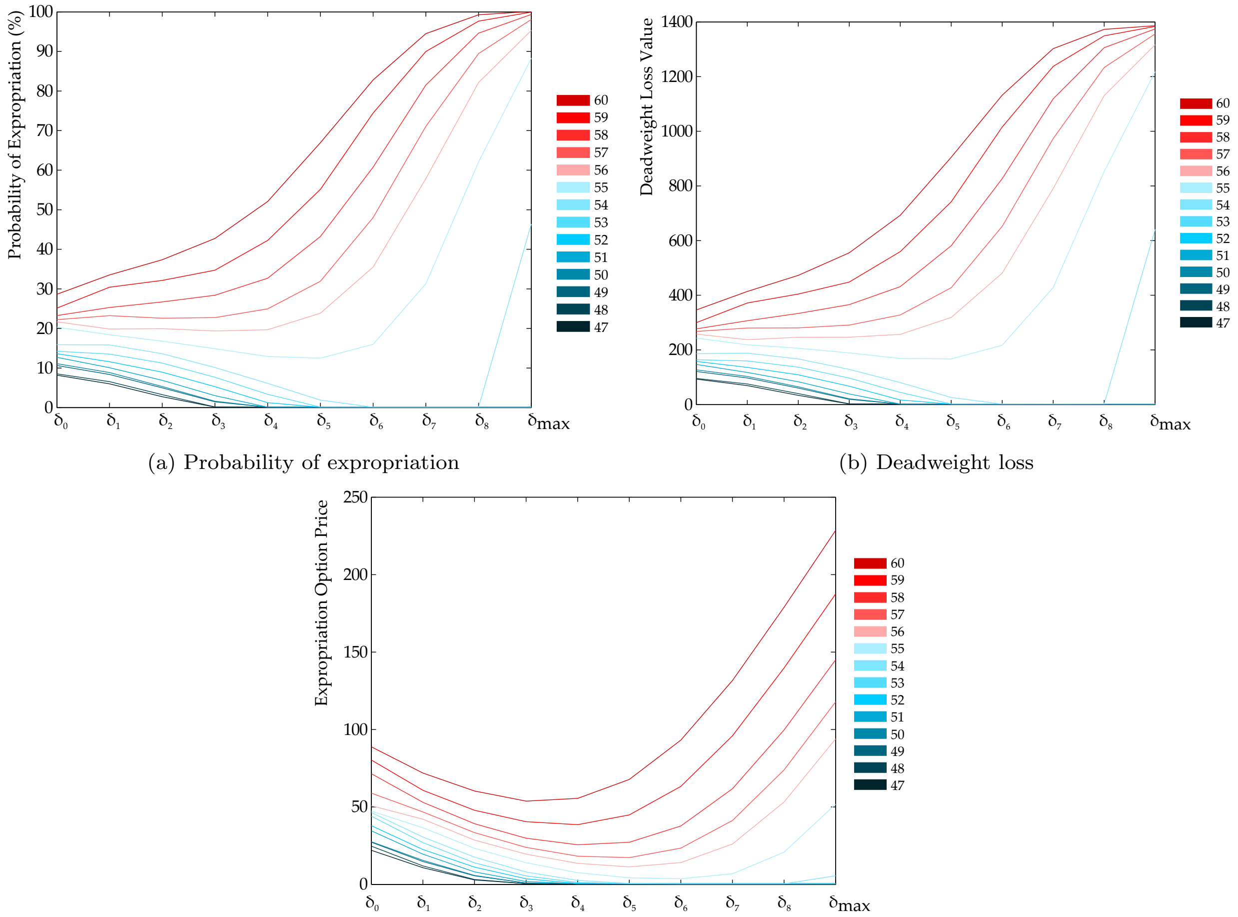
As could be seen previously in figure 1.3a on page 26, as the parameter δ increases in the nonlinear tax regime the tax capture changes *smoothly* to a more progressive regime. As a result, political risk[28] varies gradually as the progressiveness increases, in a direction determined by the initial conditions. The original 'intuition' was that a more progressive tax regime would minimise the political risk due to a higher tax capture when the underlying commodity price was higher, in the nonlinear tax case, this meant a lower risk of expropriation when the parameter δ is larger; this intuition can be contrasted with the results obtained for each commodity under variations of this tax regime which are presented below.

Oil price model under nonlinear taxes

When we analysed **how political risk varied with initial spot prices** we found that the more interesting results were in the region between $S_0 = 47$ and $S_0 = 60$. For this reason, here we show the results from that restricted interval of prices, which can then be extrapolated to the rest of the range without loss of generality.[29]

To acknowledge the increased progressiveness in taxation we chose a set of parameters δ_i as defined in page

[28] Or probability of expropriation as defined in equation (1.27) on page 31.
[29] This is case **A** as appears in table 1.2.



(a) Probability of expropriation

(b) Deadweight loss

(c) Price of expropriation option

Figure 1.6: Evolution of expropriation parameters (total probability, deadweight loss and price of the option) in the case of oil exploitation with increased progressiveness (given by δ_i) in nonlinear taxes with different initial spot prices S_0, which vary according to the colour scale at the right of each figure (Case **A** in table 1.2).

22, where $\delta_0 = 0$ was equivalent to the baseline flat corporate tax rate, and δ_{max} is the case where $\tau_{base} = 0$, the most progressive tax that can be attained maintaining equivalence and avoiding negative values for τ_{base}. The results thus obtained can be seen in figure 1.6; where the results for the political risk under different spot price conditions and progressiveness are shown for the nonlinear tax case. When prices are low, in this precise setting when S_0 is smaller or equal than 53, the *intuition* works, and both the risk of expropriation and the deadweight loss decrease with a more progressive tax regime.

However, if the initial spot price is too high what we observe is that the risk of expropriation not only does not decrease with a more progressive taxation regime, but that actually this risk *increases greatly*, reaching almost certainty of expropriation when δ_i approaches δ_{max}. This result goes completely against the intuition, and the reasons for it to happen are explained in point 1.3.4 below.

There is also another interesting result if we look at the price of the expropriation option as it is done in figure 1.6c, there we can see that even for higher spot prices, the value of the expropriation option *decreases* initially if we increase δ_i. That is, even though a government expropriates more in the case of high spot prices and higher δ_i what happens is that the value of the expropriation option is lower given that the conditions in which expropriation takes place are deteriorated.

By construction of the model, there is a strong correlation between the expropriation decision and the deadweight loss. As we could see in the definition of the expropriation value for the government, V_{gov}^{exp} in equation (1.22), there is a single reputational cost, K_2, that is not transferred to the companies and therefore is the source of the deadweight loss. As this correlation is kept throughout the studied cases, we will limit the analysis to the probability of expropriation and the price of the expropriation option from here onwards.[30]

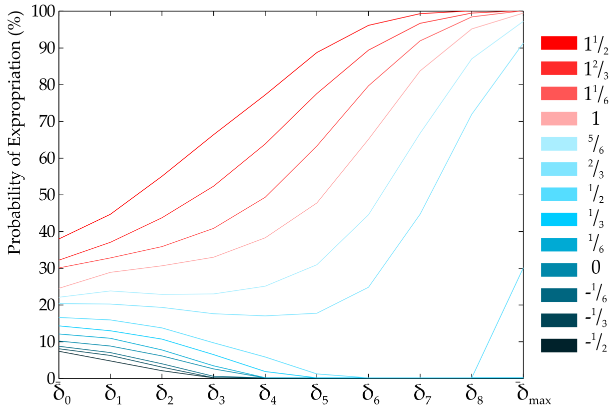
For the initial condition described as case **B** in table 1.2, that is, in order to see the effects that **the variation of the forward curve has on the overall risk of expropriation for the nonlinear tax regime**, we analysed the expropriation model with varying initial conditions where the spot price remained constant at $S_0 = 50$ while the shape of the futures curve changed varying the parameter x_0 from $x_0 = -0.5$ (slight backwardation) to $x_0 = 1.5$ (contango) as it was shown in figure 1.4b on page 34.

As before, the progressiveness of the tax regime was modified by increasing the parameter δ_i of the nonlinear taxation regime.

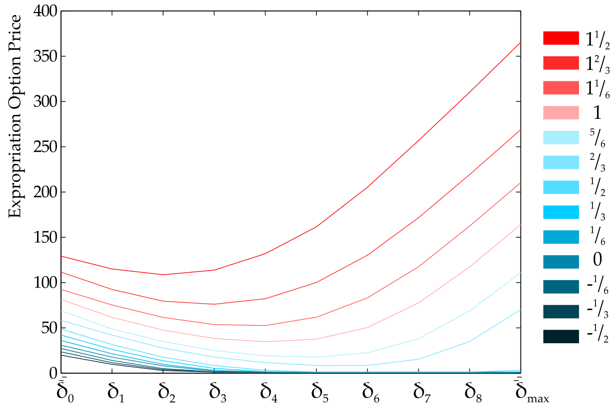
For these initial conditions, the results for the expropriation risk and the value of the option for the government are shown in figure 1.7 below, where we can observe that, similarly to what was noted in the case where S_0 changed, an increase in the values of δ_i decreases the risk of expropriation when the prices are in backwardation or when they are in slight contango, however when x_0 is large enough the prospect of higher prices in the future increases the risk of expropriation.

What is interesting is that in this case the government is not responding to current high prices, but to future high prices that can be expected from the unbiased nature of futures contracts pricing. Moreover, the price of the expropriation option *falls* initially as δ increases, even in those cases where there is more expropriation (i.e. when x_0 is higher) this is due to the same cause that was seen before, that when δ_i increases, the value of the payoff function decreases, and the expropriation takes place in worst conditions.

[30] Equations (1.27) and (1.26) respectively.



(a) Probability of expropriation



(b) Price of expropriation option

Figure 1.7: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of oil exploitation with increased progressiveness (given by δ_i) in a nonlinear tax regime with different initial shapes of the futures curves obtained by varying parameter x_0 which changes according to the colour scale at the right of each figure (Case **B** in table 1.2).

Copper price model under nonlinear taxes

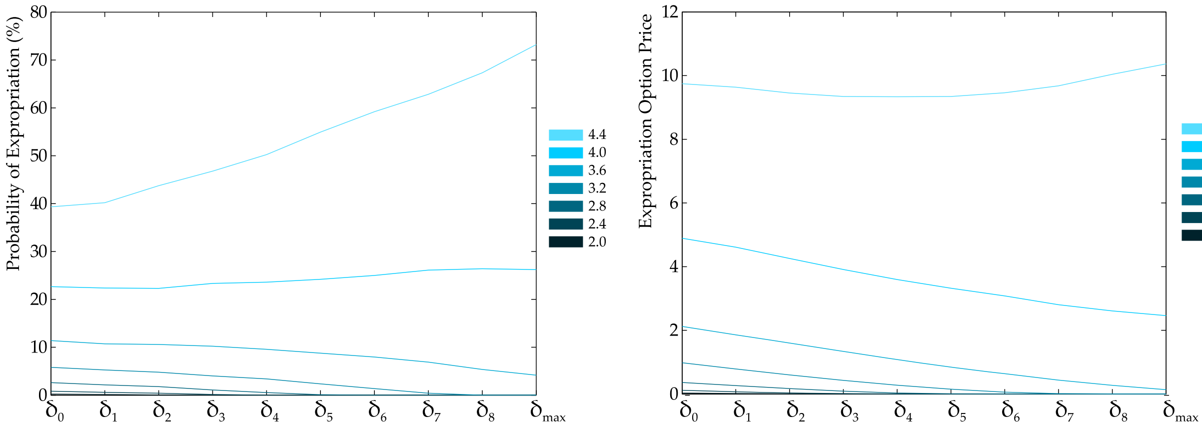
As has already been discussed, in order to generate price paths for the behaviour of copper prices, the model by Cortázar and Schwartz (2003) was selected due to its no-arbitrage property, to the fact that it had long-term reversion to the mean, and given that the necessary parameters could be obtained from the information set that was available. This price model has also non-stochastic volatility, and so it is relevant to see if the results obtained in the case of crude oil apply also for this commodity.

If results were comparable, then we would be able to extrapolate further results from one price model to the other, what really interested us then is whether we would still see an increase on the expropriation risk for high initial spot prices or for price curves in strong contango. Additionally, we observed the results for different initial conditions when there was a consensus over the long-term price.[31]

As in the previous cases, we analysed how political risk varied with **different initial spot prices** ranging from $S_0 = 2.0$ to $S_0 = 4.4\,USD/lb$ for different values of δ_i (case **C** in table 1.2). The results for the total expropriation risk and for the price of the option value are shown in figure 1.8.

As shown in the initial conditions depicted in figure 1.5a on page 35, when $\hat{v}_0 = 0$ the different initial futures curves in the Cortázar and Schwartz (2003) model are in backwardation, which according to what we just

[31] Here, long-term is defined as T the time horizon for the exploitation and depletion of the mine or oil field, where $T = 10$ years.



(a) Probability of expropriation

(b) Price of expropriation option

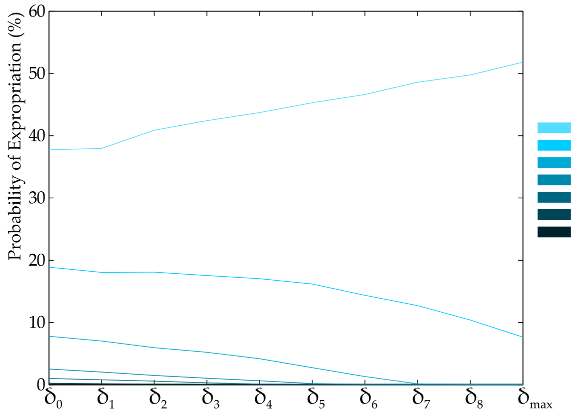
Figure 1.8: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of copper mining with increased progressiveness (given by δ_i) in a nonlinear tax regime with different initial values for the spot price of the commodity S_0, which varies according to the colour scale at the right of each figure (Case **C** in table 1.2).

saw in the oil production case, makes expropriation less likely. For this reason, the counterintuitive result of more expropriation for more progressive taxes is less pronounced than it was in the oil price model. However, given an initial spot price that is large enough we will encounter an increased expropriation risk for a more progressive taxation regime, confirming the results shown previously for the variation of S_0 in the oil price model.

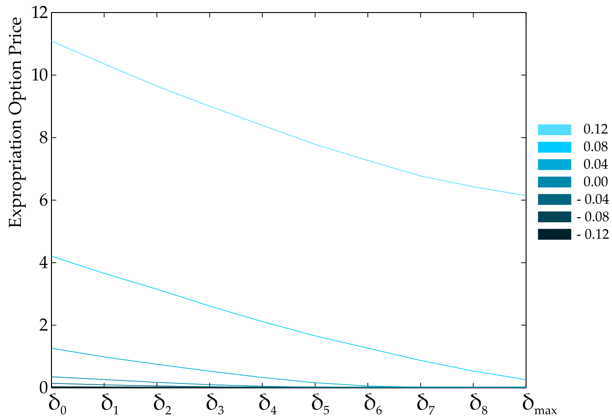
When we varied **the shape of the initial futures curve** for the case of the copper price model (case **D** in table 1.2), changing the parameter $\hat{v}_0$ from −0.12 to 0.12 (see figure 1.5b on page 35), we obtained the results shown in figure 1.9.

Again, similarly to what happened when x_0 changed in the oil price model, if the initial futures contracts curve is in stronger contango, implying a higher value for $\hat{v}_0$, the risk of expropriation might not decrease with more tax progressiveness due to the anticipation of higher prices to come in the future.

The last case to be analysed for nonlinear equivalent tax regimes (case **E** in table 1.2) was the one **where there is a consensus over the long-term price**. This was achieved by modifying the initial spot prices, in this case from $S_0 = 2.0$ to $S_0 = 4.4\,USD/lb$, while leaving constant the long-term estimate at $S_T = 2.59\,USD/lb$, according to the estimations of the Chilean Budgetary Commission. We were interested in knowing if the long-term average consensus affected the prospects of expropriation, and in this case that effectively happened, as we can see in figure 1.10, where the risk of expropriation is substantially lower for



(a) Probability of expropriation



(b) Price of expropriation option

Figure 1.9: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of copper mining with increased progressiveness (given by δ_i) in a nonlinear tax regime with different initial shapes of the futures curve obtained by varying the parameter $\hat{v}_0$, which varies according to the colour scale at the right of each figure (Case **D** in table 1.2).

even the highest initial spot prices analysed as the long-term expected price is considerably reduced.

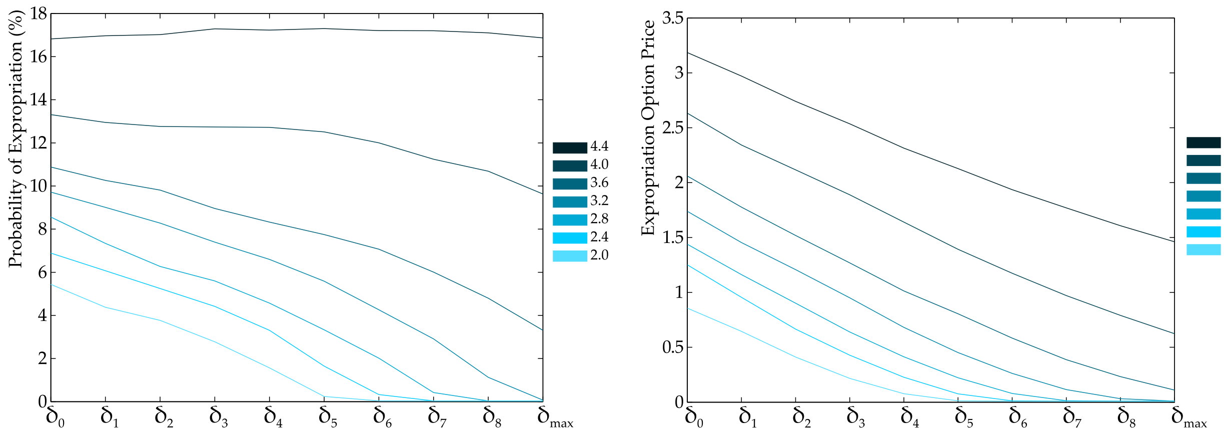
Comments on the results under nonlinear taxes

After analysing the obtained results under equivalent nonlinear taxes, it is possible to make the following remarks:

Initial spot price: For lower initial spot prices, a more progressive taxation regime effectively decreases the expropriation risk; however, this effect disappears after a certain threshold has been reached. Then, for this critical initial spot price S_0^* and for every $S_0 \geq S_0^*$ a higher value of δ (i.e. a more progressive taxation regime) has the opposite effect, increasing the risk of expropriation up until reaching nearly 100% in the most extreme cases.

Futures contracts curves shape: When the initial futures contracts curve at time t_0 is in strong contango we observed the same effect that was noted in the case of large initial spot prices, that is, the unbiased expectation of future prices affects the expropriation risk, increasing it in the case of more progressive taxation.

Competing dynamic price models: The models showed a different response to higher prices, or futures contracts curves in strong contango: the oil price model showed a stronger increase in political risk



(a) Probability of expropriation

(b) Price of expropriation option

Figure 1.10: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of copper mining with increased progressiveness (given by δ_i) in a nonlinear tax regime and varying initial spot prices with long-term average $S_T = 2.59\ USD/lb$, which vary according to the colour scale at the right of each figure (please note the inverted colour scale). This is case **E** in table 1.2.

with the increase of initial spot prices or the increase of futures contracts prices; however, this same effect was shown –though muted– for the copper price model. The causes for this difference reside in the stronger reversion to the mean shown in simulated copper prices together with the differences in the volatility for both models, which allows the existence of a larger initial dispersion of prices in the oil price model.

Now we are going to revise how political risk varied with the introduction of equivalent windfall taxes, so we can contrast the results to the nonlinear tax regime.

1.3.3 Intuition and results: Windfall taxes

One can view the windfall tax as the sum of two flat corporate profit taxes. The first one is exacted at the rate τ_i over corporate profits, while the second tax has a rate of $(1 - \tau_i)$ levelled over $[\max(S - S_{wf}, 0)]$, where S_{wf} is the windfall price and S the spot price at that moment. The resulting tax capture therefore will have a kink, as can be seen in figure 1.3b on page 26. Making that the nature of the tax will change abruptly if prices are above the previously defined windfall price.

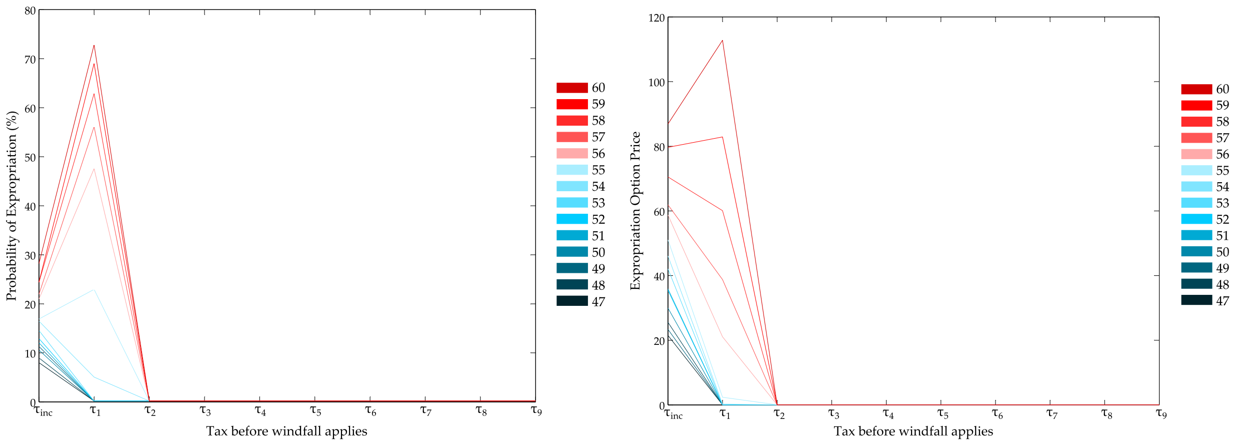
As in the case of the nonlinear tax, the 'intuition' is that a more progressive tax (i.e. both a lower initial tax rate τ_i and a lower windfall price S_{wf}) will increase the tax capture when prices are higher and therefore minimise political risk.

Oil price model under windfall taxes

We started by replicating the methodology employed for the nonlinear tax regime in order to analyse the different results that were achieved when using a windfall tax regime. For this reason, we started considering **how political risk varied with different initial spot prices** by using the same initial conditions as in the nonlinear tax regime (initial spot price, S_0, between 47 and 60).

Similarly to what has been done in previous cases, the progressiveness in the taxation regime was modified by choosing a parameter τ_i, the tax rate for prices below the windfall price, setting the initial value equal to τ_{inc}, the baseline corporate income tax, and gradually reducing it until it reaches zero. As we can see on the definition for the windfall tax regime on page 23, this reduction in the initial tax rate will imply a decrease in the value of the windfall price, so that the lowest windfall price attainable in this experimental setting (while keeping the equivalence of the tax regime) would be $S_{wf}(\tau_9 = 0)$.

Therefore, the results obtained in this case –which corresponds to Case **F** in table 1.2– can be seen in figure 1.11 below.



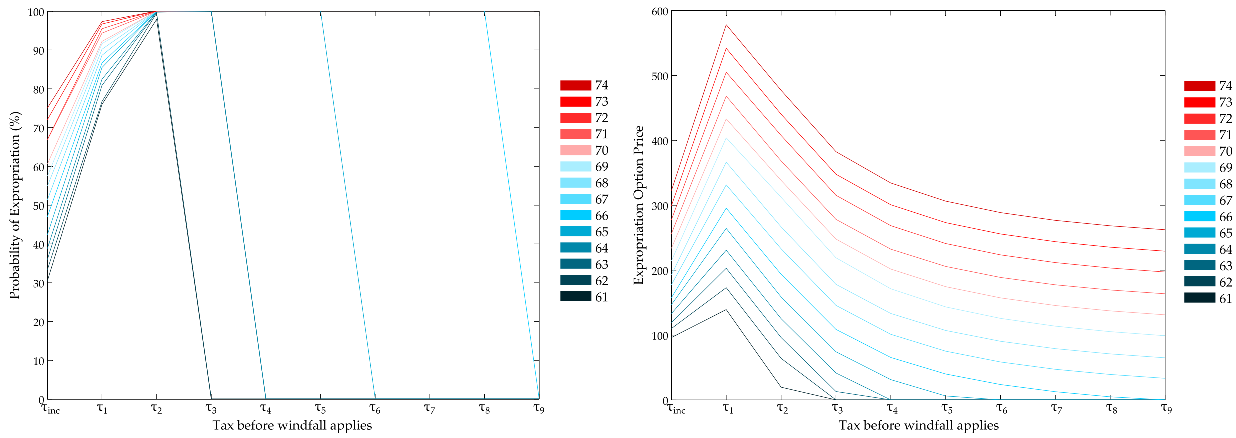
(a) Probability of expropriation (b) Price of expropriation option

Figure 1.11: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of oil exploitation with increased progressiveness (given by τ_i) in a windfall tax regime with different initial spot prices S_0, which vary according to the colour scale at the right of each figure (Case **F** in table 1.2).

At first glance, we can note immediately two things: first, for initial spot prices that are higher than a certain threshold (over 55 USD/bbl in this case) risk increases dramatically with the introduction of a windfall tax;

however, we can also note that this same expropriation risk goes to zero if taxes become more progressive. This result clearly contrasts with the nonlinear tax regime, where for the upper bound of prices in this interval we had an almost sure risk of expropriation.

This behaviour could be due to the windfall tax regime being more robust when taxes are more progressive for every single initial spot price or just for the studied interval. In order to clarify this, we considered **an interval where initial spot prices were higher** (Case **G** in table 1.2) to see if the risk evolved in a different way with progressiveness as prices got higher. The results for this new interval, with initial spot prices ranging from $S_0 = 61$ to $S_0 = 74$ are shown in figure 1.12 below.

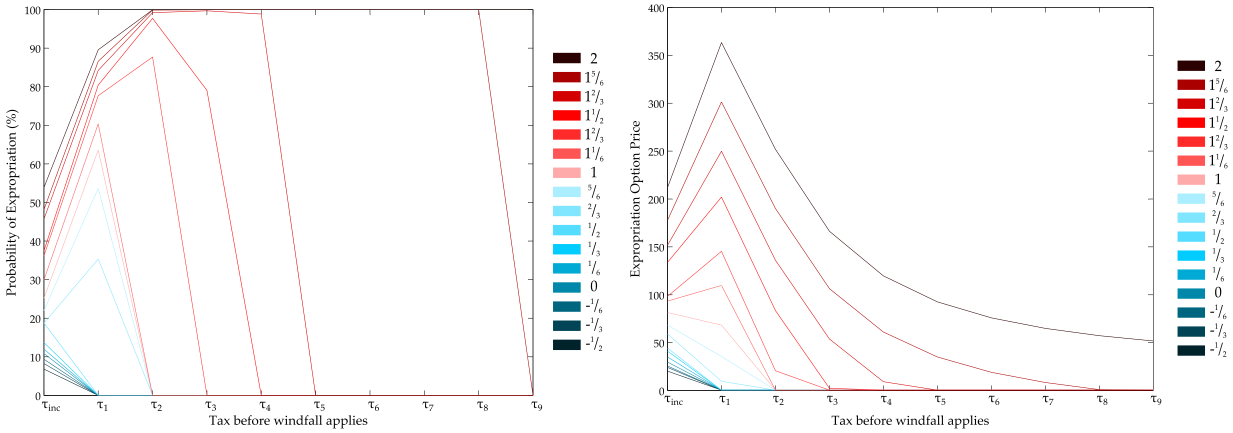


(a) Probability of expropriation (b) Price of expropriation option

Figure 1.12: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of oil exploitation with increased progressiveness (given by τ_i) in a windfall tax regime with different initial spot prices S_0, which vary according to the colour scale at the right of each figure (Case **G** in table 1.2).

Interestingly, as prices increase, the level of progressiveness required to diminish political risk also increases. That is, if initial conditions are more favourable for expropriation, more progressiveness is going to be required, until the price is so high ($S_0 = 67\, USD/bbl$ or higher in this case) that even with maximum progressiveness an equivalent tax regime is going to be unable to eliminate the political risk. Moreover, we can also see how after the price of the option jumps due to an increase in the expropriation probability it then slowly starts to decrease as this expropriation is taking place in worse conditions as tax progressiveness increases.

Similarly, to check whether **the shape of futures contracts curve generated similar results** when this curve was in strong contango, we varied the parameter x_0 (Case **H** in table 1.2) from −0.5 to 2.0 keeping the initial spot price constant at $S_0 = 50\ USD/bbl$. The results can be seen in figure 1.13 below.



(a) Probability of expropriation

(b) Price of expropriation option

Figure 1.13: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of oil exploitation with increased progressiveness (given by τ_i) in a windfall tax regime with different initial shapes of the futures curve, obtained by varying parameter x_0, which changes according to the colour scale at the right of each figure (Case **H** in table 1.2).

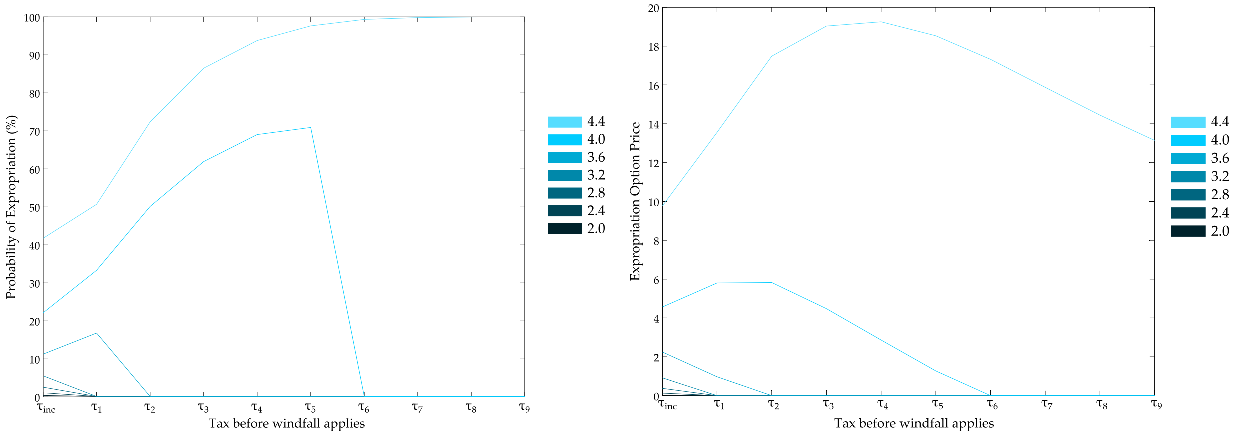
The results thus obtained are similar to the results of the extended initial spot price range (case **G**) for futures curve in contango even though the windfall tax regime proved to be quite robust at this initial spot price.

We will now look at the response that the copper price model has to the windfall price as it was done previously with the nonlinear tax regime.

Copper price model under windfall taxes

We tested different sets of copper prices generated with the Cortázar and Schwartz (2003) model using varied initial conditions to see the response they had to the real options expropriation model under windfall taxes. In the first case –Case **I** in table 1.2– we replicated **the change in the initial spot prices**, S_0, from 2.0 to 4.4 USD/lb, as it was done in the nonlinear tax regime so that we can observe the result in figure 1.14 below.

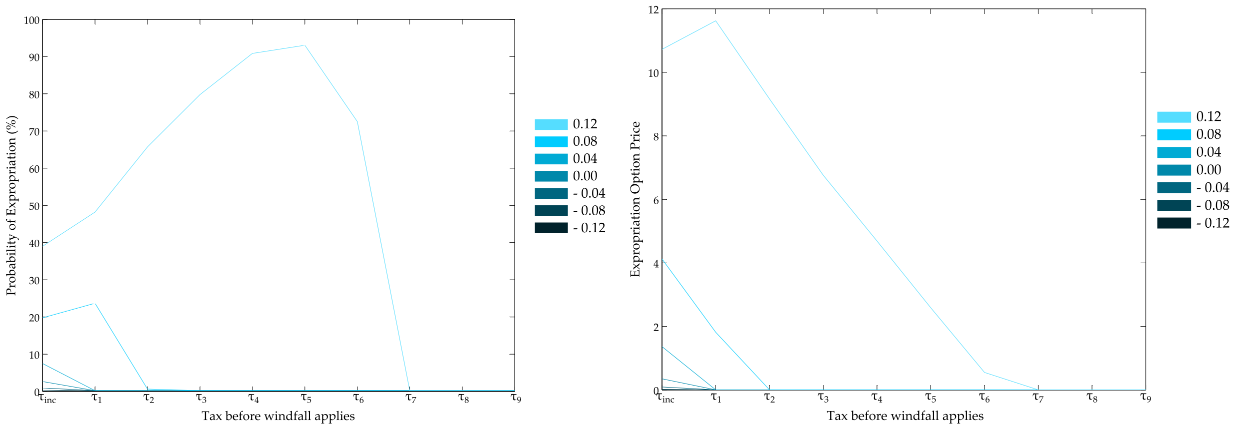
Here we can note that even if there are noticeable differences from the crude oil case, a common aspect is that for a given interval in prices the expropriation risk increases with progressiveness only to fall abruptly; and if prices are high enough (4.4 USD/lb in this setting), no equivalent tax regime can decrease the risk of expropriation risk.



(a) Probability of expropriation (b) Price of expropriation option

Figure 1.14: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of copper mining with increased progressiveness (given by τ_i) in a windfall tax regime with different initial values for the spot price of the commodity S_0, which varies according to the colour scale at the right of each figure (Case **I** in table 1.2).

When the **shape of the futures price curve was changed**, also in similarity with the nonlinear case going from backwardation (where the initial price model parameter $\hat{v}_0 = -0.12$) to a strong contango (with the same parameter $\hat{v}_0 = 0.12$), we obtain results for the expropriation model that can be seen in figure 1.15 below.

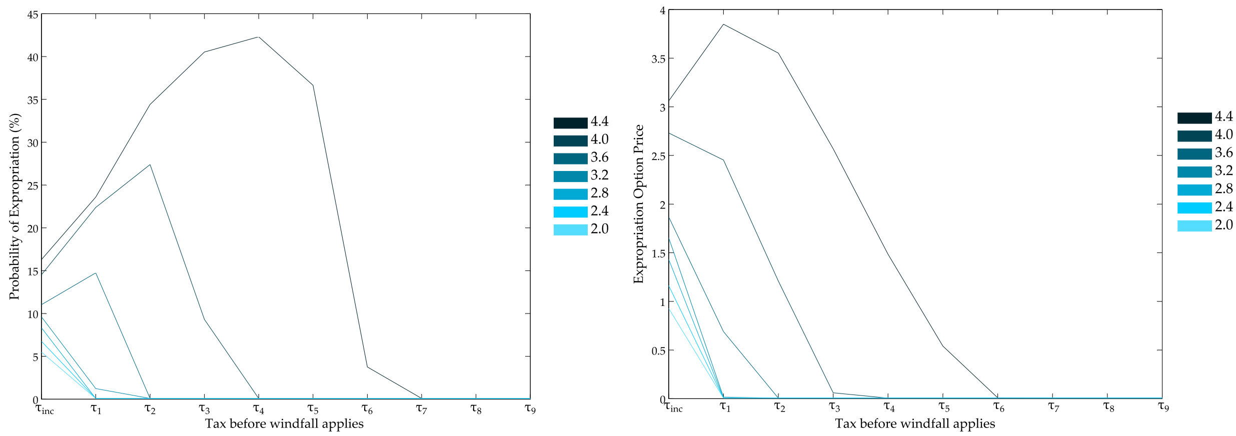


(a) Probability of expropriation (b) Price of expropriation option

Figure 1.15: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of copper mining with increased progressiveness (given by τ_i) in a windfall tax regime and different initial shape of the futures curve by varying the parameter $\hat{v}_0$, which varies according to the colour scale at the right of each figure (Case **J** in table 1.2).

These results are not dissimilar to those that can be obtained from c**hanging the initial spot price,** S_0 **while keeping the long-term copper price constant at** $S_T = 2.59\ USD/lb$, as can be seen in figure

1.16b below.



(a) Probability of expropriation

(b) Price of expropriation option

Figure 1.16: Evolution of expropriation parameters (total probability and price of the expropriation option) in the case of copper mining with increased progressiveness (given by τ_i) in a windfall tax regime and varying initial spot prices with long-term average $S_T = 2.59\ USD/lb$, which vary according to the colour scale at the right of each figure (please note the inverted colour scale). This is case **K** in table 1.2.

In both cases what we see is a repetition of the pattern from case **I** above, with the caveat that in case **J** –the variation of the futures contracts curves– this curve is not in a strong enough contango to make expropriation inevitable when progressiveness is maximal. The same can be said from keeping the long-term outlook price constant, the range that was sufficient to make expropriation unavoidable in case **I** does not suffice due to the corresponding futures curves being in backwardation.[32]

Comments on the results under windfall taxes

The results differ somewhat to those obtained with nonlinear taxes, of these differences we can mention the following:

Initial spot price: We have already seen that, all else being equal, higher initial spot prices increased the expropriation risk for the project. However, with windfall taxes we saw that there are not one, but two different initial threshold prices. If the initial prices were low enough[33] then the introduction of a more progressive taxation regime would decrease the political risk of the operations. However, for a range of initial spot prices higher than this threshold the introduction of a more progressive taxation regime is going to generate a jump in the riskiness of the operations, a risk that will eventually disappear as

[32]As can be seen in figure 1.5c on page 35.

[33]The lowest initial spot prices of case **F** as can be seen in figure 1.11.

taxes become more progressive. Finally, if the initial spot prices are high enough, then no increase in the progressiveness of the equivalent windfall tax regime can make the risk to decrease.[34]. Though there are clear differences between the crude oil and the copper price model, the phenomenon of two threshold prices can also be seen for copper in figure 1.14

The futures contracts curve and the expectation of the long-term price: The results in these cases were quite similar to those observed when the initial spot price was the one that changed. However, for the copper price model,[35] the range of the curve for futures contracts did not go into a sufficiently strong contango, nor the initial spot prices were sufficiently high to reach a second threshold, though it can be argued that if these initial conditions were sufficiently adverse, the pattern of increased risk would repeat itself again.

Competing price models: It is clear that for every type of initial scenario the copper price model was more robust when progressiveness in taxation was introduced.

Below we will try to explain why the introduction of progressiveness in taxation might increase the risk for natural resource projects as well as the different effect that this same progressiveness has on different taxation regimes.

1.3.4 Impatience and expropriation risk: An Analysis of the results

So far, we have been able to see that equivalent and more progressive tax regimes can have counterintuitive effects on the political risk of operations if they are adopted under adverse initial conditions. In this section we will analyse the reasons for the departure from this intuition, in such a way that it provides some insight on the appropriate renegotiations that can effectively take place. cases.

A brief summary of the results

The purpose of this chapter is to see how the introduction of an equivalent taxation regime can affect the political risk of a natural resources project; we can summarise the effects that these different tax regimes had on the analysed price models in table 1.3 below. There, robustness to the introduction of a more progressive taxation regime is characterised according to two dimensions: *Fiscal Stability*, or the decrease in risk that

[34] This can be observed for the highest initial spot prices of case **G** as can be seen in figure 1.12.

[35] Cases J and K in table 1.2 and figures 1.15 and 1.16 respectively.

is consequential to the introduction of a new progressive tax regime; and *Smoothness*, or how this risk can change with minor variations of the progressiveness parameter.

Table 1.3: A summary of the robustness of introducing a progressive tax regime for different price models according to two dimensions: 'Fiscal Stability' and 'Smoothness'

	Price Model	
	Crude Oil	Copper
Nonlinear	$\downarrow\downarrow$ Fiscal Stability $\uparrow$ Smoothness	$\downarrow$ Fiscal Stability $\uparrow\uparrow$ Smoothness
Windfall	$\uparrow$ Fiscal Stability $\downarrow\downarrow$ Smoothness	$\uparrow\uparrow$ Fiscal Stability $\downarrow$ Smoothness

As can be seen, windfall taxes are more robust in having a lower risk than what could be expected from the same initial conditions than a nonlinear tax. But this comes at the cost of smoothness, where a minor variation in the progressiveness parameter can have a major change on the riskiness of the project. A windfall tax can thus be less risky with high progressiveness but more volatile under variations of the progressiveness parameter.

The timing of the expropriation decision

The counterintuitive result, that the risk of expropriation increases with progressiveness, has been thoroughly revised in the past subsections. Nevertheless, when we calculate the total probability of expropriation[36] every single expropriation decision is treated as equal, while we know that there are qualitative differences if there is an early decision to expropriate.

If this happens at the earliest period, t_1, the value of the operation for the private operating firm V^{exp}_{firm} will be reduced to the compensation payment over the remaining lifetime of the mine or oilfield, $K_1 \cdot T$, while if the expropriation decision is carried out later, then the private firm is going to participate in some of the upside or downside of the market. It is therefore interesting to observe the evolution of the timing of expropriation probability with increased progressiveness: the qualitative response to expropriation timing when facing increased progressiveness in taxation was almost identical for both the nonlinear and windfall tax regimes. We can see this pattern in figure 1.17 below, where we show the timing of expropriation of one

[36]Using equation (1.27) on page 31.

of the analysed cases (Case **A** from table 1.2), in which there was a variation of the initial spot price, S_0, for nonlinear taxes.

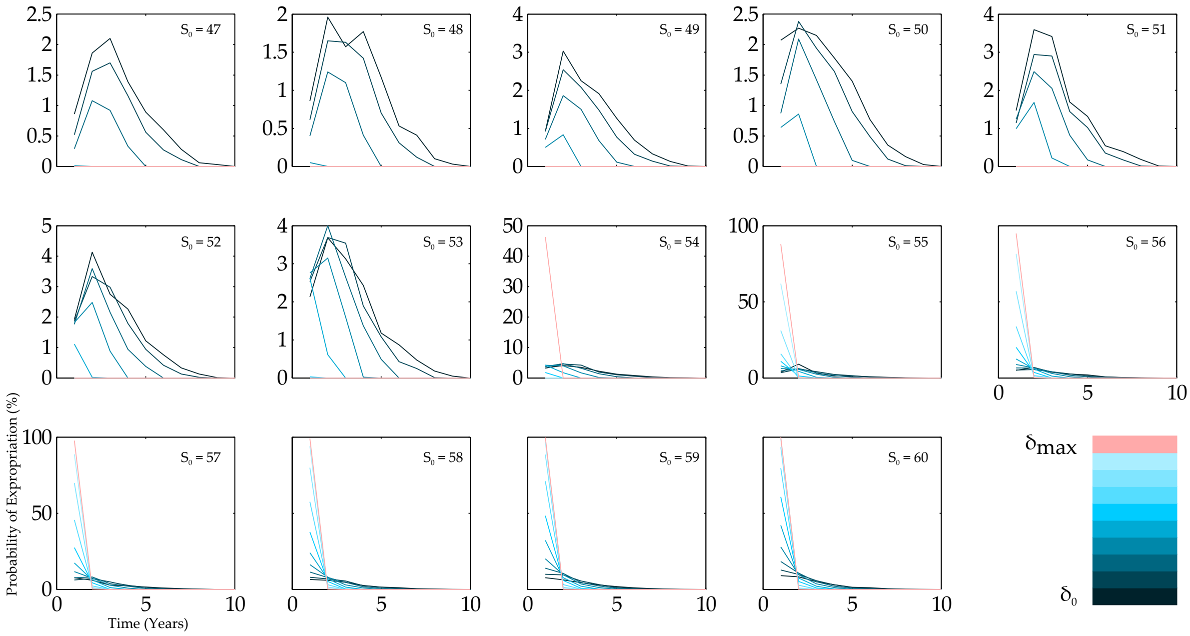


Figure 1.17: Timing of expropriation probability for the oil production case using the Trolle and Schwartz (2009) model under a nonlinear tax regime and different initial spot prices S_0, with progressiveness parameter δ between δ_0 and δ_{max}, each line representing a different value of δ according to the colour scale in the bottom right corner.

Here we can see that for low initial spot prices, S_0 from 47 to 53 USD/bbl in this case, the expropriation decision peaks at either the second or third year of operation, with expropriation risks being lower for more progressiveness –i.e. higher values of δ (lighter blue and red lines)– implying that the 'intuition' holds; however we should note that almost all expropriation in those cases with higher progressiveness takes place in the first two years.

At higher initial spot prices, the picture reverses and more progressive taxation induces a higher probability of expropriation (the counterintuitive result). Moreover, results are qualitatively different in that almost all expropriation takes place in the first year:[37] the fact that almost all expropriation decisions take place as early as possible when the tax regime is more progressive contrasts with the baseline case; and indicates that there is some intrinsic difference in the dynamics of the expropriation process when spot prices are high; something to be explored below.

[37] If we disaggregate the data further we can see that in the cases where the initial spot price is high enough, when progressiveness increases *all expropriation* takes place in the *first period of the first year*.

Payoff distribution and impatience

As has been discussed in previous sections, the expropriation model relies on an American-style option to value the expropriation risk; an option with a payoff function $\Pi(i, t_j, k)$ for each path i at time t_j with progressiveness parameter k, which has the following form:[38]

$$\Pi(i, t_j, k) = \max(V_{gain}(i, t_j) - V_{cost}(i, t_j, k), 0). \tag{1.29}$$

Where $V_{gain}(i, t_j)$ and $V_{cost}(i, t_j, k)$ represent the discounted gain and loss of exercising the option at each period t_j, so that if a government were completely short-sighted it would find attractive to expropriate whenever $\Pi(i, t_j, k) > 0$. This behaviour is prevented given that there is an alternative to exercise an option immediately, and that is to wait until the option itself becomes more *in the money*; if there are substantial prospects of further valuation we would see that governments would restrain from their willingness to expropriate in the short term even if their payoff function is positive.

As a consequence, there are going to be occasions where even if the payoff is positive, the government is going to refrain from expropriating a mine/oil field given that there are sufficient prospects of further valuation of the option; we can say that in those cases a government is not being *impatient*. In order to see how this patience, or the lack of it, evolves with a more progressive tax regime, the parameter k, we can define the *Impatience Coefficient*, as the quotient between the amount of expropriations that take place and the total amount of price paths that have a payoff function that is positive, the equation being the following:

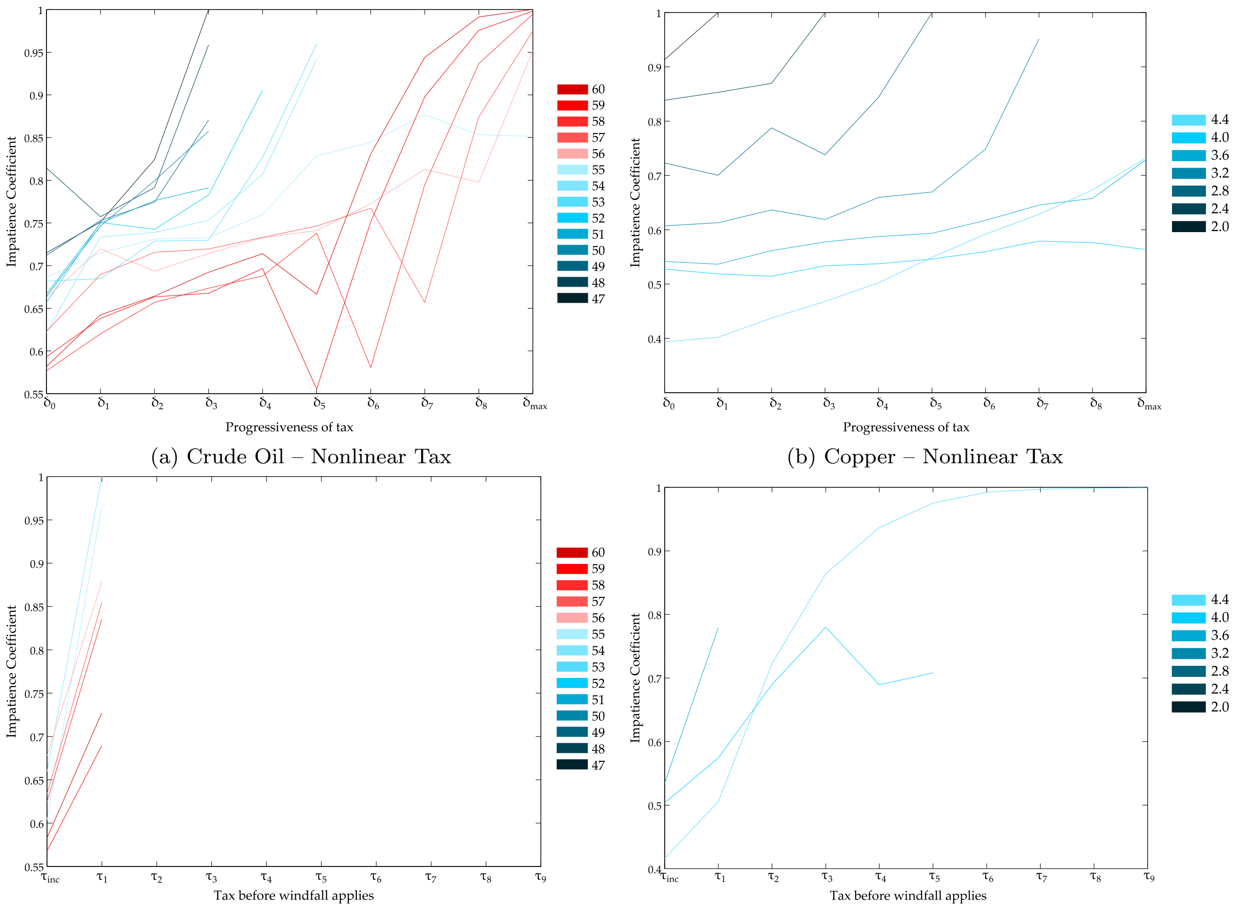
$$\textit{Impatience Coeff}\,(k) = \frac{\sum_{i=1}^{M} \boldsymbol{I}_{[t_N > t_{Z_i}]}}{\sum_{i=1}^{M} \max(\boldsymbol{I}_{[\Pi(i,t_j,k)>0]} \quad \forall\, t_j \in \{t_1, \ldots, t_{N-1}\})}\ , \tag{1.30}$$

where M is the total number of simulated price paths, $\boldsymbol{I}_{[t_N > t_{Z_i}]}$ is an indicator function equal to one if an expropriation decision is taken in price path i and the denominator is equivalent to the total number of price paths that have at least one payoff function that is positive through the lifespan of the mine/oil field.

The *Impatience Coefficient* is therefore going to be a value between 0 and 1, where 1 implies complete impatience: in that case, the government will expropriate any path that has a positive payoff function at least at one period. We can see how these coefficients evolve with progressiveness for every price model and tax regime when changing initial spot prices in figure 1.18 below.

The Impatience Coefficient increases with progressiveness, **even in those cases where the overall ex-**

[38] Taken from equation (1.20) on page 29.



(a) Crude Oil – Nonlinear Tax

(b) Copper – Nonlinear Tax

(c) Crude Oil – Windfall Tax

(d) Copper – Windfall Tax

Figure 1.18: Evolution of the *Impatience Coefficient* for the Crude Oil and Copper price models under Nonlinear and Windfall tax regimes with increased progressiveness in the applicable tax. Initial spot price of the commodities varies according to the colour scale at the right of each figure. These cases correspond to cases **A**,**C**,**F**, and **I** in table 1.2 respectively.

propriation risk is decreasing, what happens is that there are fewer prospects of an increase in the payoff function in the future. These results are also replicated with other initial conditions, such as the change in the initial futures contracts curves.

This variation in impatience can be better understood if we see how the values of the payoff function evolve with increased progressiveness. For example, in the case of the crude oil price model with nonlinear taxes (case **A** from table 1.2) the evolution of the expropriation probability and of the value of the expropriation option for two initial conditions under varying progressiveness can be seen in table 1.4 below.

Table 1.4: Expropriation probability and value of the government's expropriation option for initial spot prices S_0 = 50 and S_0 = 60 in the crude oil price model under varying progressiveness from the nonlinear taxation regime.

	Expropriation Prob S_0		Price of Exp. Option S_0	
	50	60	50	60
δ_0	10.98%	28.53%	34.16	88.35
δ_1	8.75%	33.41%	19.11	71.45
δ_2	5.22%	37.23%	7.67	59.82
δ_3	1.50%	42.60%	1.38	53.30
δ_4	0.00%	51.96%	0.00	55.09
δ_5	0.00%	66.82%	0.00	67.33
δ_6	0.00%	82.66%	0.00	92.72
δ_7	0.00%	94.37%	0.00	131.14
δ_8	0.00%	99.11%	0.00	178.51
δ_{max}	0.00%	99.98%	0.00	228.11

We can now see how the distribution of the positive values from the payoff function, $\Pi(i, t_j, \delta_i)$ evolved under these initial conditions; these values are presented in figures 1.19 and 1.20.

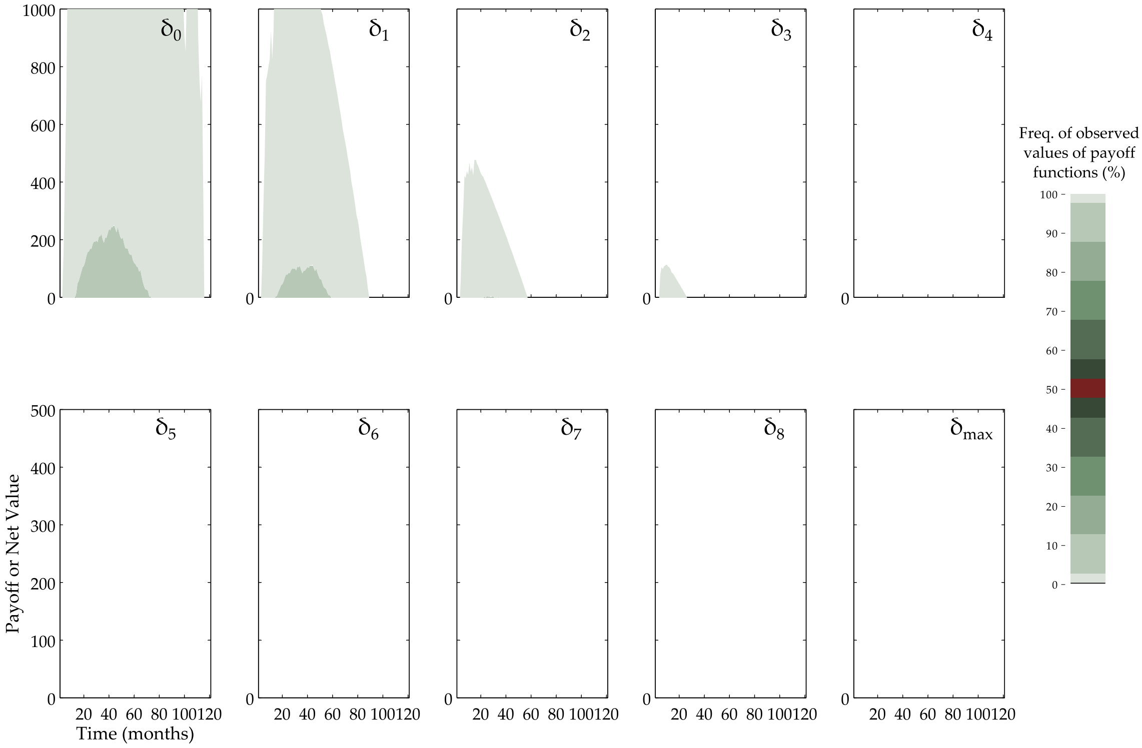


Figure 1.19: Evolution of the positive values of the undiscounted payoff function $\Pi(i, t_j, \delta)$ for the oil price model, with increasing progressiveness parameter δ (nonlinear tax regime) when S_0 = 50. Colours represent the distribution of the different price paths when M = 10,000.

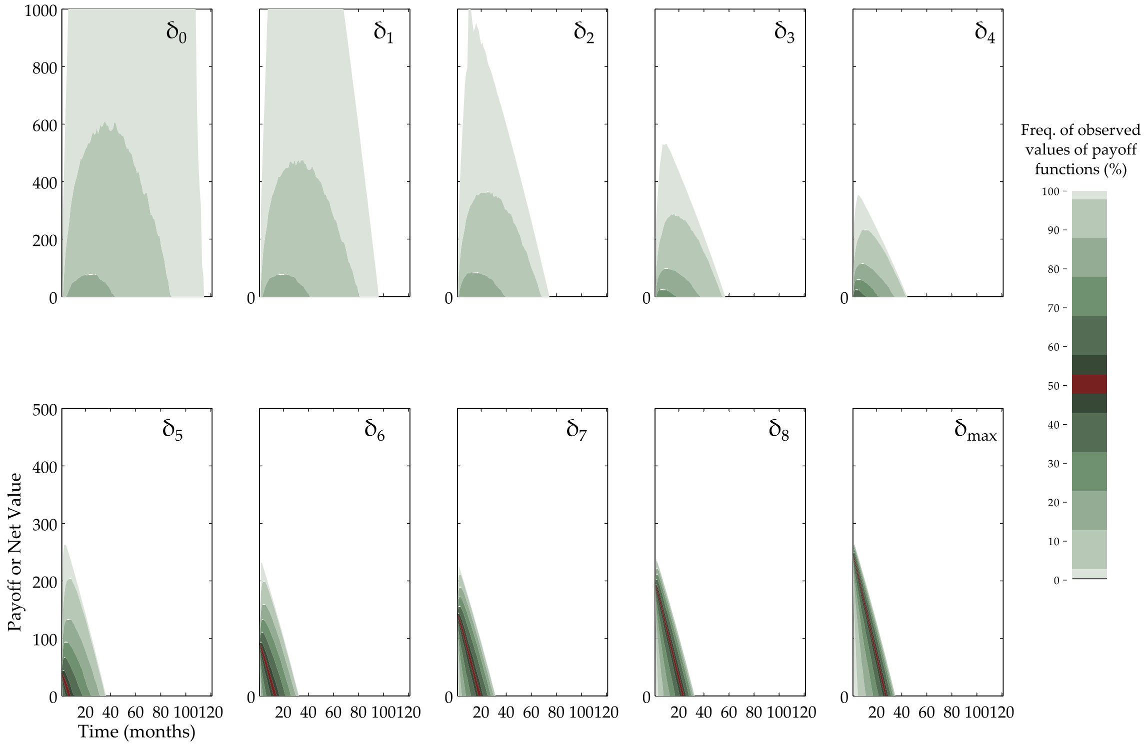


Figure 1.20: Evolution of the positive values of the undiscounted payoff function $\Pi(i, t_j, \delta)$ for the oil price model, with increasing progressiveness parameter δ (nonlinear tax regime) when $S_0 = 60$. Colours represent the distribution of the different price paths when $M = 10,000$.

From table 1.4 we know that when $S_0 = 50\, USD/bbl$ an increase in the progressiveness parameter δ will rapidly decrease the probability of expropriation from almost 11% to zero: figure 1.19 shows us the reason for this decline, that the total number of price paths that had a positive payoff decreased with the increase in δ_i until finally disappearing when the parameter was δ_4 or larger.

In the case where $S_0 = 60$, which can be seen in figure 1.20, an increase in the progressiveness parameter δ also decreases the magnitude of the most extreme positive values for the payoff function. However, we can also see that the distribution of these payoffs starts skewing towards the initial periods, and that there is a higher frequency of positive payoffs at the beginning. It is this concentration of positive payoffs at the initial periods of exploitation and the corresponding skewness of the payoff function, which suppresses the probabilities of appreciation for the American-style option, what prompts the option to be exercised.

We can extend this same analysis to the windfall tax, where the same phenomenon applies –reduction in the value of the payoff function, increase in its skewness, and an initial payoff value that it is positive– the main difference being that in some range the skewness is rapidly introduced (and hence, a jump in the expropriation risk), but as the windfall tax, τ_{wf}, becomes more progressive the magnitude of the payoff function decreases and so there is no payoff function with positive value; this can be seen more clearly in figure 1.21, which shows us the payoff function for an initial price of oil of $S_0 = 60$ under windfall taxes.

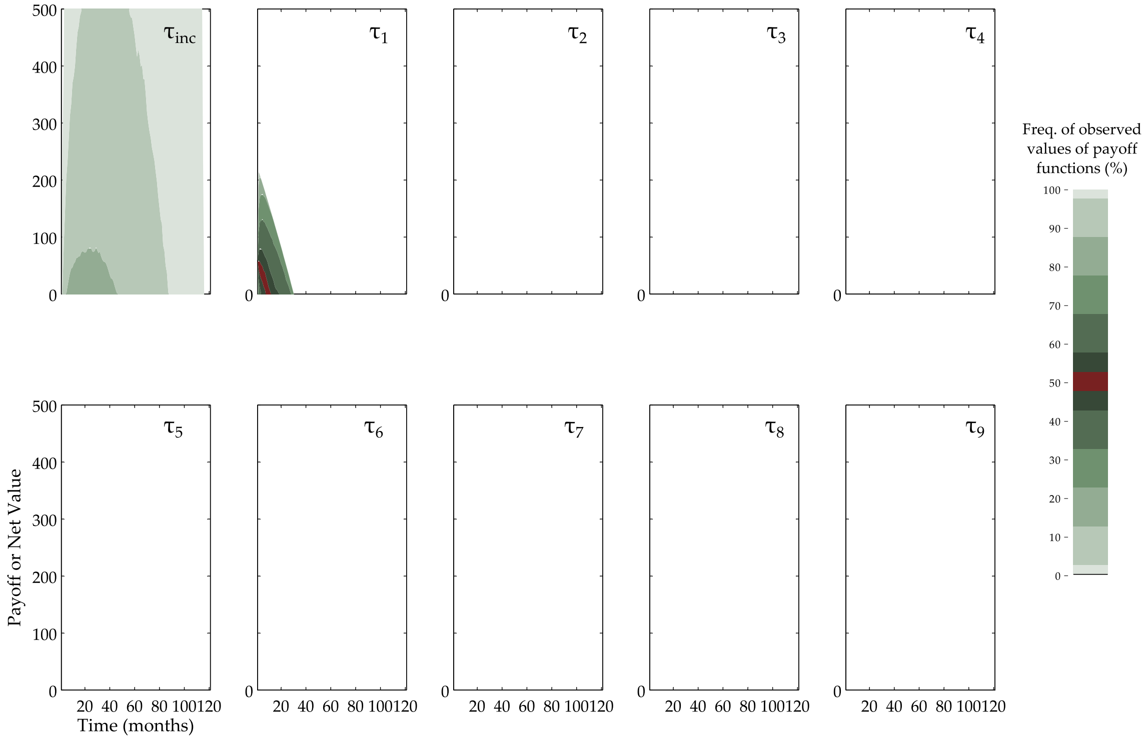


Figure 1.21: Evolution of the positive values of the undiscounted payoff function $\Pi(i, t_j, \tau_{wf})$ for the oil price model, with increasing progressiveness parameter τ_{wf} (windfall tax regime) when $S_0 = 60$. Colours represent the distribution of the different price paths when $M = 10,000$.

In this case, as we could see previously in figure 1.11a, expropriation jumps when the windfall tax regime is introduced ($\tau_{wf} = \tau_1$) and then plummets. What it is interesting in this case is the surge in expropriation risk that is caused by the extreme skewness of the payoff function; as the windfall acts like a barrier to further appreciation of tax collection for prices over S_{wf1}.

In summary, when taxes become too progressive and initial conditions are not favourable (high initial prices or futures curves into strong contango), the maximum magnitude of the payoff function decreases, but at the same time the initial conditions of this payoff begin to be *in the money*, the option has an immediate value. And it is this combination of lower maximum values for payoff that decreases expectations and initial favourable conditions that make expropriation favourable under more progressive tax regimes which make equivalent progressive taxation to be riskier when initial conditions exceed certain thresholds.

1.4 Conclusions

As we have been able to see in this chapter, the initial hypothesis described as the 'intuition' –that a more progressive taxation regime lowers the political risk of natural resource operations– is only partially true. Whenever current spot prices or the unbiased expectation of future prices are sufficiently large, the government will become more impatient after introducing an equivalent taxation regime that is more progressive, expropriating more and in worse conditions than if the baseline corporate profit tax were maintained.

That being said, it must be still emphasised that for a broad range of prices, a more progressive tax regime effectively decreases the probability of expropriation and enhances the total social value of the mining/oil operations.

Some conclusions that apply to every model analysed in this chapter are the following.

Long-term expectations matter

The expropriation model as set by Schwartz and Trolle (2010), implicitly relies on the assumption that the no-arbitrage condition holds at every moment. As we considered that both firms and the government were risk neutral, this condition allows us to replace the value of the initially expected spot price of the underlying commodity at time t_j, $E_{t_0}[S_{t_j}]$, with the value at t_0 of the futures contract maturing at t_j, $F(t_0, t_j)$.

The consequence of this is that the shape of the futures curve at the initial moment has a long-term effect, affecting the firm's and the government's expectations of income from the operations up until the end of the life of the mine/oil field. This is due to the dynamics of the price models being used, a dynamic behaviour that is further enforced by the 'calibration' of price paths as detailed on page 65.

This long-term dependence of the price distribution implies that the risks of expropriation can be foreseen ex ante by both parties, and therefore that firms will value their expected cash flows at an additional discount when expropriation risks seem to be higher.

Negotiating change

Another conclusion that can be drawn from the results is that negotiating a change in the tax regime becomes especially sensitive when prices or the expectation of future prices are high. To minimise compensation costs, governments can be tempted to negotiate a tax modification that leaves companies' expected income after taxes unchanged, and so could be willingly agreed by both parties. However, as we have seen in this chapter, changing the tax regime under unfavourable initial conditions for an equivalent but more progressive taxation structure will increase the political risks of the operations and decrease the total social value for firms and governments alike.

Therefore, negotiations to change a tax regime should be done considering long-term price expectations, and in those cases where the futures prices are high, the government and the firms should abandon the idea that a tax reform that does not affect the expected income for the companies can be carried out without major side effects. The answer in this case is to choose a different sort of tax reform, one that increases reputational costs, K_2, or that compensates the increased tax burden on companies with upfront payments or tax breaks that force governments to become more patient if they wish to retrieve taxes from accumulated gains.

The role of nonlinear and windfall tax regimes

As we mentioned at the beginning of this chapter, the definition of an equivalent taxation regime is sufficiently broad to allow a number of possible taxation regimes that vary in its progressiveness. This chapter focused on only two families of taxes, a nonlinear tax regime, following the suggestion of Stroebel and van Benthem (2013), and a windfall tax regime which is inspired by the optimal tax proposed by Engel and Fischer (2010). As could be noted in the results, the windfall tax regime appeared to offer more assurances of fiscal stability when initial conditions were equivalent, and taxes were highly progressive.

However, this increased robustness in fiscal stability terms must be weighed against the increased volatility with respect to the progressiveness parameter shown by the windfall tax regime. A small variation in τ_{wf} can have a huge incidence in perceived risks, and therefore in those cases where there is a higher uncertainty about the value of the parameters, the inclusion of a nonlinear tax regime that decreases the risk would be preferable as it would result in a tax regime that withstands fluctuations of the parameters without a massive jump in risk.

Extending the model

All the variations of the model presented in this chapter take production parameters as certain. However, as we have just seen, the inclusion of some volatility in the magnitudes can have a major effect in the perceived political risk; and more so if the equivalent taxation regime that's being implemented is highly sensitive to these changes.

Even when there are national resource companies in operation and the extraction process is well known, some uncertainty about the costs of operation will remain[39] and therefore it would be interesting to see how uncertainty on C_{firm} and C_{gov} would affect the decision process.

Moreover, the size of the mine/oil field is known only approximately when the operations begin; and the exploitation rate is going to be driven by this process as well as by the current and expected price of the commodity. A variation of the multiple real options analysis by Aleksandrov and Espinoza (2011) may represent the ability of natural resources companies to adapt their production rate according to market and geological news, a version of which will be presented in the following chapter.

Finally, some opacity in the production variables can be strategically managed by the multinational firms in order to minimise risks; therefore, providing an effective complement to fiscal stability promises made without commitment.[40] Considering how this can be done will provide additional tools for governments so that they can maximise the social benefit that arises from the exploitation of their national resources.

[39]See for example COCHILCO (2008) for an estimation of copper extraction costs in Chile.

[40]This is the line taken by Dixit (2004) among others.

Appendix

1.A Price Paths for Monte Carlo Simulations

The dynamic price models used in this chapter generate a sequence of spot prices S_{i,t_j} for each commodity, together with a corresponding futures contracts curve for every single price path available in the simulation at every period and for every maturity. These price paths and futures contracts are going to depend on some initial conditions (of which initial spot price and the shape of the futures contracts curve at the initial time are most important) and on the realised values of a random Wiener processes. Coincidentally, in these two models the stochastic element is described using three variables dz_1^*, dz_2^* and dz_3^* which are correlated Wiener processes so that:

$$\begin{aligned} dz_1^* dz_2^* &= \rho_{12} dt, \\ dz_1^* dz_3^* &= \rho_{13} dt, \\ dz_2^* dz_3^* &= \rho_{23} dt. \end{aligned} \tag{1.31}$$

Hence, if we know the correlation parameters, ρ_{ij}, we can generate these elements and the subsequent price paths from independent standardised normal random variables using a Cholesky decomposition.

1.A.1 The Trolle and Schwartz (2009) price model

In the model presented by Trolle and Schwartz (2009) the dynamics of the spot price of a commodity are based on a *single stochastic volatility model* that relies on Itô's lemma to replace the spot price for $s = \log(S)$. Therefore, for each generated path i we will have the following equations:

$$ds_{i,t} = \left(\varphi + \alpha x_{i,t} + \alpha \phi_{i,t} - \frac{1}{2}\sigma_S^2 v_{i,t}\right) dt + \sigma_S \sqrt{v_{i,t}} dz^*_{1,i,t} \ , \tag{1.32}$$

$$dx_{i,t} = \left(-\gamma x_{i,t} - \left(\frac{\alpha}{\gamma} + \rho_{12}\sigma_S\right) v_{i,t}\right) dt + \sqrt{v_{i,t}} dz^*_{2,i,t} \ , \tag{1.33}$$

$$dv_{i,t} = (1 - \kappa_v v_{i,t})dt + \sqrt{v_{i,t}} dz^*_{3,i,t} \ , \tag{1.34}$$

$$d\phi_{i,t} = \left(\frac{\alpha}{\gamma} v_{i,t} - 2\gamma\phi_{i,t}\right) dt \ . \tag{1.35}$$

As can be noted, the stochastic volatility is described by equation (1.34), and affects the dynamics of both the log of the spot price, $s_{i,t}$, and of the futures curves parameter, $x_{i,t}$. Given certain initial conditions we can simulate paths for the spot price using equation (1.32); and for each path i, where $i \in \{1, \dots, M\}$, we can generate futures contracts at every time t_j maturing at time t_l according to:

$$F_i(t_j, t_l) = \exp\left[\varphi(t_l - t_j) + s_{i,t_j} + \frac{\alpha}{\gamma}\left(1 - e^{-\gamma(t_l - t_j)}\right) x_{i,t_j} + \frac{\alpha}{2\gamma}\left(1 - e^{-2\gamma(t_l - t_j)}\right)\phi_{i,t_j}\right] \ . \tag{1.36}$$

1.A.2 The Cortázar and Schwartz (2003) price model

The article by Cortázar and Schwartz (2003) introduces us to another mean-reversal model for generating prices that are consistent with a no-arbitrage condition in their futures curve. In this chapter this model was used to generate a representation of the behaviour of copper prices and their corresponding futures contracts at every time t, by simulating the spot, S_t, the demeaned convenience yield, y_t, and the expected long-term spot price return v_t (with a long-term average $\bar{v}$ as a parameter). For the risk-neutral process we will have the following equations for each generated path i:

$$dS_{i,t} = (v_{i,t} - y_{i,t} - \lambda_1)S_{i,t}dt + \sigma_1 S_{i,t} dz^*_{1,i,t} \ , \tag{1.37}$$

$$dy_{i,t} = (-\kappa y_{i,t} - \lambda_2)dt + \sigma_2 dz^*_{2,i,t} \ , \tag{1.38}$$

$$dv_{i,t} = a(\bar{v} - v_{i,t} - \lambda_3)dt + \sigma_3 dz^*_{3,i,t} \ , \tag{1.39}$$

where, as before, $dz^*_{1,i,t}$, $dz^*_{2,i,t}$, and $dz^*_{3,i,t}$ are correlated Wiener processes. After some rearrangement of the variables we can minimise the number of parameters to be found and improve the fit of the process, therefore we consider the following new variables:

$$\hat{y}_{i,t} = y_{i,t} + \frac{\lambda_2}{\kappa} \ , \tag{1.40}$$

$$\hat{v}_{i,t} = v_{i,t} - \lambda_1 + \frac{\lambda_2}{\kappa} \ , \tag{1.41}$$

and

$$\beta = \frac{a\bar{\hat{v}} - \lambda_3 + \sigma_{13}}{a^2} \ ; \tag{1.42}$$

where $\bar{\hat{v}}$ is the long-term average of $\hat{v}$, and is calculated ex post. We thus have now the following simplified dynamic equations without the use of the risk adjustment factor λ_i:

$$dS_{i,t} = (\hat{v}_{i,t} - \hat{y}_{i,t})S_{i,t}dt + \sigma_1 S_{i,t} dz^*_{1,i,t} \ , \tag{1.43}$$

$$d\hat{y}_{i,t} = (-\kappa \hat{y}_{i,t})dt + \sigma_2 dz^*_{2,i,t} \ , \tag{1.44}$$

$$d\hat{v}_{i,t} = [a^3\beta - a\hat{v}_{i,t} + a(1-a)\bar{\hat{v}} - a\sigma_{13}]dt + \sigma_3 dz^*_{3,i,t} \ . \tag{1.45}$$

With these equations and some initial conditions for S_0, $\hat{y}_0$, and $\hat{v}_0$, we can generate every i path, with $i \in \{1, \dots, M\}$, at time t for the spot price of the commodity $S_{i,t}$, and therefore construct the futures curve for each point using equation (1.46).

$$F_i(t_j, t_l) = S \cdot exp\left[-\hat{y}_{i,t_j} \frac{1 - e^{-\kappa t_l}}{\kappa} + \hat{v}_{i,t_j} \frac{1 - e^{-a t_l}}{a} + B(t_l) \right] \ , \tag{1.46}$$

for a futures contract at time t_j maturing at t_l, where $B(t_l)$ is defined by,

$$B(t_l) = -\frac{\sigma_{12}}{\kappa^2}\left(\kappa t_l + e^{-\kappa t_l} - 1\right) + \frac{\sigma_2^2}{4\kappa^3}\left(-e^{-2\kappa t_l} - 4e^{-\kappa t_l} + 2\kappa t_l - 3\right) + \beta\left(a t_l + e^{-a t_l} - 1\right)$$
$$- \frac{\sigma_3^2}{4a^2}\left(e^{-2a t_l} - 4e^{-a t_l} - 2a t_l + 3\right) - \frac{\sigma_{23}}{\kappa^2 a^2(\kappa + a)}\begin{pmatrix} \kappa^2 e^{-a t_l} + \kappa a e^{-a t_l} + \kappa a^2 t_l \\ +\kappa^2 a t_l + \kappa a e^{-\kappa t_l} + a^2 e^{-\kappa t_l} \\ -\kappa a e^{-(\kappa+a) t_l} - \kappa^2 \\ -\kappa a - a^2 \end{pmatrix}. \quad (1.47)$$

1.A.3 The parameters of these models

In table 1.5 we can look at the parameters used in the generation of prices and futures curves. For the oil price model, we used the same parameters used in the paper by Schwartz and Trolle (2010) –that is, the single stochastic volatility model– so that results remain comparable in the baseline case. In the case of the copper price model, the parameters were found using the methodology detailed in the paper by Cortázar and Schwartz (2003), using daily copper prices and their associated futures contracts.[41]

Table 1.5: Parameters used in the path generation process described in 1.A.1 and 1.A.2

Value of the parameters			
Trolle and Schwartz (2009) Crude oil		Cortázar and Schwartz (2003) Copper	
κ	1.0125	κ	2.1354
σ_v	2.8226	a	0.1344
α	0.1365	β	-0.3430
γ	0.7796	σ_1^2	0.0984
σ_S	0.2275	σ_2^2	0.4238
φ	0.0054	σ_3^2	0.0021
ρ_{12}	-0.8797	ρ_{12}	0.9900
ρ_{13}	-0.0912	ρ_{13}	-0.4944
ρ_{23}	-0.1128	ρ_{23}	-0.4887
η	1		
r	0.05	r	0.05
ϕ_0	0.33	$\hat{y}_0$	-0.07
v_0	2.79	$\bar{\hat{v}}$ †	0.025

† $\bar{\hat{v}}$ is the long-term average of variable $\hat{v}$ as calculated from available data.

[41] Price data was taken from Bloomberg from 3,375 daily observations of copper prices and futures contracts expiring in 1, 2, 3, 6, 9, 12, 36, 48, 60, 72, 84, 96, 108 and 120 months.

1.A.4 Final calibration

As we are assuming a risk-neutral process, the no-arbitrage condition implies that at time t_j the expected spot price of the commodity at time t_l is equivalent to the futures price of the commodity maturing at the same price, so that we have

$$F(t_j, t_l) = E_{t_j}[S_{t_l}] \ . \tag{1.48}$$

This is implicitly assumed in the construction of the models and in the definition of the futures contract price in equations (1.36) and (1.46). However, as the generated paths use a discrete time variation, $\triangle t$, the identity (1.48) does not verify exactly. This was necessary in the original valuation model by Schwartz and Trolle (2010) model so that V_{firm}^{exp} and V_{firm},[42] as well as V_{gov}^{exp} and V_{gov}[43] remain equivalent at time t_0 if there is no risk of expropriation.

Therefore, we introduced a calibration parameter in the data process of creating these prices and futures contracts so that the generated spot prices $S_{i,t}$ are being represented unbiasedly by the futures contracts, and so equation (1.48) verifies for all maturities, t_l, in future contracts of the form $F(t_0, t_l)$. We thus have a calibrated spot price S^*_{i,t_n} given by the following equation,

$$S^*_{i,t_n} = S_{i,t_n} \cdot F(t_0, t_n) \left(\frac{1}{M} \sum_{j=1}^{M} S_{j,t_n} \right)^{-1} , \tag{1.49}$$

we then replace the generated spot price with the calibrated price $S^*_{i,t}$ for all purposes in the model.

[42] From equations (1.21) and (1.23) at page 29.

[43] From equations (1.22) and (1.24) at the same page as above.

Chapter 2

Decisions under Threat of Expropriation: Abandonment and Scheduling of Production

This chapter extends the expropriation model presented in Chapter 1. Governments might attempt a tax reform that –while keeping expected tax capture constant– decreases political risk. Here, however, producers are able to respond to the risk of expropriation or to expected negative income flows by either abandoning the operations or by changing the schedule of production. Results are mixed: the abandonment option increases the value of the firm in a few cases where the skewness of progressive tax regimes generates scenarios that are too bleak, and thus abandonment enhances the ex-ante value of the operations. However, abandonment does not seem to be socially optimal compared with the no abandonment case. On the other hand, introducing production flexibility is beneficial to all parties as long as mutual expectations converge. If not, firms and governments will try to outguess *each other: generating an iterative cycling of production, which may prove detrimental to the parties involved. Finally, when considering the response of producers, the introduction of progressiveness in taxation does not appear to be welfare enhancing.*

JEL Classification: D25, D81, G13, H25, H30, L11, Q34, Q38.

Keywords: Non-renewable resources, political risk, abandonment of operations, scheduling of production, multiple real option, progressive taxation, equivalent taxation.

2.1 Introduction

The previous chapter introduced us to the issue of unexpected risks that might arise when a more progressive tax regime is bargained between two parties. Even under a conservative approach –a tax deal that was *equivalent* to the previously existing taxation regime– initial conditions might encourage that the tax modification, which was intended to reduce expropriation risk, makes it more relevant.

We have already discussed why this unintended change in political risk is quite an important matter for countries looking to encourage foreign investment; and we can relate it to the story of Guinea's Simandou iron ore deposit seen in the dissertation's introduction: a country might be successful in attracting a first batch of investors, but then political instability can lead to a stalemate.

In this chapter we go a step further and see what sort of responses multinational firms might take when naïve, negligent, or simply politically-captured governments introduce tax progressiveness irrespective of the effects that it might have on the stability of private investments. As previously, we limit the study to the effect that tax capture has on the government finances: this is reasonable if we assume that mining or oil extraction operations are capital intensive, usually located far away from urban centres and therefore, with limited spillovers for developing countries apart from the taxes that the state is able to receive. Further evidence of the lack of economic complementarities (at least for the case of mineral extraction in developing countries) can be seen in how marginally located the extractive sector is (especially mining) in the product space of each developing nation.[1]

When producers are able to respond to the perceived threats posed by taxation –the fact that the governments might or might not be more prone to expropriate the assets– they can either produce results that are beneficial for them or, inadvertently, end up in a worse place than before. In this chapter we explore the nature of those results and conclude two things:

- That the decision to abandon operations can, at best, give mixed advantages to the firm over the baseline scenario, but that it can serve as a deterrent to the implementation of a progressive taxation regime given the detrimental effect it has on the value of the operations for the government.
- That the scheduling of production converges in desirable equilibria when governments and companies interact **only if** the degree of progressiveness in taxation is low; in other cases, results are extremely sensitive to initial conditions.

[1] See, for example, the *Atlas of Economic Complexity* by Hausmann et al. (2014).

In the second case, we found an interesting result referring to how the surplus generated by the flexibility in production was split. Interestingly, it was always to the advantage of the government to introduce flexibility in production: the value of the operations for the state were always higher if some degree of production flexibility was introduced.[2]

2.1.1 Motivation

This chapter aims to show us how progressiveness in taxation and production flexibility interact. We already saw in the previous chapter that the effects of progressiveness in taxation were not straightforward, and therefore we should not expect that introducing flexibility in production can have a single, well defined effect.

Promoting production flexibility to avoid aggressive taxation regimes

As we will see in the literature review, a lot has been written about better and more profitable ways to schedule production; what seems lacking is a review of how the additional gains from varying production rates are divided between the investing firm and the government. This chapter does not introduce any bargaining position in the imposition of new taxes, only the requirement that they remain *equivalent*, a concept defined in the previous chapter, and that would imply that both parties would be acting in good faith when renegotiating the tax regime.

We already saw that under some initial conditions (high initial prices, or forward curves in strong contango) the introduction of tax progressiveness would be bad for both firms and government: the fact that production flexibility would be able to make some scenarios even more unattractive for the government is something that could generate a bargaining possibility for the firms (towards the government) in order to deter the introduction of high progressiveness in taxation. What we found in this aspect was quite disheartening: at its best, flexibility in production increased the value of the operations *for the government*, although it did not change the fact that elevated levels of progressiveness in taxation would lower the total tax take.

Under the conditions that we see in this chapter, governments would be eager to expect more production flexibility from firms: however this is a view taken only from one side of the equation –tax income for the country– while this chapter conveniently forgets about the problems of procyclicality in government spend-

[2]For these results, please see figure 2.19 on page 130.

ing,[3] although there might be more evidence of countercyclical spending in recent times (see, for example Céspedes and Velasco, 2014) which would make –again– governments more friendly towards production flexibility.

Hypothesis: A degree of production flexibility should be beneficial to producers

The **hypothesis to be tested** in this chapter is that producers can take actions, either *abandoning production or changing the schedule of extraction*, that will partially counteract the political risk generated by the introduction of more progressive taxation regimes or by an unfavourable set of initial prices. The evidence from the cited literature pointed out that this flexibility should favour the firms, but governments and producers might not converge in their expectations of tax capture (by the government) versus production scheduling, so that these results need to be tested.

2.1.2 Literature review

An early model using real options and considering abandonment –in the form of postponement of operations– was the one presented by Cortázar and Casassus (1998); which was further refined in order to divide the investment process in many stages in Cortázar, Schwartz and Casassus (2001). In these models, substantial value was found in production flexibility through the purposeful delay of operations, in the first case, and in the optionality of dividing the investment in different segments that allowed for sequential further investment (if there was geological uncertainty on the nature of the available resources), for the latter. These models, while being an excellent introduction to representing the operations of a mine with a real options methodology, assumed that the whole risk was exogenous: in the form of the uncertainty in prices and in the geological qualities of a mine.

The model that was used as a basis for Chapter 1 –the one presented in Schwartz and Trolle (2010)– introduces an endogenous expropriation risk: how it interacted with progressive taxation was the matter that kept us interested in the previous chapter.

Here, we rely again on the least squares method (the LSM method) by Longstaff and Schwartz (2001) to create reasonable expectations for the future that allows for a valuation of an American-style real option by an agent that is not omniscient about the future. This is used on **Section 2.2** to model reasonable and unbiased expectations for the government upon the timing of expropriation.

[3]Some examples can be seen in Velasco (2011).

Thus, this chapter deals with an old problem: how companies can choose production when facing a predatorial government. An early example of this is the paper by Osmundsen (1995), where asymmetric information about the size of the reserves generates incentives for the firms to vary their rate of production in a multi-period game to mask the true size of reserves and thus avoid a ratchet effect on the taxes they must pay.
Additionally, even in the absence of political risk (either due to expropriation or to tax uncertainty), there is additional evidence for companies to invest taking into account when the mine or oil field will be operational. Bar-Ilan and Strange (1996) argue that delays in production (in their paper, due to intrinsic investment lags) might be beneficial if price volatility is high enough.
To schedule a production calendar, Caldentey, Epstein and Sauré (2008) use dynamic programming in order to arrange an optimal extraction sequence for the different production blocks of a mine. The model used in **Section 2.3**, however, is an adaptation of Aleksandrov and Espinoza (2011), which is a simplified version of Aleksandrov, Espinoza and Gyurkó (2013), both achieve the same results, but the first paper does it more parsimoniously. These two papers use the multiple real option valuation method introduced in Aleksandrov and Hambly (2010): its flexibility allows that the progressive tax regime, the abandonment decision, and the different production heuristics are integrated into one model.

An insight from Level-K Thinking

Level-k or *cognitive hierarchy models* refer to those models where agents react to an interaction where there is no previous learning or learning is difficult to assume plausibly. They are modelled through a number (k) of iterated best responses to the other agent's action; they are clearly models that do not assume knowledge of a Nash equilibrium, which is something to be expected if the game is unknown and there are no repeated interactions.
In this chapter, the heuristic production model presented on page 87 shares some aspects with Level-k thinking, with k being the number of iterations that we assume that the host governments and the investing firms would employ when trying to outguess each other. The two iterative heuristics introduced in **Section 2.3**, do this: before any production is actually committed, firms react to a hypothetical expropriation function, which in its turn is driven by each new best response by the firms; until it (hopefully) converges to a single production function impervious to the rate of expropriation.
These sort of models have been shown experimentally to represent accurately what happens when we need to guess other people's actions (see, for example, both Nagel, 1995; Bosch-Domènech, Montalvo, Nagel and

Satorra, 2002): in the case of Bosch-Domènech et al. a solution might involve a value of k as little as $k = 3$ when there is a large number of participants trying to outguess each other.

In the extensive literature review presented by Crawford (2013), the author puts level-k models in the group of optimisation-based learning models that relax the assumption that both participants play a Nash equilibrium from the beginning. This is considered as appropriate where "lack of clear precedents, makes simple learning models implausible". A more comprehensive review of *Level-k* models can be found in Crawford, Costa-Gomes and Iriberri (2013). Finally, Crawford and Iriberri (2007), explain the winner's curse in auctions due to the non-equilibrium qualities of the result in a level-k model; this result offers a cautionary note on the suboptimality that we can achieve with the production heuristic in this chapter.

2.1.3 About the structure of this chapter

Here we take the modified expropriation decision model presented in the previous chapter and broaden it to take into account the fact that producers can take measures to respond to the expectation of heightened risk (due to higher rates of expropriation) by doing two things: either abandoning the extraction process or modifying the rate of extraction. Thus, the modifications being introduced to the real options expropriation model are the following:

- The introduction of an abandonment criterion, by which firms stop producing if their best and unbiased expectation of discounted future earnings is not positive.

- For the same abandonment process, the design of a rational expectations model by which the government would make a *best guess* about the abandonment timing made by firms, so as to prevent or foster expropriation.

- To decide the production function, the multiple real option model presented in Aleksandrov and Hambly (2010) is used; specifically as the modified version of how it was implemented in Aleksandrov and Espinoza (2011). It is combined with the previous expropriation model, letting firms react to the perceived heightened risk by shifting production timing.

- And finally, the implementation of a series of iterative heuristics that represent the guessing up process of both the governments and firms, to see if there is convergence to a specific –and preferably better– arrangement when firms face expropriation risk.

From **Section 2.2** to **Section 2.4** the different models are introduced; how they work and how they differ from what has been done previously. Then, in **Sections 2.5** and **2.6** the main results to the two substantial modifications to the model are presented.

Firstly, the rationale behind the introduction of the abandonment model is detailed in **Section 2.2**, where the new payoff function is explained. The section begins by noting the differences between the payoff function of the American-style real option used in the previous chapter with the one that includes abandonment; with an emphasis on the presence of an LSM-generated prediction for the timing of abandonment as governments are not omniscient. The difference between the timing when abandonment occurs, and the expected period when government thinks this abandonment is going to happen will generate distortions in the perceived value for the government that will change its behaviour towards the extractive operations. Then follows a description of the experimental setting and concludes with an overview of the findings, which, as mentioned before, are analysed in detail in **Section 2.5**.

In **Section 2.3**, the modified version of the model employed by Aleksandrov and Espinoza (2011) is dissected, taking special interest in how it is going to be integrated with the abandonment model seen previously. The experimental setting is of special importance, as it details how governments and firms are going to interact: the former through the variation of how they expropriate given a certain progressiveness in taxation, and the latter responding through the variation in the production schedule to minimise risk and maximise their value of the operations. This section also concludes with an overview of the general results that are going to be analysed in **Section 2.6**.

In order to clarify the Aleksandrov and Hambly (2010) multiple real option model we introduce a simple production model in **Section 2.4** before presenting the main results. Here, the dynamic programming procedure that underlies the multiple real option model is dissected, as well as how the LSM model and a logit model contribute to generate forecasts of the future for each participant. This model also illustrates the consequences of each party (the government and the investing firm) trying to outguess each other.

The following sections present the general results, with **Section 2.5**, showing the consequences of introducing the abandonment option. This section starts by posing ‘The intuition’, meaning the result we should normally expect to obtain after a quick look to the available incentives. Then it proceeds to confront this intuition with the obtained results; being especially interested in the importance of early expropriation when taxation is too progressive, relative to the gains/losses for the firms and governments, and also comparing the results with the baseline scenario of no abandonment. The section concludes with a dissection of the abandonment formulae to explain the nature and the origin of the results.

Then, **Section 2.6** presents the results stemming from the model where firms have some freedom over choosing production. As in the previous section, this one also starts with posing 'The intuition', or the expected results, to then see what actually happens. First, the conditions for the experimental setting are discussed after seeing the result from abandonment; then the heuristics for the interaction are compared and one of them (the non-naïve production heuristic) is deemed to be superior –it achieves better outcomes for the producer– and so it is analysed in detail. Afterwards, how production evolves is depicted and the concept of *convergence* is defined and used to judge the effectiveness of the iteration heuristic under different taxation scenarios. Finally, the results of introducing production flexibility are quantified for firms and governments, and reasons for the failure to converge under certain scenarios are proposed.

To end the chapter, the conclusions in **Section 2.7** tie the results from the previous sections and discusses the merits and disadvantages of letting producers respond to perceived political risk, together with a set of suggestions to extend the model further.

The results in a nutshell

As in the previous chapter, here we also contrasted the hypothesis –that a producer can take two kinds of actions, either abandoning production or changing the schedule of extraction, which will improve the value of the operations for itself; and especially when progressive taxation is used– with the results of comparing what happened when an oil production model with varying degrees of taxation progressiveness was expanded to give the producer the ability to abandon operations or to vary its production schedule. After doing this, the main results we obtained were the following:

The ability to abandon does not add too much value: The intuition –that the ability to abandon an unproductive extractive operation should add value to the firm– does not verify in practice. The results for the firm are quite mixed (see table 2.11 on page 112) and are very sensitive to initial conditions. Additionally, the overall effect for the producer and the government combined (see table 2.13 on page 113) is almost consistently negative.

Abandonment is difficult to predict: The predictive power of the unbiased expectation for the timing of abandonment for a certain price path, i, made at a certain period t_j, $E_{t_j,i}[X_i - 1]$,[4] is quite limited.

[4]In this model X_i is the discrete period where operations cease (at time t_{X_i}), so the timing of abandonment –the last discrete period of production– is $X_i - 1$ for a given price path, i.

The period-to-period abandonment rate is not as dense as to generate a prediction that responds with enough accuracy to the state variables at time t_j. The consequence of this is that governments cannot tailor their willingness to expropriate to the future of the operations, which results in the government being the clear loser when the possibility of abandonment is introduced (see table 2.12 on page 113).

Production flexibility has a clear winner: Counterintuitively, when producers are able to schedule their production function in order to maximise the value of the operations they might be outguessed by the governments. And therefore, the government emerges –surprisingly– as the part that benefits the most from production flexibility (see figure 2.19 on page 130).

Non-convergence can be very damaging: The production heuristic that was proposed dealt badly with scenarios where early expropriation was relevant, and therefore producers could become trapped in cycles where they were repeatedly outguessed by the government. The results for these scenarios of cycling production (or non-convergence) were uncertain and extremely sensitive to the number of iterations that were used. An insightful producer could become more damaged by his willingness to predict the actions of the government than it would be if the firm had acted naïvely under these scenarios.

As mentioned above, we will now proceed to describe the modifications introduced to the expropriation model when abandonment was considered.

2.2 Modelling the response of producers to political risk: A first approach with abandonment

The previous chapter left open the possibility of extending the model of expropriation's interaction with the taxation regime, in such a way that producers can counteract *somehow* the change in the perceived risk of expropriation.

One possibility of extending the model of expropriation, as it was presented in the previous chapter, is to allow the possibility of abandonment, so that a natural resources company abandons production if it is facing the prospect of continuous low or negative discounted income. This possibility was not considered in the original paper that initiated this dissertation (see Schwartz and Trolle, 2010). However, as taxes become more progressive the timing of expropriation decisions should vary and so should the incentives to abandon, for this reason an abandonment model was introduced as seen below.[5]

2.2.1 A simple abandonment model

The basic assumption of the abandonment model is to assume that risk neutral producers consider the futures contracts curve as an *unbiased estimator* of the expectation of future prices (the same criteria used in the previous chapter and the basis of the no-arbitrage condition on the dynamic price models used in both chapters), so that a modification of the equation which defines V_{firm},

$$V_{firm}(t_0, k) = \frac{1}{M} \sum_{i=1}^{M} \left(\sum_{n=1}^{N} e^{-r(t_n - t_0)} \left(S_{i,t_n} - C_{firm}\right) \left(1 - Tax(S_{i,t_n}, k)\right) Y_{t_n} \right), \tag{2.1}$$

is used to calculate the expected value of firm's operations in absence of expropriation for path i at time t_j, this modified version is defined as V_{firm}^{abn} here below.

$$V_{firm}^{abn}(i, t_j, k) = \sum_{n=j+1}^{N} e^{-r(t_n - t_j)} \left(F_i(t_j, t_n) - C_{firm}\right) \left(1 - Tax(F_i(t_j, t_n), k)\right) Y_{t_n} . \tag{2.2}$$

Therefore, if we assume that the abandonment decision is costless but irreversible for producers, a lower bound estimator would be that producers will not continue operations if the value of $V_{firm}^{abn}(i, t_j) < 0$ for price path i at time t_j, that is, if the unbiased expectation is that production will continue at loss –in discounted value– for the next and subsequent periods (t_{j+1} and over). With this information it is possible to generate an abandonment indicator for each simulated price path i: this would be $X_i \in \{1, \ldots, N+1\}$ where N is the number of simulated steps, and therefore if no abandonment takes place we define $X_i = N+1$. Accordingly, t_{X_i} is the time at which operations cease, so that $t_{X_i - 1} \in \{t_1, \ldots, t_N\}$ is the last productive period.

In this scenario, the government will work with imperfect information (i.e. it cannot exactly predict *when* the abandonment is going to take place). So in order to assess the value of the enterprise it will rely on the expected moment of expropriation to asses Π, the payoff of the American-style option that characterises this model.

We thus introduce modifications to the equations that value the cost and gain obtained by expropriating the

[5] And its results are analysed in detail in section 2.5.

operations, $V_{cost}(i,t_j)$ and $V_{gain}(i,t_j)$,[6]

$$V_{cost}(i,t_j,k) = \Big[\sum_{n=j+1}^{N} e^{-r(t_n-t_j)}[(F_i(t_j,t_n) - C_{firm}) \cdot Tax(F_i(t_j,t_n),k)]Y_{t_n}\Big] + K_1 \cdot (t_N - t_j) + K_2 \ , \tag{2.3}$$

$$V_{gain}(i,t_j) = \sum_{n=j+1}^{N} e^{-r(t_n-t_j)}(F_i(t_j,t_n) - C_{gov})Y_{t_n} \ , \tag{2.4}$$

replacing them with equations (2.5) and (2.6), below, for every time $t_j \in \{t_1,\ldots,t_n\}$ at each path i,

$$V^{abn}_{cost}(i,t_j,k) = \begin{cases} \left[\displaystyle\sum_{n=j+1}^{E_{t_n,i}[X_i-1]} e^{-r(t_n-t_j)}[(F_i(t_j,t_n)) - C_{firm})\,Tax(F_i(t_j,t_n),k))]Y_{t_n}\right] & \text{if } t_j < t_{X_i-1}, \\ + K_1 \cdot (E_{t_j,i}[t_{X_i-1}] - t_j) + K_2 & \\ 0 & \text{if } t_j \geq t_{X_i-1}. \end{cases} \tag{2.5}$$

$$V^{abn}_{gain}(i,t_j) = \begin{cases} \displaystyle\sum_{n=j+1}^{E_{t_n,i}[X_i-1]} e^{-r(t_n-t_j)}(F_i(t_j,t_n) - C_{gov})Y_{t_n} & \text{if } t_j < t_{X_i-1}, \\ 0 & \text{if } t_j \geq t_{X_i-1}. \end{cases} \tag{2.6}$$

A note on the expected timing of abandonment

In the equations above, the costs and the gains from the payoff of the expropriation option are limited by the abandonment decision taken at time t_{X_i}. However, this precise moment is not going to be known by the government, and therefore the government will have to estimate the most probable timing for abandonment given the known variables (time remaining in operation, prices and future curves).

Thus, the expected timing of abandonment, $E_{t_j,i}[X_i - 1]$, can be generated. This will be a unique value for each time $t_j < t_{X_i-1}$, at each price path i, which is generated using the LSM method.

If, at any moment the expected timing of abandonment is lower than the remaining life of the operations, $E_{t_j,i}[X_i - 1] < N$, the expectation of abandonment will thus decrease the expected costs and gains from

[6] The total cost and gain of expropriating assets at time t_j on a price path i, which are used for the immediate payoff function, Π, of an American-style option as defined in the previous chapter.

exercising the option.

The new payoff function

With these newly generated values, V_{cost}^{abn} and V_{gain}^{abn}, we construct a modified payoff function Π^{abn} as it was defined on the American-style real option in the previous chapter,

$$\Pi(i,t_j)^{abn} = \max(V_{gain}^{abn}(i,t_j) - V_{cost}^{abn}(i,t_j), 0). \tag{2.7}$$

Then, again, the LSM method was run to value this option.

This change[7] from Π to Π^{abn} should modify the timing of the exercise of the expropriation option. Additionally, the overall value of the extractive operations should be modified both for the firm and the government to acknowledge that there is a chance that operations cease before t_{Z_i}, the time where the expropriation decision takes place. So that the present value of these operations in presence of political/expropriation risk changes to the equations shown below.

$$V_{firm}^{exp,abn}(t_0) = \frac{1}{M}\sum_{i=1}^{M}\left(\left[\sum_{n=1}^{\min(X_i-1,Z_i)} e^{-r(t_n-t_0)}(S_{i,t_n} - C_{firm})(1 - Tax(S_{i,t_n},k))Y_{t_n}\right]\right.$$
$$\left. + e^{-r(t_{Z_i}-t_0)}K_1\cdot(E_{t_j,i}[t_{X_i-1}] - t_{Z_i})\cdot I_{[X_i-1\geq Z_i+1]}\right), \tag{2.8}$$

$$V_{gov}^{exp,abn}(t_0) = \frac{1}{M}\sum_{i=1}^{M}\left(\left[\sum_{n=1}^{\min(X_i-1,Z_i)} e^{-r(t_n-t_0)}\left[(S_{i,t_n} - C_{firm})Tax(S_{i,t_n},k)\right]Y_{t_n}\right]\right.$$
$$\left. + \left[-e^{-r(t_{Z_i}-t_0)}(K_1\cdot(E_{t_j,i}[t_{X_i-1}] - t_{Z_i}) + K_2) + \sum_{n=Z_i+1}^{X_i-1} e^{-r(t_n-t_0)}(S_{i,t_n} - C_{gov})Y_{t_n}\right]\cdot I_{[X_i-1\geq Z_i+1]}\right). \tag{2.9}$$

Where the value for the firm is the sum of the post-tax income before expropriation or abandonment plus any remaining compensation, while the value for the government is the tax income plus the whole income stream after expropriation but prior to abandonment. As before, $I_{[X_i-1\geq Z_i+1]}$ is an indicator function for

[7]The parameter Π, being the instantaneous payoff without abandonment.

each path i, which takes the value 1 if $[X_i - 1 \geq Z_i + 1]$ and zero otherwise.

We should also note that the expression for the payment of compensation to the firms in case of expropriation in these equations is given by

$$K_1 \cdot (E_{t_j,i}[t_{X_i-1}] - t_{Z_i}) \ , \tag{2.10}$$

as we assume that the government will pay based on what is considered its 'best guess'.

All the results from the abandonment case which are stated here below and with more detail in Section 2.5 are calculated considering these modifications to the original formulae.

2.2.2 Experimental setting

For the case of evaluating the effect of abandonment, we relied on the initial conditions presented in the previous chapter for the prices of copper and oil. We tested under different initial conditions the calibrated Cortázar and Schwartz (2003) model for copper price and futures and the Trolle and Schwartz (2009) model for oil.

As in the previous chapter, the direction of the results was equivalent for these two price models and for the initial conditions; so for parsimony we focused on the Trolle and Schwartz (2009) model for oil price; which is the *better behaved* of them both: for a similar initial price range it is able to show both decreasing expropriatory risk and heightened early expropriation, which makes it suitable for our study.

Similarly, we introduced different equivalent corporate income tax regimes, differing only on their progressiveness given a set of initial conditions: using the same notation as in the previous chapter where the corporate tax is defined as

$$Tax(S, k). \tag{2.11}$$

Meaning that the value of the corporate income rate will vary with the underlying commodity price S and a progressiveness parameter k. In the previous chapter we explored two of such regimes –a nonlinear tax and a windfall tax– and we found a much more gradual response to the treatment (i.e. increased progressiveness of taxation) with the nonlinear tax. Thus –again for parsimony– in this chapter we restricted the analysis to the case with a nonlinear progressive tax:

$$Tax(S,k) = Tax(S_{i,t_n},\delta) = \delta S_{i,t_n} + \tau_{base}(\delta). \tag{2.12}$$

Where the progressiveness parameter is represented by the value of δ as it was used in the previous chapter, from an equivalent tax regime where $\delta_0 = 0$ and $\tau_{base}(\delta_0)$ is equivalent to τ_{inc} (no progressiveness), going all the way to δ_{max}, the maximum value of progressiveness for this sort of taxation regime, where $\tau_{base}(\delta_{max}) = 0$. Thus, results considering the possibility of abandonment can be compared to those obtained in the previous chapter, allowing us to assess the direct effect of introducing the possibility that firms have to costlessly leave a mine or oil field.

2.2.3 An overview of the findings

Following the order set in the previous chapter, we will start revising what was inferred from beforehand, 'the intuition', and then contrast it with the most relevant results obtained, which are analysed in detail in Section 2.5.

The intuition

The expected consequence of introducing the possibility for producers to costlessly abandon the mine/oil field is quite straightforward: firms would see an increase in the value of their operations given that they would no longer be subject to continue producing at a loss when prices –and the expectation of future prices– are low. For the government the effect is more difficult to predict, as the changes in the rate of expropriation due to early abandonment would affect the expected value for the government: there would be additional incentives to expropriate earlier due to the shorter expected lifespan of operations, which would increase the value of what was effectively expropriated. On the other hand, there would be less opportunities of expropriation as some abandoned operations would have eventually rebounded: neither governments nor producers foresee the future perfectly.

Results

The first observed result was that the abandonment rate increased with taxation progressiveness, represented in this chapter through the nonlinear tax parameter δ, as can be seen in figure 2.3 on page 104: more progressive taxation made abandonment more appealing. Not surprisingly, when we looked at the timing of abandonment[8] we could notice that it increased with time, as there were fewer probabilities to regain current losses when the end of the operations of a mine/oil field is near.

When we analysed the behaviour of the government facing abandonment, we could see that the introduction of this option made operations riskier only on specific cases, with more expropriation taking place only when prices were either not too low nor too high.[9] The effect on the firms and on the government was mixed; in many cases the introduction of an abandonment option benefited the firm,[10] there were relevant exceptions to the rule in those cases where the initial prices were too high; whereas the government lost almost at every single scenario when the abandonment option was introduced.[11] The sum of both effects was also mixed (as it can be seen in figure 2.9 on page 114), but table 2.13 on page 113 shows that although in some cases the gains for the firm compensated the losses for the government, in the overwhelmingly majority of tax progressiveness scenarios the overall result for society was negative.

Analysis

The analysis of these results, which can be seen from page 115 onwards, points out to the fact that there are two opposite effects when the abandonment option is introduced. On one side, the payoff function as has been previously defined[12] has a lower value than in the case of non-abandonment, a constant reduction that makes expropriation less likely. However, the fact that both the government and the producer can anticipate an abandonment decision decreases the compensation to be paid in case of expropriation.[13] A lower cost of compensation (i.e. expropriation becoming cheaper in one dimension) would imply higher rates of early expropriation which is what can be seen in figure 2.6 on page 109.

2.3 A further approach: Varying the rate of production

In order to simulate the possibility that firms vary their extraction rate according to the price dynamics of the underlying commodities, we relied on a multiple real option model presented by Aleksandrov and Hambly (2010) and applied for the oil extraction case by Aleksandrov and Espinoza (2011).

[8] Cf. figure 2.4 on page 105.
[9] See a definition of what constitutes a low/high initial price on page 119.
[10] See table 2.11 on page 112.
[11] See table 2.12 on page 113.
[12] In this case the modified function is $\Pi^{abn}(i,t_j) = \max(V^{abn}_{gain}(i,t_j) - V^{abn}_{cost}(i,t_j), 0)$.
[13] This compensation refers to the value associated with payment K_1 in equation (2.5).

This model attempts to determine a production function using a multiple real option model where production is divided into discrete blocks, and the decision to produce one of these blocks corresponds to an exercise decision of those available for that option.

To solve it, Aleksandrov and Hambly (2010) relied on two methods, on the one side they used the Longstaff and Schwartz's (2001) least squares Monte Carlo method (the LSM method) to find a lower bound for the value of this option, whereas the upper bound was found using the model described by Rogers (2002) and Haugh and Kogan (2004), which relies on a duality approach: a minimisation over a space of martingales. The relative difference in value between the lower and upper bounds when the number of paths is sufficiently large[14] was found to be below 1.5%. For this reason we relied solely on the value provided by the lower bound model based on the LSM model; as this was already implemented in the valuation of the expropriation model used in the previous chapter; making the results more comparable.

2.3.1 A simplified model

The model, as applied in Aleksandrov and Espinoza (2011) was modified in order to fit the purpose of our research as will be described now.

As before, we suppose that the mine or oil field is depleted at a precise time T, after which no extraction is possible. Up until now, we have assumed that production was constant at each period, so that Y_{t_j} was the same for all $t_j \in \{t_1, \dots, t_N\}$,[15] here production changes for each period t_j and for each path i. This new production is composed by an annual base rate of production Y_{base} that remains fixed and constant for the time of extraction, together with a discretionary amount to be produced during the same period, which is determined by this model. The model chooses the optimal production throughout the life of the mine or field (from time t_0 to t_N) for the operations of the company, maximising the value of the discretionary production capacity. Therefore, for the effects of the model we will refer only to this discretionary production decision unless explicitly told otherwise.

Production is thus divided into blocks, with a maximum production capacity at any time t_q of k_{t_q} blocks, each of them of size y_{prod}, where $q \in \{1, \dots, Q\}$, Q being the number of discrete periods where a production

[14] Aleksandrov and Hambly (2010) used 20,000 paths to establish the lower bound, and 1,000 paths to find the upper bound value.

[15] This was not a requirement of the previous models, which just required Y_t to be exogenous, something that is going to change now.

decision occurs, and also the life expectancy of the operations in years.[16,17]

An optimal extraction strategy at time t_q maximises the firm's income from production, a value stated as $V_{t_q}^{*,m_{p,q}}$ where $m_{p,q}$ is the total number of exploitation blocks available at time t_q, and $m_p = m_{p,1}$ is the total number of blocks at the beginning of the extractive operations.[18]

Additionally, we assume that the price of the underlying commodity is described by the dynamic price models already used previously and described in the appendix of the previous chapter, with the difference that in this case prices would vary annually, so that we would have a price S_{i,t_q} for price path i at time t_q.

The payoff (after taxes) for the firm of the exploitation of *one block of production*, h_{i,t_q}, at time t_q in the price path i is defined as:

$$h_{i,t_q} = \begin{cases} \max\left(0, \left[S_{i,t_q} - C_{firm}\right] \cdot (1 - Tax(S_{i,t_q}, k)) \cdot y_{prod}\right) & \text{if } t_q = T, \\ \left[S_{i,t_q} - C_{firm}\right] \cdot (1 - Tax(S_{i,t_q}, k)) \cdot y_{prod} & \text{if } t_q < T. \end{cases} \tag{2.13}$$

As can be noticed, we only assume that the payoff h_{i,t_q} is non-negative at time T, as firms can choose not to produce at all in the last period, $t_T = T$, if it is not profitable, while deferring production in the cases where $t_q < t_T$. The company has the possibility to extract k_{t_q} blocks in each period t_q and thus to receive up unto $k_{t_q} \cdot h_{i,t_q}$ from the discretionary production annually. To this we should add what is received from the production of Y_{base} which remains constant throughout the life of the mine or oil field.

An extraction policy is defined as π_k so that it comprises a series of stopping times, that is, times where one of the m_p extraction decisions is taken,[19] each stopping time belongs to a set of m_p elements, $\{\tau_l\}_{l=1}^{m_p}$, where $\tau_1 \leq \tau_2 \leq \ldots \leq \tau_{m_p}$ and $\tau_l \in \{t_1, \ldots, t_T\}$. We must remember that the number of stopping times for each period should be smaller than k_{t_q}, in such a way that $\#\{j : \tau_j = s\} \leq k_s$. Then, the value of the policy at time t_q is given by

$$V_{t_q}^{\pi_k, m_{p,q}} = E_{t_q}\left[\sum_{l=(m_p - m_{p,q}+1)}^{m_p} e^{-r(\tau_l - t_q)} h_{i,\tau_l}\right]. \tag{2.14}$$

There is therefore an optimal extraction policy, $\pi^* = \{\tau_1^*, \tau_2^*, \ldots, \tau_{m_p}^*\}$, such that the value in the equation above is maximised. Formally this is defined as,

[16] We must note that in this model, production decisions are taken annually, meaning that there are T steps for production, whereas the N steps mentioned in previous models were usually months. This is done to reflect that production is not entirely flexible and coincides with the rigidities for the production decision shown in the paper by Caldentey et al. (2008).

[17] In this specific case we must note that $T = Q$ given that production changes annually.

[18] So that the total size of the mine or oil field at the initial time t_1 is equivalent to $m_p \cdot y_{prod} + Y_{base} \cdot T$.

[19] As each production decision implies exhausting one of the m_p blocks available at time t_1.

$$V_{t_q}^{*,m_{p,q}} = \sup_{\pi_k} V_{t_q}^{\pi_k,m_{p,q}} = \sup_{\pi_k} E_{t_q}\left[\sum_{l=(m_p-m_{p,q}+1)}^{m_p} e^{-r(\tau_l-t_q)} h_{i,\tau_l}\right]. \tag{2.15}$$

In order to obtain the mathematical solution a multiple real option model was used, so that the value of $V_{t_q}^{*,m_{p,q}}$ at time t_q was defined as the maximum value from one of the following scenarios:

1. The payoff obtained by producing k_{t_q}, the maximum production capacity, and leaving $(m_{p,q} - k_{t_q})$ blocks to be exploited later. The value today of the remaining reserves being:

$$e^{-r\Delta t_q} E_{t_q}[V_{t_{q+1}}^{*,m_{p,q}-k_{t_q}}] \ .$$

2. Producing n_{t_q} units at time t_q, where $0 < n_{t_q} < k_{t_q}$, in this case the value of the remaining reserves would be the same as before, but with n_{t_q} units being extracted:

$$e^{-r\Delta t_q} E_{t_q}[V_{t_{q+1}}^{*,m_{p,q}-n_{t_q}}] \ .$$

3. Finally, not extracting at all during time t_q, so that $m_{p,q} = m_{p,q+1}$, the value of this decision being:

$$e^{-r\Delta t_q} E_{t_q}[V_{t_{q+1}}^{*,m_{p,q}}] \ .$$

Hence, if n_{t_q} units[20] are produced at time t_q the overall payoff for the firm will be

$$n_{t_q} \cdot h_{i,t_q} + e^{-r\Delta t_q} E_{t_q}\left[V_{t_{q+1}}^{*,m_{p,q}-n_{t_q}}\right]. \tag{2.16}$$

Using a dynamic programming formulation the value function $V_{t_{q+1}}^{*,m_{p,q}}$ at time t_{q+1} can be expressed as shown below when $m_{p,q} > k_{t_q}$:

$$\begin{aligned} \text{for } t_q = T, \quad V_T^{*,m_{p,T}} &= k_T \cdot h_{i,T}, \\ \forall t_q < T, \quad V_{t_q}^{*,m_{p,q}} &= \max\Big\{ \Big(k_{t_q} h_{i,t_q} + e^{-r\Delta t_q} E_{t_q}\left[V_{t_{q+1}}^{*,m_{p,q}-k_{t_q}}\right]\Big), \\ & \Big((k_{t_q}-1) h_{i,t_q} + e^{-r\Delta t_q} E_{t_q}\left[V_{t_{q+1}}^{*,m_{p,q}-(k_{t_q}-1)}\right]\Big), \dots \\ & \dots, \Big(h_{i,t_q} + e^{-r\Delta t_q} E_{t_q}\left[V_{t_{q+1}}^{*,m_{p,q}-1}\right]\Big), \Big(e^{-r\Delta t_q} E_{t_q}\left[V_{t_{q+1}}^{*,m_{p,q}}\right]\Big)\Big\}. \end{aligned} \tag{2.17}$$

[20] Where $0 \le n_{t_q} \le k_{t_q}$.

And in the case where the available reserves $m_{p,q} \leq k_{t_q}$, we will have:

$$\begin{aligned} \text{for } t_q = T, \quad V_T^{*,m_{p,T}} &= m_{p,T} h_{i,T}, \\ \forall t_q < T, \quad V_{t_q}^{*,m_{p,q}} &= \max\left\{ \left(m_{p,q} h_{i,t_q}\right), \left((m_{p,q}-1) h_{i,t_q} + e^{-r\triangle t_q} E_{t_q}\left[V_{t_{q+1}}^{*,1}\right]\right), \dots \right. \\ &\qquad \left. \dots, \left(e^{-r\triangle t_q} E_{t_q}\left[V_{t_{q+1}}^{*,m_{p,q}}\right]\right)\right\}. \end{aligned} \tag{2.18}$$

For the implementation of this model it was required to use a suitable approximation for the expected value function at time t_q, $E_{t_q}\left[V_{t_{q+1}}^{*,m_{p,q}-n_{t_q}}\right]$, and all its variants, this was done adapting the LSM method using a multiple regression that considered the spot price of the underlying commodity as well as the futures contracts curve parameters at time t_q as the known variables for the least squares approximation of the expected value at time t_{q+1}, in the same way as it has been implemented in both the previous and the current chapter for the Schwartz and Trolle valuation model. A more detailed view of the solving procedure for this dynamic programming function can be found either in Aleksandrov and Espinoza (2011) or in Aleksandrov and Hambly (2010).

On the nature of extraction costs

Using the flexibility of the multiple real options model, it is possible to introduce more state variables: Aleksandrov and Espinoza (2011) use stochastic extraction costs that are dependent on previous extraction costs. Another version of this model –without expropriation risk involved– can be seen in the paper written by Aleksandrov et al. (2013), where extraction costs are correlated to oil prices through the use of a geometric Brownian motion with a correlation parameter. In the first case, it is shown that volatility will affect the production schedule; and on the second model, correlating costs with oil prices had little to no effect in the final production schedule found in that paper. Therefore, in order to keep the relation between factors as clear as possible it was decided to keep costs constant throughout the analysis.

2.3.2 Experimental setting

Unlike in the cases we have seen previously, in this model it is unpractical to use the same set of initial conditions as before (e.g. a set of initial spot prices, S_0) for an extensive analysis.[21] What has been done

[21] Calculating each one of the results requires at least one order of magnitude more time and computational power than in the previous chapter or in the case of abandonment.

instead is to take a representative set of initial conditions and then see how the corresponding production changes with the values of equivalent but more progressive taxes, so that we are able to appraise how the taxation regime changes the production decision and, in its turn, how political risk affects this same production decision.

As in the case involving abandonment, progressiveness in taxation is going to be achieved using a set of equivalent taxes, and as with the abandonment case, the set of equivalent progressive taxes, $Tax(S,k)$, will be subject to the same nonlinear tax seen previously, where the parameter k is replaced by δ as it appears in equation (2.12) on page 79.

So, once the particular initial conditions are selected, the price path models are generated using the models by Trolle and Schwartz (2009). Similarly, the different values for the progressiveness parameter δ and the associated value $\tau_{base}(\delta)$ used to assess the effect of a more progressive taxation regime are based on generating taxes that are *equivalent* to τ_{inc} as seen before: both in the previous chapter and in the abandonment case.

The parameters

The additional parameters that belong exclusively to the **modified** version of the Aleksandrov and Hambly (2010) multiple real option model used in this dissertation can be seen in table 2.1. The criteria to choose these values was, firstly, to assure consistency with previously used parameters, so that the total amount of mineral/oil to be extracted remained consistent with the values for Y_{t_n} shown previously. Another consideration was to allow a yearly decision process for the production decision ($q \in \{1,\ldots,Q\}$) while maintaining the possibility to expropriate at each of the original steps (where t_j is such that $j \in \{1,\ldots,N\}$).

Table 2.1: Parameters used in the modified version of the Aleksandrov and Hambly (2010) multiple real options model used in this chapter.

Parameter	values
r	0.05
m_p	10
k_{prod}	2
y_{prod}	5
Y_{base}	5
T	10
Q	10
N	120

Therefore, r is the risk-free rate, m_p is the total number of flexible extraction blocks at the beginning of the operations, k_{prod} is the maximum number of blocks that can be exploited at each period, y_{prod} is the size of each one of these extraction blocks, Y_{base} is the constant (yearly) base production, T is the lifespan of the mine/oil field and Q is the total number of periods where a production decision is taken (please note that $Q = T$ as the production is decided on a yearly basis). It is important to notice that in this dissertation k_{t_q} is constant and equal to k_{prod} $\forall$ q, this is not a mandatory restriction; for example, in the implementation of the multiple real option model by Aleksandrov and Espinoza (2011) the authors consider varying production capacity to acknowledge technological improvements during the exploitation process.
Finally, we must note that the number of discrete periods is both $N = 120$ for the expropriation decision as seen previously and $Q = 10$ in order to conform to an annual decision process for production.

Multiple iterations to optimise production

In the set up for the implementation of the multiple real option decision model for production by Aleksandrov et al. (see both Aleksandrov and Espinoza, 2011; Aleksandrov et al., 2013), there was neither taxation nor any uncertainty regarding property rights. As we introduced them in this dissertation, we needed a way to assess the producers' response to the possibility of expropriation and to different taxation regimes, this was done using an iterative process where the producers reacted both to newly established risks of expropriation, as well as to variations in the taxation regime.
We considered two approaches to this problem, one was to assume that the producer chooses an initial production function in the absence of knowledge that its assets can be expropriated. We call this the *naïve producer*, who then adjusts his production function to the knowledge that there can be expropriation, given that this initial production schedule will generate a best response from the government that will include this possibility. The second case was to assume that the producer knows that there is a risk of expropriation, a risk that is calculated as the best response by a government to a 'dummy' producer that extracts at a constant rate throughout the period, this producer is going to be called, *non-naïve*.
We thus generated two sets of iteration processes which proceeded as follows.

a. Price paths were generated for either copper or oil crude, using the pricing models that appear in Cortázar and Schwartz (2003) (for copper)[22] and the one in Trolle and Schwartz (2009) (for oil price), and were

[22] As mentioned, we limit the analysis in this chapter to the results obtained only for the oil price model.

aggregated in order to go from monthly to annual steps (i.e. reducing the steps from 120 to 10 so as to go from $\triangle t_j$ to $\triangle t_q$, or from a monthly to a yearly process).

Then, for the *naïve producer* the production model was run immediately afterwards:

b. We generated different values for the tax progressiveness parameter δ, from δ_0 to δ_{max} according to what we have seen about generation of equivalent tax regimes in the previous chapter.

c. The modified Aleksandrov and Hambly (2010) production model stated on page 82 was run, therefore obtaining a production function, $\pi^*_{k,i}$ for each path i where $\pi^*_{k,i} = \{\tau_{l,i}\}_{l=1}^{m_p}$, for which the stopping times are $\tau_{l,i} \in \{t_1, \dots, t_T\}$, with $\tau_{j,i} \leq \tau_{k,i}$ if $t_j \leq t_k$.

d. We ran the real options expropriation model detailed in section 2.2, which is the extended version of the real options expropriation value model that acknowledges the possibility that producers abandon the mine or oil field, therefore obtaining an abandonment or an expropriation time, t_{X_i} and $t_{Z_i} \in t_j$ with $j \in \{1, \dots, N, N+1\}$, for each simulated path i.

e. We calculated the *expected probability of expropriation* for each simulated path i, so that producers had some knowledge, akin to the expected continuation value in the LSM model, in such a way that expropriation probability can be internalised, and so production can be modified to minimise the expected risk.

f. For each of the values of δ we ran the modified Aleksandrov and Hambly (2010) model, considering this time the expected probability of expropriation that had already been calculated and so obtaining a new production function defined by $\pi^*_{k,i}$.

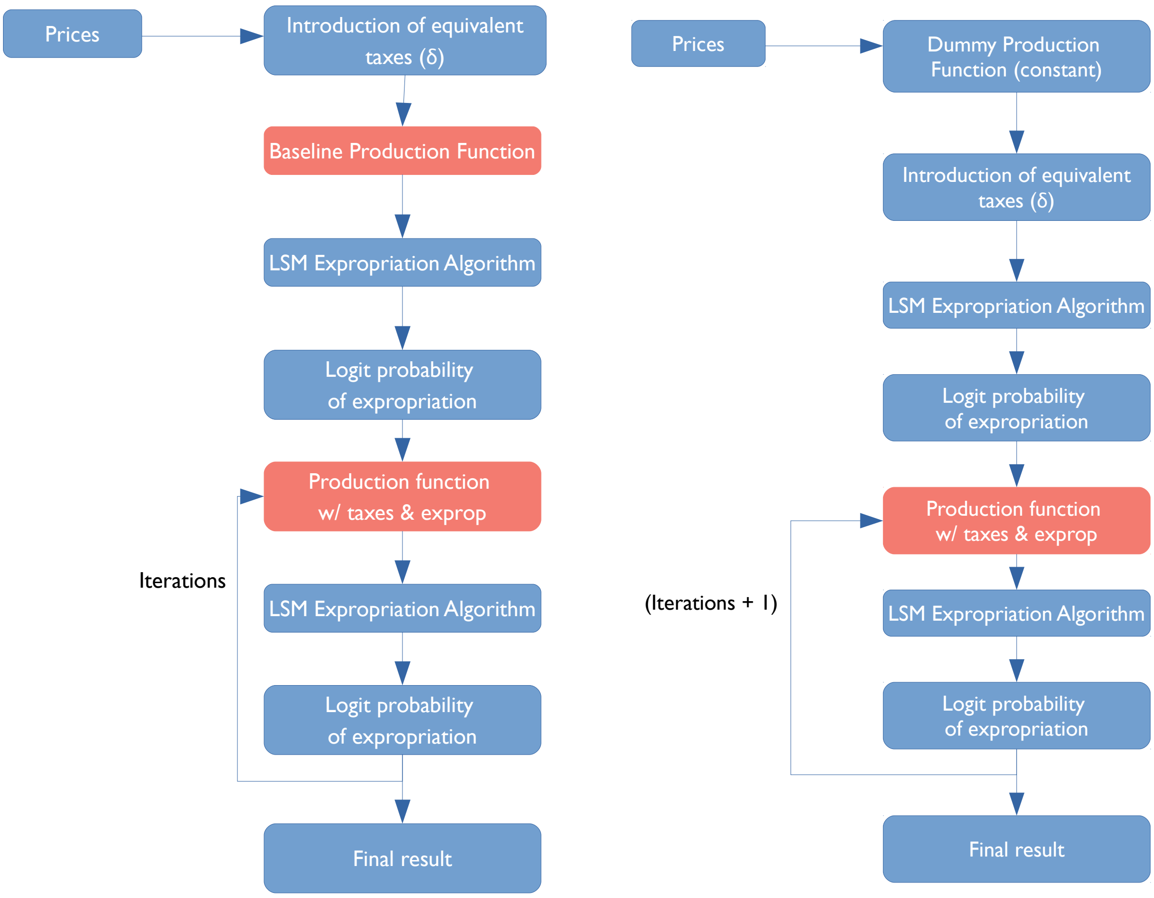
g. Again, for each of the δ values, a new expropriation/abandonment decision was calculated as in **d.**

h. In similar fashion, for each of the δ values, a new *expected probability of expropriation* was calculated as in **e.**

i. A new iteration started from **f.**

Therefore, as a result we had $(N_{iterations} + 1) \cdot N_\delta$ results for each simulation,[23] where $N_\delta = 10$ is the number of simulated taxation regimes of varying progressiveness from δ_0 to δ_{max}. The flowchart of the left in figure 2.1 shows what was done in each step.

[23]The initial –naïve– production function, called *baseline production function* plus all the successive iterations where there was a new production schedule being calculated.



(a) Naïve producer (b) Non-naïve producer

Figure 2.1: Comparison between the flowcharts of the two multiple iterations heuristics seen in this chapter. They show the interaction between the firms choosing a production schedule (in red) and the government introducing expropriation as a revenue maximising strategy

The *non-naïve producer* differs in that immediately after the generation of price paths (point **a.**, above) we generated a dummy production variable, where Y_t was constant. It was to this dummy production function that the *expected (logit) probability of expropriation* was calculated, and then, the process proceeded as above from point **f.** onwards.

Therefore, the producer –as shown on the right flowchart of figure 2.1– would first choose the production with a prior of what the expropriation chances are: in order to keep the number of production decisions comparable with the naïve producer, there were $[N_{iterations}+1]$ iterations of the algorithm, so that the results from each production schedule could be compared between the naïve and the non-naïve producer.

A note on the expected (logit) probability of expropriation

In points **e.** and **f.** of the iterative process above, and just before production for the non-naïve producer, we estimated an *expected probability of expropriation* for each path i at every moment t_j. That is, the unbiased probability that an expropriation was going to take place over the next period. To do this, we relied on the approach taken by Longstaff and Schwartz (2001) to assess the expected value of holding an option in their LSM method, in this case, instead of a traditional least squares regression, a *logit regression* on the cumulative expropriation decisions was employed, so that we could model the binary nature of the expropriation decision. This logit regression was made at each time t_j with $j \in \{1, \ldots, N\}$ for each price path i; the dependent variable being the expected probability that operations are expropriated at each price path i during the next period, t_{j+1}, while the known parameters were chosen to be the spot price and futures contracts curve parameters, together with an indicator of remaining reserves in the mine or oil field; all of these independent variables can be assumed to be of public knowledge and so are suitable parameters to build an unbiased indicator from the producers' perspective.

As in the model by Longstaff and Schwartz (2001), we need to estimate an expected value in order to avoid omniscience from the producer. If it were the case that the firm knew precisely when it was going to be expropriated, the production decision would be trivial as it would imply producing as much as it could before the expropriation took place. In this iterative model, however, the producer makes an informed, unbiased decision on the odds of expropriation, which nevertheless does not rule out the possibility that the company faces an expropriation that was unexpected depending on the fit of the logit model.

Once this *expected probability of expropriation* is calculated, it is inserted in the model in letter **f**. What we do here is to multiply the cumulative risk of expropriation as calculated with the logit regression with the operational income that firms receive from the exploitation of the mine/oil field, h_{i,t_q}, from equation (2.23) in this same section above. In fact, we discount the probability that the operations are expropriated from the income of the same operations. Therefore, firms must react to this variation of the income stream by adjusting their production function; this adjustment is what concerns us in the analysis of the results described below and analysed in detail on page 116.

2.3.3 An overview of the findings

This final extension to the expropriation model which we started presenting on the first chapter, the implementation of the flexible production model by Aleksandrov and Hambly (2010) in a context where there is the probability of expropriation with progressive taxation, had a different implementation than the ones seen previously, and for that same reason the structure of the results and the analysis is different as we can see in Section 2.6 on page 116.

The intuition

Following the results obtained in the papers by Aleksandrov et al. (i.e. Aleksandrov and Espinoza, 2011; Aleksandrov et al., 2013) we expected an increase on the firm's value for the extractive operations: even if those papers just stated that the gains were to be accrued by the extractive operations as a whole, and not by any specific party, it could be inferred that the main winners would be those who chose the production schedule. With respect to the production function, Y_{i,t_q}, and considering that the risk of expropriation that was introduced is cumulative, we would have expected that the production were biased towards the present, so that it avoided higher risks of expropriation in the future, which is a qualitatively different result than the one obtained previously.

Results and analysis

The results for the optimised production rate confirmed the intuition for low values of taxation progressiveness (the parameter δ), in those cases the iterative process *did* displace production towards the first half of the life of the mine/oil field. However when δ increased, we saw that the production function started *cycling* with each iteration for every value over a threshold, except when the parameter δ was too high and early expropriation made the modification of production, irrelevant. If we looked at the evolution of expropriation risk, the results were different, for higher values of δ the introduction of production flexibility made operations riskier, and successive iterations did not ameliorate this risk. And finally, when looking at the overall value of the operations for both the firm and the government, we could see that the introduction of production flexibility increased the value of the operations for both of them when the taxation parameter δ is low; on the contrary, for the government, production flexibility seems to be convenient in every case, even when production cycles. What is interesting is that, in those cases were the iterative process *cycled*, there was a higher chance that the whole iteration heuristic lowered the value of operations –for both the overall value and the firm– as producers and governments were engaged in a costly catch-up guessing process.

That the iterative procedure works for some initial conditions but not for others is interesting, and can be explained by looking at the setting of the model, at how progressiveness in taxation skews payoffs for governments and firms, and at the distribution of the risk; on page 132 there is a discussion about the sources of this behaviour, which can be attributed to the lack of responsiveness of the modified production model to risk conditions on the first period, which leaves the model as especially ineffective to high values of progressiveness in taxation (or higher values of δ) given the fact in those most of the expropriation takes place immediately, without giving enough room for firms to respond.

To illustrate this further, we now introduce what we call 'a simple model' in the following section to show in detail how the production decisions and the predictive mechanisms work.

2.4 Introducing production flexibility, a three-period model

In order to illustrate the multiple real option model presented in the previous section, we introduce here a simple three-period model; which offers interesting insights on how production is scheduled and on the inner workings of the prediction mechanisms embedded in the model.

As said before, the simplest version of a model of this kind is one that contains three periods: t_0, t_1, and t_2. In period t_0 no production takes place, but forward prices are known and the government can decide whether it is convenient to expropriate paying a compensation to the operators –proportional to the remaining life of the operations– K_1, and also incurring in reputational costs of K_2.[24] The government can also take the decision to expropriate in t_1, paying a lower compensation for a shorter remaining life and appropriating only the production from t_2.

Producers can allocate extraction in discrete blocks during t_1 and t_2. Also, this simple model considers that the risk-free rate, r, is zero, which avoids price drift in the price model that was custom-built for this model. The first step was to define a price model for the underlying commodity; with this in place we ran a simplified version of the Aleksandrov and Hambly (2010) model in order to schedule the production. Finally, an expropriation model was run and unbiased estimators for the probability of expropriation were generated: so that the main stages depicted on the flowcharts of figure 2.1 on page 89 were replicated.

[24] In the same way as they are presented in the formula for $V_{cost}(i, t_j, k)$, equation 2.3 on page 77.

2.4.1 The simplest price model

In order to create a process where productions decisions are taken, we require a price model for an underlying commodity, the one used here and summarised in figure 2.2 consists of a number of elements detailed below.

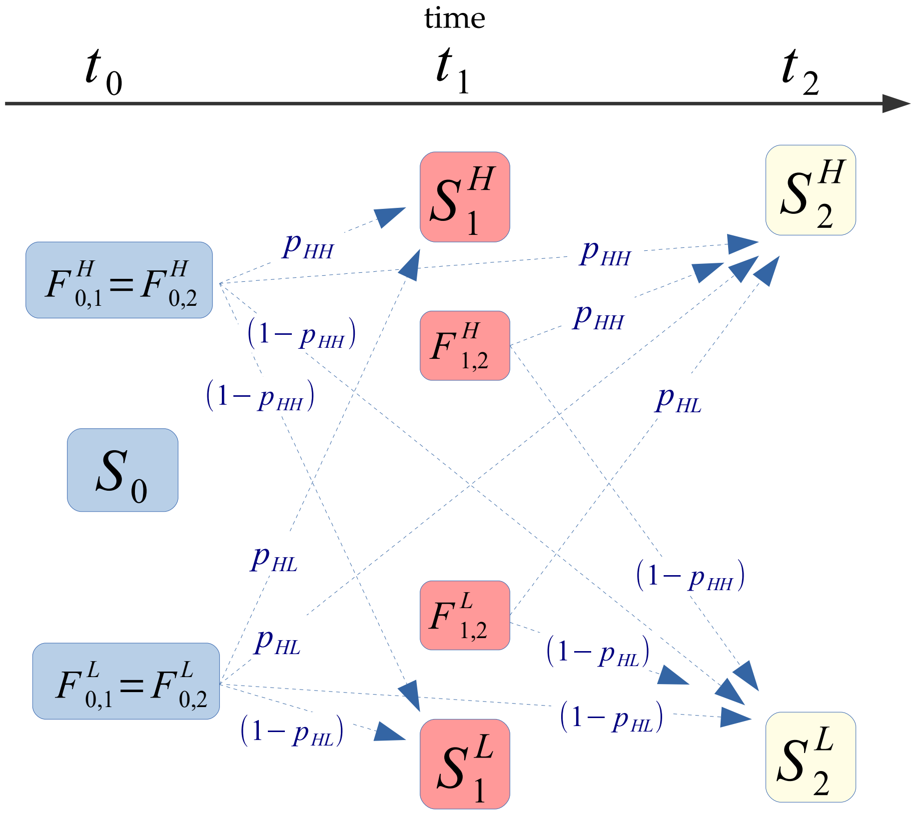


Figure 2.2: Schematic view of the three-period price model used in this section: at time t_0, the values in blue (the spot price, S_0 and the forward contracts for t_1 and t_2) are defined. The spot price at the next period, S_1^H or S_1^L, will happen with a probability that is conditional on the value of the forward contract that existed at t_0. At the next period, t_1, this spot price is defined (i.e. there is no further uncertainty) and the new forward contract will be –again– the unbiased indicator for the spot price at time t_2.

First, in this model, everyone knows that at each period t_n (where $n \in \{1,2\}$), the underlying commodity can take only one of two possible spot prices: it can be either a high price, S_n^H, or a low price, S_n^L. At time t_0 the values of the forward contracts for periods t_1 and t_2 are observed, and can also only take one of two possible values, $F_{0,n}^H$ or $F_{0,n}^L$, for $n \in \{1,2\}$.

At the next period, t_1, the spot price is observed (it is either S_1^H or S_1^L) as well as the value for the forward contract at time t_2, which can also take one of two possible values $F_{1,2}^H$ or $F_{1,2}^L$. The price at which these contracts are valued reflects an unbiased expectation of future prices, $F_{n,m} = E_n[S_m]$.[25] Additionally, we assume that the value for each forward contract is going to be one of just two possible values, meaning that:

$$F^H_{0,1} = F^H_{0,2} = F^H_{1,2} \ , \tag{2.19}$$

and

$$F^L_{0,1} = F^L_{0,2} = F^L_{1,2} \ . \tag{2.20}$$

Finally, at time t_2, the price of the underlying commodity is observed for that period, conditional on the value of the previous forward price.

In order to assign values for the spot prices and for the forward contracts, while keeping the no-arbitrage condition, we must proceed backwards. First we set the possible values that the spot prices can take in table 2.2, together with the conditional probabilities of an increase in price at the next period (the probability that the price is S^H_{n+1} at time t_n) given that at time t_n we know the value of the forward contract for next period. As can be seen in this table, we assume that the high price S^H_n has the same value in both periods, and the same happens with the low price S^L_n.

Table 2.2: Parameters of three-period price model

Parameter	Value
S^L_1, S^L_2	1
S^H_1, S^H_2	2
p_{HH}	0.8
p_{HL}	0.2

As said before, besides setting the value for the low and the high spot prices there are two other parameters, p_{HH}, and, p_{HL}, which feature prominently in the schematic view of the price model of figure 2.2, these are the probabilities that next period's price is high (S^H_{n+1}) conditional on the value of today's forward price maturing at t_{n+1} being high or low, respectively. So that the value of the forward contracts, $F^H_{n,m}$ and $F^L_{n,m}$ in this simple price model are derived from these parameters:

[25]This spot-forward price equivalence was instrumental to build the prices for the general model in the appendix of the previous chapter, and is viewed again on page 105 of this chapter.

$$F^H_{n,m} = p_{HH} \cdot S^H_m + (1 - p_{HH}) \cdot S^L_m \ , \tag{2.21}$$

and

$$F^L_{n,m} = p_{HL} \cdot S^H_m + (1 - p_{HL}) \cdot S^L_m \ . \tag{2.22}$$

So that these forward contracts abide by the no-arbitrage rule: each forward contract is an unbiased indicator of the prices in the future.[26] Therefore, with the data from table 2.2 and equations (2.21) and (2.22) in mind we can obtain the values of the forward contracts in this case, which are $F^H_{n,m} = 1.7$ and $F^L_{n,m} = 0.8$.

The simple nature of the price model allows us to list all the possible price paths –32 cases– which can be seen in Table 2.3. However, these price paths are not all equally feasible; due to the no-arbitrage condition that keeps forward contracts as unbiased indicators of future spot prices. In this case we can work backwards to assign to each price path a probability so that the model remains consistent; this is shown in the column aptly labelled *Probability*.

We are now going to use these price paths to define the proper extraction schedule for each one of them, and then the government will intervene and evaluate the possibility of expropriation.

[26] The process is even simpler, given that we had defined before that the risk free rate, r, is $r = 0$.

Table 2.3: Summary of all the possible price paths for the underlying price model of the commodity described in this section: the column on the right shows us the implied probability of each price path so that the no-arbitrage condition is kept.

No.	$F_{0,1}$	$F_{0,2}$	S_1	$F_{1,2}$	S_2	Probability
1	1.8	1.8	2	1.8	2	12.8%
2	1.8	1.8	2	1.8	1	0.8%
3	1.8	1.8	2	1.2	2	3.2%
4	1.8	1.8	2	1.2	1	3.2%
5	1.8	1.8	1	1.8	2	3.2%
6	1.8	1.8	1	1.8	1	0.2%
7	1.8	1.8	1	1.2	2	0.8%
8	1.8	1.8	1	1.2	1	0.8%
9	1.8	1.2	2	1.8	2	3.2%
10	1.8	1.2	2	1.8	1	3.2%
11	1.8	1.2	2	1.2	2	0.8%
12	1.8	1.2	2	1.2	1	12.8%
13	1.8	1.2	1	1.8	2	0.8%
14	1.8	1.2	1	1.8	1	0.8%
15	1.8	1.2	1	1.2	2	0.2%
16	1.8	1.2	1	1.2	1	3.2%
17	1.2	1.8	2	1.8	2	3.2%
18	1.2	1.8	2	1.8	1	0.2%
19	1.2	1.8	2	1.2	2	0.8%
20	1.2	1.8	2	1.2	1	0.8%
21	1.2	1.8	1	1.8	2	12.8%
22	1.2	1.8	1	1.8	1	0.8%
23	1.2	1.8	1	1.2	2	3.2%
24	1.2	1.8	1	1.2	1	3.2%
25	1.2	1.2	2	1.8	2	0.8%
26	1.2	1.2	2	1.8	1	0.8%
27	1.2	1.2	2	1.2	2	0.2%
28	1.2	1.2	2	1.2	1	3.2%
29	1.2	1.2	1	1.8	2	3.2%
30	1.2	1.2	1	1.8	1	3.2%
31	1.2	1.2	1	1.2	2	0.8%
32	1.2	1.2	1	1.2	1	12.8%

2.4.2 Simplifying the parameters of the multiple real option model

We are going to simplify the parameters related to the operations used in this simple model in comparison with the ones shown in the previous section. As there are only two periods where the extraction can take place we define that m_p, the reserves, are **two blocks**, and the production capability, k_{prod}, is **of two blocks as well**: so that in each of the periods the complete reserves can be extracted.

Table 2.4: Parameters used in the simple model in order to illustrate the Aleksandrov and Hambly (2010) multiple real options model used in this chapter.

Parameter	values
r	0
m_p	2
k_{prod}	2
y_{prod}	1
T	2
τ_{inc}	0.6
C_{firm}	0.3

Where, following the notation seen in this chapter, y_{prod}, is the size of each one of the exploitation blocks, $T = n = 2$, the number of periods, τ_{inc}, the flat corporate income rate, and C_{firm} is the extraction cost by an efficient private firm.

The first step in order to get the production schedule is to define the payoff (after taxes) of one block of production, $h_{i,n}$, for each one of the 32 price paths, i, and at each period, $n \in \{1,2\}$. Following equation 2.23 on page 96: we get the payoff considering –initially– a flat tax rate $\tau_{inc} = 0.6$ defined previously, and we get:

$$h_{i,n} = \begin{cases} \max\left(0, [S_{i,2} - C_{firm}] \cdot (1-\tau_{inc}) \cdot y_{prod}\right) & \text{if } n = 2, \\ [S_{i,1} - C_{firm}] \cdot (1-\tau_{inc}) \cdot y_{prod} & \text{if } n = 1. \end{cases} \tag{2.23}$$

In order to find the appropriate production schedule, following equation (2.18)[27] on page 84 we need to determine first $V_T^{*,m_{p,T}}$ which in this case is $V_2^{*,m_{p,2}}$, and which can take one of three values as $m_{p,2} \in \{0,1,2\}$; however, as there is no base production, the value $V_2^{*,0}$ will be zero for every price path.[28]

Then, assessing the value of $V_1^{*,m_{p,1}}$ implies getting an estimate for $E_1[V_2^{*,m_{p,2}}]$ in each of the three possible values of $m_{p,2}$; in order to do this we use the existing forward price $F_{1,2}$ as the unbiased estimator of the spot price at t_2. With that information it is possible to find the production schedule that maximises $V_1^{*,m_{p,1}}$.

[27] As in this simple model $m_p = 2$ and $k_{prod} = 2$; so $m_{p,q} \le k_{t_q}$ which corresponds to equation (2.18).

[28] That is, the value of the operations is zero if there are no production blocks available.

We need to remember that in the first period the reserves, $m_{p,1}$, are always going to be 2, so $V_1^{*,m_{p,1}} = V_1^{*,2}$. Considering the parameters from table 2.4, the whole procedure to generate an optimal production schedule for each price path is detailed in table 2.5 below; please note that the value function at the first period, $V_1^{*,2}$, implies choosing the maximum continuation value from one of three options: $2 \cdot h_{i,1}$, $h_{i,1} + E_1[V_2^{*,1}]$, or $E_1[V_2^{*,2}]$. With this information the firm can decide its production schedule, shown as columns Y_1 and Y_2 at the right of table 2.5.

Table 2.5: The generation of the production schedule using a multiple real options model given the price paths and forward contracts that appear in table 2.3.

							$V_1^{*,2}$				
No.	$h_{i,2}$	$h_{i,1}$	$V_2^{*,2}$	$V_2^{*,1}$	$E_1[V_2^{*,2}]$	$E_1[V_2^{*,1}]$	$2 \cdot h_{i,1}$	$h_{i,1} + E_1[V_2^{*,1}]$	$E_1[V_2^{*,2}]$	Y_1	Y_2
1	0.68	0.68	1.36	0.68	1.2	0.6	1.36	1.28	1.2	2	0
2	0.28	0.68	0.56	0.28	1.2	0.6	1.36	1.28	1.2	2	0
3	0.68	0.68	1.36	0.68	0.72	0.36	1.36	1.04	0.72	2	0
4	0.28	0.68	0.56	0.28	0.72	0.36	1.36	1.04	0.72	2	0
5	0.68	0.28	1.36	0.68	1.2	0.6	0.56	0.88	1.2	0	2
6	0.28	0.28	0.56	0.28	1.2	0.6	0.56	0.88	1.2	0	2
7	0.68	0.28	1.36	0.68	0.72	0.36	0.56	0.64	0.72	0	2
8	0.28	0.28	0.56	0.28	0.72	0.36	0.56	0.64	0.72	0	2
9	0.68	0.68	1.36	0.68	1.2	0.6	1.36	1.28	1.2	2	0
10	0.28	0.68	0.56	0.28	1.2	0.6	1.36	1.28	1.2	2	0
11	0.68	0.68	1.36	0.68	0.72	0.36	1.36	1.04	0.72	2	0
12	0.28	0.68	0.56	0.28	0.72	0.36	1.36	1.04	0.72	2	0
13	0.68	0.28	1.36	0.68	1.2	0.6	0.56	0.88	1.2	0	2
14	0.28	0.28	0.56	0.28	1.2	0.6	0.56	0.88	1.2	0	2
15	0.68	0.28	1.36	0.68	0.72	0.36	0.56	0.64	0.72	0	2
16	0.28	0.28	0.56	0.28	0.72	0.36	0.56	0.64	0.72	0	2
17	0.68	0.68	1.36	0.68	1.2	0.6	1.36	1.28	1.2	2	0
18	0.28	0.68	0.56	0.28	1.2	0.6	1.36	1.28	1.2	2	0
19	0.68	0.68	1.36	0.68	0.72	0.36	1.36	1.04	0.72	2	0
20	0.28	0.68	0.56	0.28	0.72	0.36	1.36	1.04	0.72	2	0
21	0.68	0.28	1.36	0.68	1.2	0.6	0.56	0.88	1.2	0	2
22	0.28	0.28	0.56	0.28	1.2	0.6	0.56	0.88	1.2	0	2
23	0.68	0.28	1.36	0.68	0.72	0.36	0.56	0.64	0.72	0	2
24	0.28	0.28	0.56	0.28	0.72	0.36	0.56	0.64	0.72	0	2
25	0.68	0.68	1.36	0.68	1.2	0.6	1.36	1.28	1.2	2	0
26	0.28	0.68	0.56	0.28	1.2	0.6	1.36	1.28	1.2	2	0
27	0.68	0.68	1.36	0.68	0.72	0.36	1.36	1.04	0.72	2	0
28	0.28	0.68	0.56	0.28	0.72	0.36	1.36	1.04	0.72	2	0
29	0.68	0.28	1.36	0.68	1.2	0.6	0.56	0.88	1.2	0	2
30	0.28	0.28	0.56	0.28	1.2	0.6	0.56	0.88	1.2	0	2
31	0.68	0.28	1.36	0.68	0.72	0.36	0.56	0.64	0.72	0	2
32	0.28	0.28	0.56	0.28	0.72	0.36	0.56	0.64	0.72	0	2

2.4.3 Expropriation and production flexibility results: Iterations

Once the production has been scheduled by the producer, the government can determine on whether it is going to expropriate the operations given a certain price path. We can build a small weighted LSM model[29] that illustrates how this works for the production schedule and price model we have just seen in table 2.5. In order to do this, we should build a couple of payoff functions and establish those parameters that are characteristic to the expropriation process to replicate the methodology used both in this chapter and in the previous one. There are three additional parameters: C_{gov}, the cost that a government would incur to operate the mine/oil field, K_1, the annual compensation to be paid to the producers, and K_2, the reputational cost for expropriating assets. The values for these parameters can be seen in table 2.6.

Table 2.6: Parameters used exclusively in the expropriation process of the simple model developed in this section.

Parameter values	
K_1	0.15
K_2	0.3
C_{gov}	0.5

For each price path, the construction of the immediate payoff function $\Pi_{i,n}$ is quite straightforward, and it involves using equations 2.3 and 2.4 on page 77 to determine $V_{cost}(i,n)$ and $V_{gain}(i,n)$: as in the previous cases, the government uses the forward contracts as unbiased estimators of future prices. In this case, the expropriation decision takes time either in t_0 or in t_1, with the government taking possession of next year's production.

As seen previously, the immediate payoff function is constructed as[30]

$$\Pi(i,n) = \max(V_{gain}(i,n) - V_{cost}(i,n), 0) \ , \tag{2.24}$$

And expropriation will take place if the payoff function is positive and larger than the continuation value (i.e. the expected value of the immediate payoff function at t_{n+1}). In this simple model only $\Pi(i,1)$ needed to be estimated, and $E_{i,0}[\Pi(i,1)]$ was estimated using a linear approximation with $F_{1,2}(i)$ and $Y_1(i)$ as the variables used to predict the performance of the prices and the inventory in the next period.

With the immediate payoffs and $E_{i,0}[\Pi(i,1)]$ it was possible to build an expropriation decision matrix by the government as can be seen in table 2.7.

[29] Taking into account that each price path has a different probability of occurrence.

[30] See equation 2.7 on page 78.

Table 2.7: Calculating the decision to expropriate after the change in production using American-style real options for each price path of the simple model.

	V_{cost}		V_{gain}		Payoff Function			Expropriation?	
No.	t_0	t_1	t_0	t_1	$\Pi(i,t_0)$	$\Pi(i,t_1)$	$E_{i,t_0}[\Pi(i,t_1)]$	t_0	t_1
1	2.5	0.55	2.6	0	0.1	0	0.0625	TRUE	FALSE
2	2.5	0.55	2.6	0	0.1	0	0.0625	TRUE	FALSE
3	2.5	0.55	2.6	0	0.1	0	0	TRUE	FALSE
4	2.5	0.55	2.6	0	0.1	0	0	TRUE	FALSE
5	2.5	2.35	2.6	2.6	0.1	0.25	0.1875	FALSE	TRUE
6	2.5	2.35	2.6	2.6	0.1	0.25	0.1875	FALSE	TRUE
7	2.5	1.63	2.6	1.4	0.1	0	0.0625	TRUE	FALSE
8	2.5	1.63	2.6	1.4	0.1	0	0.0625	TRUE	FALSE
9	2.5	0.55	2.6	0	0.1	0	0.0625	TRUE	FALSE
10	2.5	0.55	2.6	0	0.1	0	0.0625	TRUE	FALSE
11	2.5	0.55	2.6	0	0.1	0	0	TRUE	FALSE
12	2.5	0.55	2.6	0	0.1	0	0	TRUE	FALSE
13	1.78	2.35	1.4	2.6	0	0.25	0.1875	FALSE	TRUE
14	1.78	2.35	1.4	2.6	0	0.25	0.1875	FALSE	TRUE
15	1.78	1.63	1.4	1.4	0	0	0.0625	FALSE	FALSE
16	1.78	1.63	1.4	1.4	0	0	0.0625	FALSE	FALSE
17	1.78	0.55	1.4	0	0	0	0.0625	FALSE	FALSE
18	1.78	0.55	1.4	0	0	0	0.0625	FALSE	FALSE
19	1.78	0.55	1.4	0	0	0	0	FALSE	FALSE
20	1.78	0.55	1.4	0	0	0	0	FALSE	FALSE
21	2.5	2.35	2.6	2.6	0.1	0.25	0.1875	FALSE	TRUE
22	2.5	2.35	2.6	2.6	0.1	0.25	0.1875	FALSE	TRUE
23	2.5	1.63	2.6	1.4	0.1	0	0.0625	TRUE	FALSE
24	2.5	1.63	2.6	1.4	0.1	0	0.0625	TRUE	FALSE
25	1.78	0.55	1.4	0	0	0	0.0625	FALSE	FALSE
26	1.78	0.55	1.4	0	0	0	0.0625	FALSE	FALSE
27	1.78	0.55	1.4	0	0	0	0	FALSE	FALSE
28	1.78	0.55	1.4	0	0	0	0	FALSE	FALSE
29	1.78	2.35	1.4	2.6	0	0.25	0.1875	FALSE	TRUE
30	1.78	2.35	1.4	2.6	0	0.25	0.1875	FALSE	TRUE
31	1.78	1.63	1.4	1.4	0	0	0.0625	FALSE	FALSE
32	1.78	1.63	1.4	1.4	0	0	0.0625	FALSE	FALSE

Subsequent iterations

If the producers realise that the government is going to expropriate given the production schedule; they will be able to forecast the probability of expropriation given the available data (spot and forward prices) using a weighted logit model. In table 2.8 we can see the results of this *best available forecast* for the producers, where the probability of expropriation is depicted accurately for t_2 but with some degree of uncertainty for t_1.

Table 2.8: Production and expropriation decisions together with the associated weighted logit probability of expropriation for **Iteration 0** –the baseline case– in the simple model.

	Iteration 0					
			Expropriation?		Logit Prob of Exprop	
No.	Y_1	Y_2	t_0	t_1	t_0	t_1
1	2	0	TRUE	FALSE	92%	0%
2	2	0	TRUE	FALSE	92%	0%
3	2	0	TRUE	FALSE	92%	0%
4	2	0	TRUE	FALSE	92%	0%
5	0	2	FALSE	TRUE	92%	100%
6	0	2	FALSE	TRUE	92%	100%
7	0	2	TRUE	FALSE	92%	0%
8	0	2	TRUE	FALSE	92%	0%
9	2	0	TRUE	FALSE	74%	0%
10	2	0	TRUE	FALSE	74%	0%
11	2	0	TRUE	FALSE	74%	0%
12	2	0	TRUE	FALSE	74%	0%
13	0	2	FALSE	TRUE	74%	100%
14	0	2	FALSE	TRUE	74%	100%
15	0	2	FALSE	FALSE	74%	0%
16	0	2	FALSE	FALSE	74%	0%
17	2	0	FALSE	FALSE	20%	0%
18	2	0	FALSE	FALSE	20%	0%
19	2	0	FALSE	FALSE	20%	0%
20	2	0	FALSE	FALSE	20%	0%
21	0	2	FALSE	TRUE	20%	100%
22	0	2	FALSE	TRUE	20%	100%
23	0	2	TRUE	FALSE	20%	0%
24	0	2	TRUE	FALSE	20%	0%
25	2	0	FALSE	FALSE	6%	0%
26	2	0	FALSE	FALSE	6%	0%
27	2	0	FALSE	FALSE	6%	0%
28	2	0	FALSE	FALSE	6%	0%
29	0	2	FALSE	TRUE	6%	100%
30	0	2	FALSE	TRUE	6%	100%
31	0	2	FALSE	FALSE	6%	0%
32	0	2	FALSE	FALSE	6%	0%

As producers can foresee this information regarding expropriation probabilities (they can foresee imperfectly but unbiasedly), firms can adjust the payoff of their production schedule taking into account the cumulative probability that these flows will not be realised due to expropriation. They will thus change their production schedule to the one that appears in table 2.9. The fact that there is no absolute certainty on the expropriation at t_1 shifts the production in different ways. Again, a weighted logit model to forecast expropriation can be made and a further iteration to optimise production can be scheduled.

Table 2.9: Production and expropriation decisions together with the associated weighted logit probability of expropriation for **Iteration 1** in the simple model.

	Iteration 1					
			Expropriation?		Logit Prob of Exprop	
No.	Y_1	Y_2	t_0	t_1	t_0	t_1
1	0	2	FALSE	TRUE	47%	100%
2	0	2	FALSE	TRUE	47%	100%
3	0	2	TRUE	FALSE	47%	0%
4	0	2	TRUE	FALSE	47%	0%
5	2	0	TRUE	FALSE	47%	0%
6	2	0	TRUE	FALSE	47%	0%
7	0	2	TRUE	FALSE	47%	0%
8	0	2	TRUE	FALSE	47%	0%
9	0	2	FALSE	TRUE	5%	100%
10	0	2	FALSE	TRUE	5%	100%
11	0	2	FALSE	FALSE	5%	0%
12	0	2	FALSE	FALSE	5%	0%
13	2	0	TRUE	FALSE	5%	0%
14	2	0	TRUE	FALSE	5%	0%
15	0	2	FALSE	FALSE	5%	0%
16	0	2	FALSE	FALSE	5%	0%
17	0	2	FALSE	TRUE	24%	100%
18	0	2	FALSE	TRUE	24%	100%
19	2	0	FALSE	FALSE	24%	0%
20	2	0	FALSE	FALSE	24%	0%
21	2	0	FALSE	FALSE	24%	0%
22	2	0	FALSE	FALSE	24%	0%
23	0	2	TRUE	FALSE	24%	0%
24	0	2	TRUE	FALSE	24%	0%
25	2	0	FALSE	FALSE	2%	0%
26	2	0	FALSE	FALSE	2%	0%
27	2	0	FALSE	FALSE	2%	0%
28	2	0	FALSE	FALSE	2%	0%
29	2	0	FALSE	FALSE	2%	0%
30	2	0	FALSE	FALSE	2%	0%
31	0	2	FALSE	FALSE	2%	0%
32	0	2	FALSE	FALSE	2%	0%

We can repeat this process further, as is presented in the diagrams of figure 2.1, and so a second iteration is shown in table 2.10: it is very interesting to notice that in this case the logit probability of expropriation has the same values as in the baseline case (table 2.8), which means that the production decision in a third iteration will be the same as in iteration number one (table 2.9). In this simple model the expectations of the government and of the firm do not converge and production will cycle between the production schedule of Iteration 1 and Iteration 2 indefinitely: the final production values will depend on the level-k thinking of both the government and of the investing firm.

We have thus shown how even a simple model can be affected by the expectations of expropriation and how

Table 2.10: Production and expropriation decisions together with the associated weighted logit probability of expropriation for **Iteration 2** in the simple model.

	Iteration 2					
			Expropriation?		Logit Prob of Exprop	
No.	Y_1	Y_2	t_0	t_1	t_0	t_1
1	2	0	TRUE	FALSE	92%	0%
2	2	0	TRUE	FALSE	92%	0%
3	0	2	TRUE	FALSE	92%	0%
4	0	2	TRUE	FALSE	92%	0%
5	0	2	FALSE	TRUE	92%	100%
6	0	2	FALSE	TRUE	92%	100%
7	0	2	TRUE	FALSE	92%	0%
8	0	2	TRUE	FALSE	92%	0%
9	2	0	TRUE	FALSE	74%	0%
10	2	0	TRUE	FALSE	74%	0%
11	2	0	TRUE	FALSE	74%	0%
12	2	0	TRUE	FALSE	74%	0%
13	0	2	FALSE	TRUE	74%	100%
14	0	2	FALSE	TRUE	74%	100%
15	0	2	FALSE	FALSE	74%	0%
16	0	2	FALSE	FALSE	74%	0%
17	2	0	FALSE	FALSE	20%	0%
18	2	0	FALSE	FALSE	20%	0%
19	2	0	FALSE	FALSE	20%	0%
20	2	0	FALSE	FALSE	20%	0%
21	0	2	FALSE	TRUE	20%	100%
22	0	2	FALSE	TRUE	20%	100%
23	0	2	TRUE	FALSE	20%	0%
24	0	2	TRUE	FALSE	20%	0%
25	2	0	FALSE	FALSE	6%	0%
26	2	0	FALSE	FALSE	6%	0%
27	2	0	FALSE	FALSE	6%	0%
28	2	0	FALSE	FALSE	6%	0%
29	0	2	FALSE	TRUE	6%	100%
30	0	2	FALSE	TRUE	6%	100%
31	0	2	FALSE	FALSE	6%	0%
32	0	2	FALSE	FALSE	6%	0%

in these cases expectation might not converge, something that we will see in detail in Section 2.6.

2.5 How Producers Respond: Results from the Abandonment Option

After the descriptions of the models and the introduction of a simple variation to the production function (the *simple model*), we present here the results. In this section we will focus on the first modification to the canonical model: introducing the possibility of abandonment in the case that future prospects are not encouraging.

The framework of this modification is explained in detail in Section 2.2, and it basically assumes that the abandonment option is costless for the producer, we know that there can be substantial costs related to the cleaning-up and termination of operations, but it can be assumed without loss of generality that all those expenses can be taken into account when determining the operational costs, C_{firm}, by adding the cost of closure to the operations and putting these closure costs into an escrow account until operations cease.

Furthermore, it is assumed that the condition for abandonment is that the expected value of the operations for the firm, $V^{abn}_{firm}(i, t_j)$ is non-positive at time t_j, this value is defined by the equation below:[31]

$$V^{abn}_{firm}(i, t_j) = \sum_{n=j+1}^{N} e^{-r(t_n - t_j)} \left(F_i(t_j, t_n) - C_{firm}\right) (1 - Tax(F_i(t_j, t_n), k)) Y_{t_n} \ . \tag{2.25}$$

This triggers an abandonment decision X_i for each simulated path i, thus changing the payoff function and the overall value of the operations.

2.5.1 The intuition

The reference case seen in the previous chapter, where there is no possibility of abandonment, is just a special case of the model stated above where $X_i = (N + 1)\ \forall\, i$; therefore in *absence of expropriation* the additional flexibility that producers have, to abandon production, should increase the value for the firm, so that $V^{abn}_{firm} \geq V_{firm}$. However, the fact that governments *can infer*[32] when operations are going to cease will modify expropriation decisions, and therefore alter the expected value for firms and governments.

Therefore, *ex-ante* we would expect that the option to abandon will enhance the value of the operations for the firm. On the other hand, the effects on the value of the operations for the government are not clear due to the fact that the government can alter the rate at which it expropriates.

[31] Taken from equation (2.2) on page 76.

[32] We have been clear that the government will work, at its best, with a rough estimator built by computing the expected timing of closure with a version of the LSM model.

2.5.2 Effects of the abandonment option

We analysed the effects of this abandonment possibility when the same initial conditions that were used in the previous chapter apply. The effects are similar in all cases and therefore can be conveniently summarised by focusing solely on the results stemming from the variation of the initial spot price S_0 for the oil production case, as these were the results that were analysed in detail at the end of previous chapter. Moreover, we limit the analysis of progressive taxation regimes to the nonlinear case as this has better defined and smoother transitions.

The dynamics of abandonment

If we run the real option model with abandonment possibility using the oil price model by Trolle and Schwartz (2009), with different initial spot prices S_0, we can see in figure 2.3 that the total probability of abandonment varied slightly between these different initial conditions (i.e. low effect of S_0), but that it increased as progressiveness in taxation became more relevant; here measured as the parameter δ_i goes from δ_0 to δ_{max}.[33]

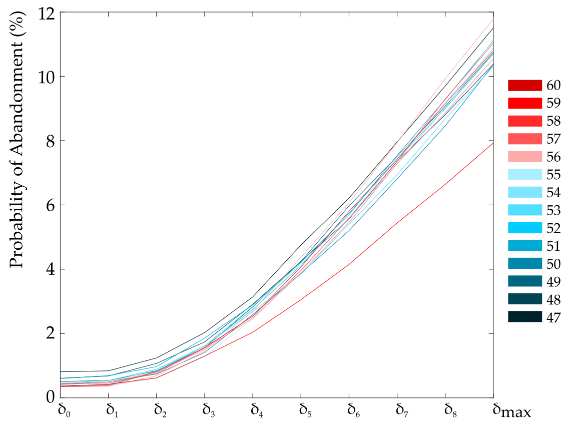


Figure 2.3: Total probability of abandonment for the Trolle and Schwartz (2009) model under different initial spot prices S_0 (varying according to the colour scale on the right), for δ between δ_0 and δ_{max}.

The first result can be attributed to the fact that the evaluated initial conditions are not that different. We can expect for very low initial spot prices to have a higher abandonment rate than when S_0 is higher, this

[33] We keep using the nonlinear progressive tax regime, where δ_0 is equivalent to the initial corporate income tax τ_{inc}; and δ_{max} is the tax regime where the corporate income tax rate depends exclusively on the underlying commodity price so that the rate

$$Tax(S_{i,t_j}, \delta_{max}) = K \cdot S_{i,t_j} \ ,$$

with K being a constant.

for the mere fact that even if both price models have reversion to the mean, initial conditions do matter as they influence the expected value at time T. Moreover, given the no-arbitrage condition the expected price at time $t_j \in \{t_1, \ldots, t_N\}$ is going to be equivalent to the futures value at time t_0, due to the spot forward equivalence,[34] which implies that there are fewer chances of V^{abn}_{firm} to be negative if the initial spot price is high and/or if the futures curve is in strong contango.

The second result, that companies abandon production at a higher rate when the progressiveness taxation parameter, δ, is higher can be attributed to the fact that taxes skew payments heavily in the case of a more progressive taxation structure, as high taxes present when the underlying commodity price is also high bear the brunt of it. Therefore, if the company is facing losses at some time t_j, it can count less on a future increase in prices to remedy that situation when δ is large.

However, even though we have seen that the overall profile of abandonment probabilities is nearly homogeneous in the previously analysed interval of initial spot prices, S_0, it is important to observe the timing of these decisions to asses any existing pattern. These results can be seen in figure 2.4.

In this figure, we can observe that there are no discernible differences between the timing of the abandonment option for the different initial spot prices. In every case, the probability of abandonment increases with time and with δ in a similar fashion; we know that there are reasons to expect higher abandonment rates as time passes, the probability of a surge in prices that compensates current losses is smaller when there is less remaining time for exploitation, we are thus left with one source of variation of the abandonment probabilities: taxation progressiveness as measured by δ, whose effect remains unclear.

Now we are going to assess the effect that the introduction of this abandonment possibility has on the overall political risk, and on the valuation of the operations for both the firm and the government.

Variation of overall political risk

We can compare the total probability of expropriation between the reference case without abandonment option and the corresponding case when this possibility is introduced, the results for oil extraction using the model by Trolle and Schwartz (2009) can be seen in figure 2.5.

When abandonment is introduced, there are mixed effects, a decrease in the expropriation risk for much of

[34] This equivalence was seen in the previous section, and assumes that the forward price at time t_j and maturing at t_l is the best indicator of the expectation at time t_j of the spot price of the commodity at time t_l,

$$F(t_j, t_l) = E_{t_j}[S_{t_l}],$$

essentially, a no-arbitrage clause.

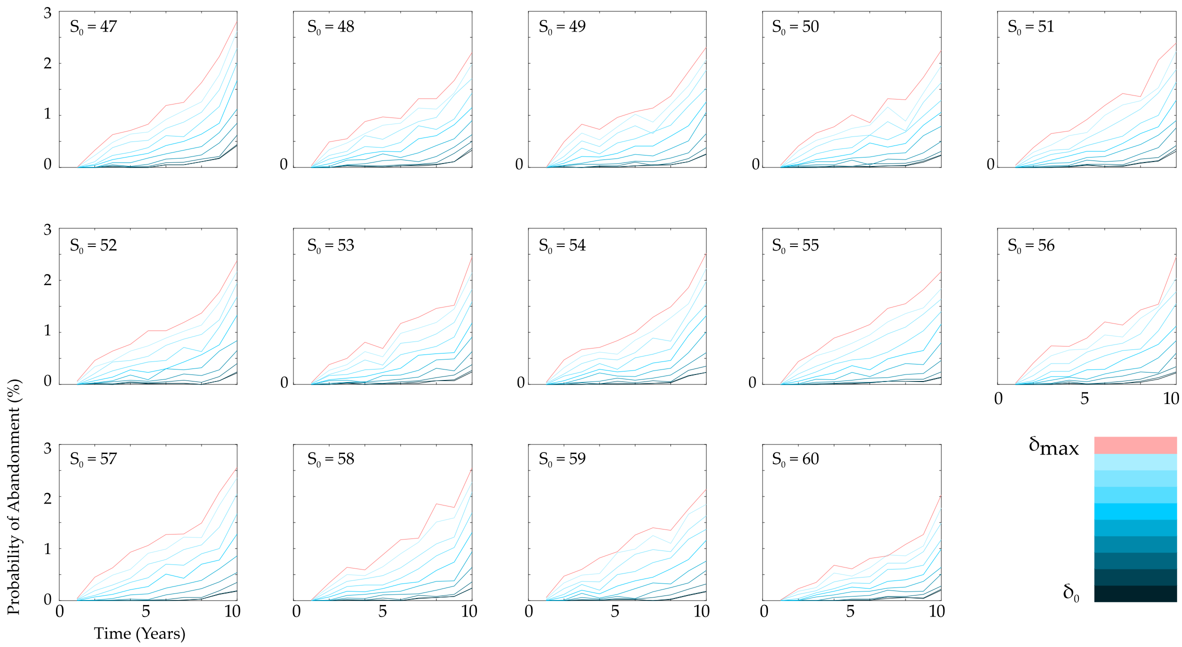


Figure 2.4: Timing of abandonment probability for the Trolle and Schwartz (2009) model under different initial spot prices S_0, for taxation progressiveness –measured by parameter δ– going between δ_0 and δ_{max}, each line representing a different value of δ according to the colour scale in the bottom right corner.

the tax progressiveness spectrum coupled with:

- The fact that for low initial prices, there is almost no discernible effect as tax progressiveness is low. Then, as δ increases, there are mixed effects. On one set of cases, there is an initial abatement of expropriation followed by a sudden increase when close to δ_{max}.
- For those initial conditions where an increase in δ increases the risk of expropriation in absence of an abandonment option, its introduction decreases the probability of expropriation, except for the highest price in our interval, something we could blame on the increase in early expropriation.

And this last fact is precisely what we find when we look at the timing of the exercise of the expropriation option for different initial conditions as in figure 2.6. To draw some conclusions, this figure needs to be compared with the figure for expropriation times for the oil model presented in the previous chapter: which represented the timing of expropriation for each initial spot price S_0 without an abandonment option.

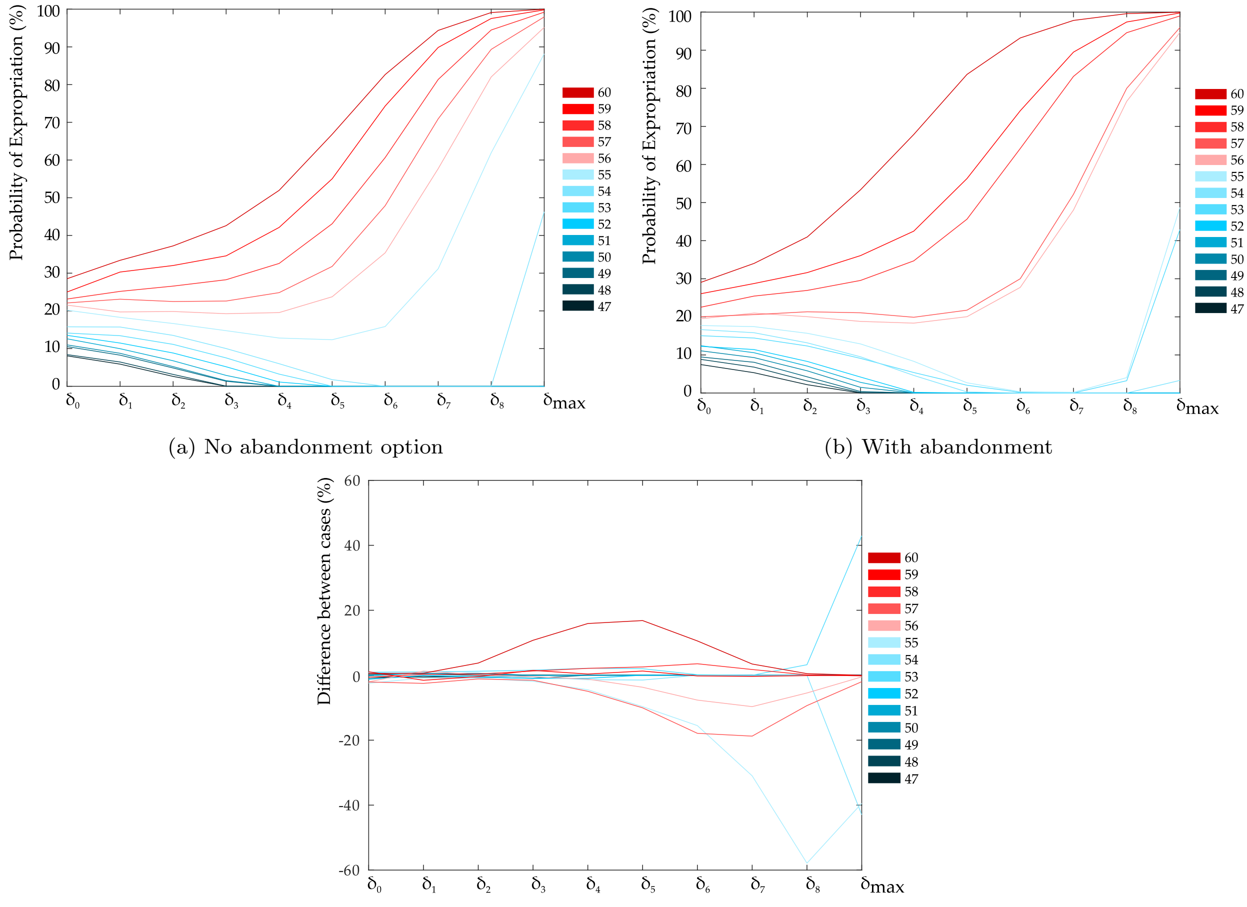
Thus, in figure 2.7 we are presented with such comparison; the difference in expropriation times between the abandonment case minus expropriation when abandonment is not feasible. Figure 2.7 shows us the effect that we were discussing previously about early expropriations, these tend to be the major influencers in the change of the overall effect over risk when the abandonment option is introduced.

Nevertheless, this analysis does not take into account that there might be less expropriations because there are fewer cases where operations are viable. For this case we should take into account the difference between the total number of expropriations plus the abandonment with the expropriations where no abandonment is possible. All these can be seen in figure 2.8: but again, early expropriation dwarfs any effect that abandonment may have when the interval of initial prices is $S_0 \in [53, 57]$ for this case.

This confirms what was noted in figure 2.5, where one of the effects observed in the total expropriation rate when abandonment was introduced was a variation in the expropriation rate when progressiveness was not too high, but initial prices hovered between the $S_0 \in [53, 57]$ interval. This complements the fact that the *timing* of the expropriation, when values of δ are high in the cases without abandonment, is realised as soon as possible *even in the case of low initial spot prices*, such as between the cases where $S_0 = 47$ and $S_0 = 52$, whereas in the case without abandonment[35] that precise early expropriation risk in the case of low initial spot prices was mostly non-existent.

This decrease in the probability of an earlier expropriation decision for low initial prices should raise the value of the operations for the firm, and the opposite should happen for the initial price interval $S_0 \in [53, 57]$ where this probability increases. This means that we should expect two effects from the introduction of the abandonment option on the value of the operations of the firm, on one hand the value $V_{firm}^{exp,abn}$ should increase given the ability of firms to discard the less profitable operations, but on the other hand higher early expropriation rates for the middle of the analysed interval of initial prices would cause a decrease in the total value.

[35] Cf. figure 2.7 for prices $S_0 \in [47, 52]$.



(a) No abandonment option

(b) With abandonment

(c) Difference between abandonment (case **b)**) and no abandonment (case **a)**)

Figure 2.5: Comparison between the total probability of expropriation in the case of oil exploitation with increased progressiveness in taxation –exemplified by δ_i– and different initial spot price S_0 (varying according to the colour scale on the right) for the cases with and without abandonment possibility. On graph **(c)** we can see the differences between the two graphs (Abandonment minus Non-abandonment).

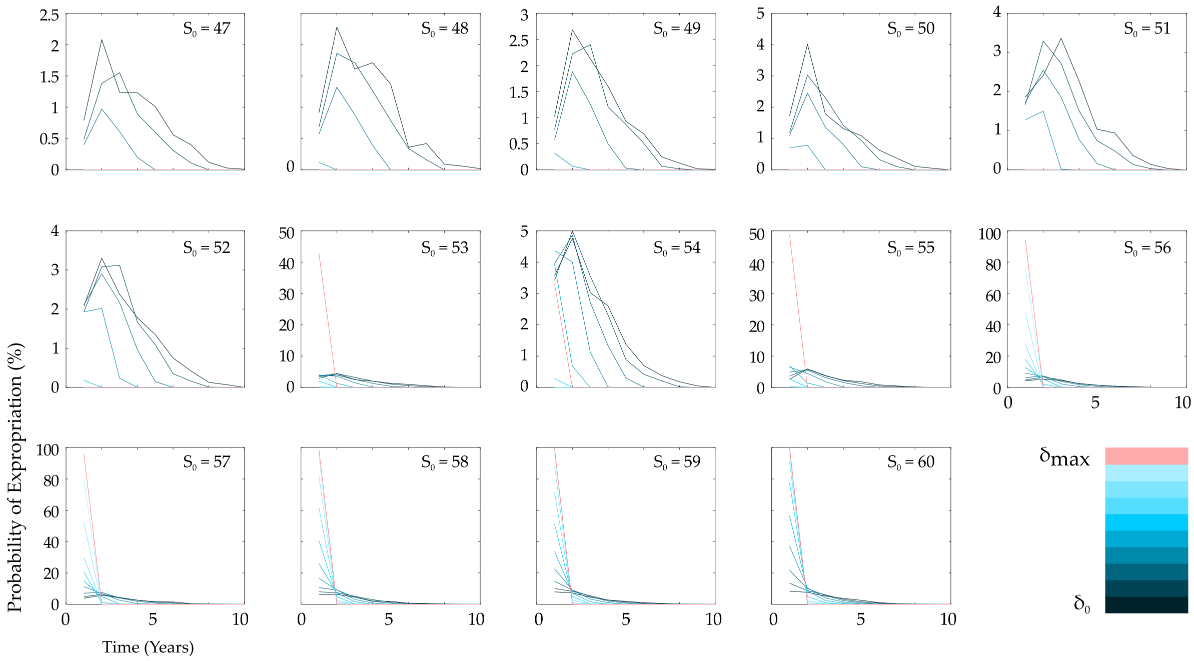


Figure 2.6: Timing of expropriation probability for the Trolle and Schwartz (2009) model under different initial spot prices S_0, for progressiveness in taxation given by parameter δ between δ_0 (no progressiveness) and δ_{max} considering the abandonment option, each line representing a different value of δ according to the colour scale in the bottom right corner.

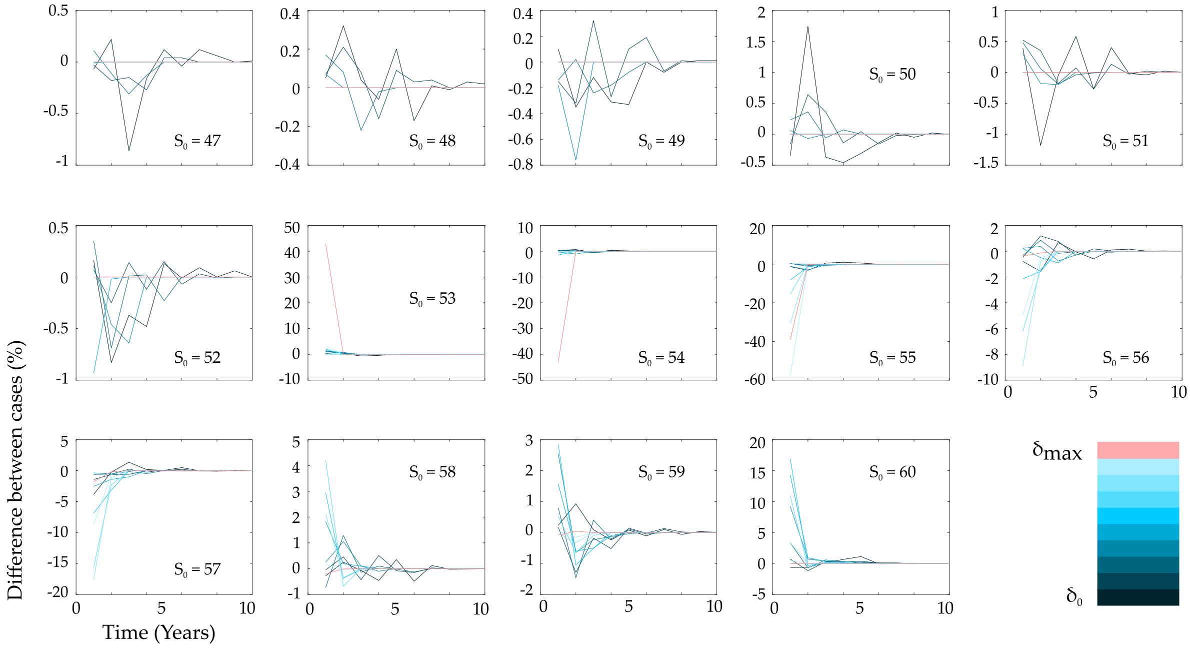


Figure 2.7: Timing of the difference of expropriation rates probabilities (the case for abandonment –seen in this chapter– minus the case without abandonment seen in the previous one) for the Trolle and Schwartz (2009) model under different initial spot prices S_0, for progressiveness in taxation given by parameter δ between δ_0 (no progressiveness) and δ_{max}, each line representing a different value of δ according to the colour scale in the bottom right corner.

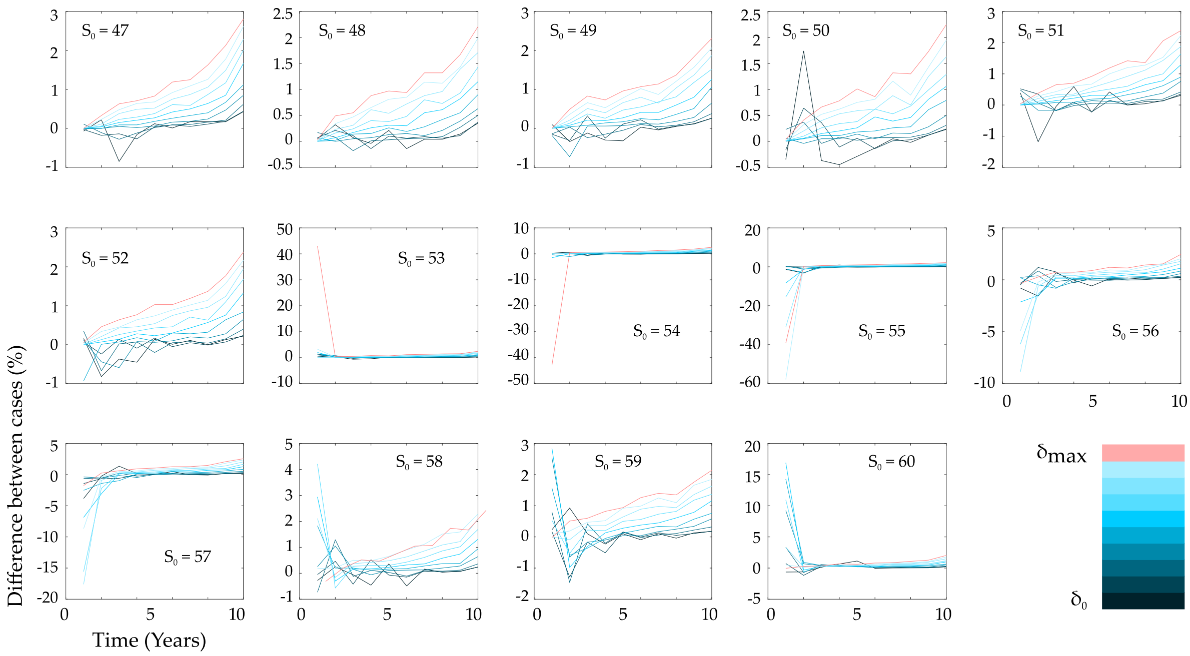


Figure 2.8: Timing of the difference between expropriation plus abandonment rates minus the timing of expropriation decisions when there is no abandonment (i.e. the case for abandonment –seen in this chapter– minus the case without abandonment seen in the previous one) for the Trolle and Schwartz (2009) model under different initial spot prices S_0, for progressiveness in taxation given by parameter δ between δ_0 (no progressiveness) and δ_{max} considering the abandonment option, each line representing a different value of δ according to the colour scale in the bottom right corner.

Value of the operations for the firm and for the government

Having observed how abandonment affects the expropriation probability and its timing, we are now going to focus on the effect that this possibility has on the value of the operations both for the natural resources firm and for the government. In table 2.11 we can see the difference between value of the operations for the firm in presence of expropriation with or without abandonment. In this table, a positive value implies that the introduction of the possibility to abandon **increases** the value for the firm. One surprising result is that this difference *is positive and increases* for most of the cases as the progressiveness parameter δ becomes larger, meaning that even as the operations become riskier at initial low risk environments (i.e. the probability of expropriation increases), the value of abandoning non-profitable operations compensates the decrease in income stemming from the larger expropriation probability.

Table 2.11: Variation of the value of V_{firm}^{exp} with the introduction of an abandonment option on the oil exploitation model by Trolle and Schwartz (2009) varying S_0 (positive value means that the abandonment option increases the value **for the firm**)

	S_0 Initial Values													
	47	48	49	50	51	52	53	54	55	56	57	58	59	60
δ_0	0.7%	-0.8%	0.8%	-0.6%	0.1%	1.0%	-1.1%	-0.7%	2.8%	1.9%	2.5%	0.4%	-0.9%	-0.3%
δ_1	0.5%	-0.4%	0.0%	-0.7%	-0.6%	0.0%	-0.7%	0.0%	0.6%	-1.2%	2.3%	-0.2%	1.5%	0.2%
δ_2	0.4%	0.2%	0.2%	-0.2%	-0.1%	0.3%	-0.5%	0.3%	0.6%	-0.1%	0.7%	-0.2%	0.6%	-2.0%
δ_3	0.6%	0.7%	1.3%	1.1%	0.8%	0.8%	0.0%	0.5%	1.1%	0.5%	0.9%	-0.8%	-1.1%	-8.7%
δ_4	1.2%	1.4%	1.4%	2.0%	1.5%	1.8%	0.9%	1.7%	3.1%	1.4%	3.9%	-1.3%	-0.1%	-15.2%
δ_5	2.0%	2.4%	2.2%	3.1%	2.4%	2.3%	2.5%	3.2%	7.7%	4.1%	8.6%	-1.9%	-1.0%	-20.4%
δ_6	3.1%	3.5%	3.3%	4.3%	3.5%	3.4%	5.3%	3.3%	14.1%	7.8%	18.7%	-3.7%	0.6%	-16.8%
δ_7	4.2%	4.7%	4.5%	5.6%	4.7%	4.6%	7.0%	4.4%	30.2%	11.3%	24.5%	-3.1%	-0.1%	-7.5%
δ_8	5.4%	6.1%	5.8%	7.1%	6.0%	5.9%	6.0%	5.6%	72.8%	7.9%	14.8%	-1.4%	-2.2%	-2.6%
δ_{max}	6.8%	7.6%	7.3%	8.7%	7.4%	7.3%	-23.1%	47.8%	64.9%	-1.7%	0.2%	-2.9%	-3.4%	-2.0%

In the case of those high risk initial conditions (i.e. high initial spot prices for the underlying commodity) we have already seen in figure 2.5 that the relative expropriation probability decreases as the tax progressiveness parameter δ becomes larger if there is an abandonment possibility.[36] Therefore, it is not surprising that in almost every case the value of the operations for the firm increases as there is no trade-off between abandonment and political risk as it was in the case with less riskier initial conditions. The only exception is when initial prices are too high and then the risk of expropriation increases (again, see figure 2.5c), this makes abandonment a bad option: there is no compensation for expropriation if the mine or oil field is abandoned in a high risk scenario.

On the other hand, the consequences for the **government** of introducing the possibility of abandonment

[36] This is shown in graph 2.5c, where we can observe the difference between the value in the abandonment minus the no-abandonment cases.

are shown in table 2.12. In this table, the value of the extractive operations is lower for the government when the abandonment option is introduced, and this difference increases when the taxation progressiveness parameter δ becomes larger. Moreover, the difference between the case without abandonment and when firms can cease operations is larger for low risk environments.

Table 2.12: Variation of the value of V_{gov}^{exp} with the introduction of an abandonment option on the oil exploitation model by Trolle and Schwartz (2009) varying S_0 (positive value means that the abandonment option increases the value **for the government**)

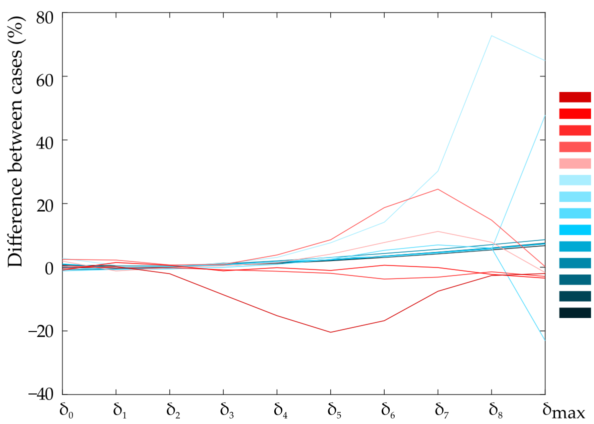
	S_0 Initial Values													
	47	48	49	50	51	52	53	54	55	56	57	58	59	60
δ_0	0.0%	0.2%	0.1%	0.2%	0.1%	0.1%	0.1%	-0.1%	0.0%	0.1%	0.1%	0.0%	-0.1%	0.1%
δ_1	0.0%	-0.1%	0.0%	-0.3%	-0.3%	0.0%	-0.6%	-0.3%	-0.1%	-0.3%	0.1%	-0.2%	-0.1%	-0.8%
δ_2	-0.9%	-1.0%	-0.5%	-1.2%	-1.0%	-0.9%	-1.6%	-1.0%	-0.4%	-1.1%	-0.2%	-0.9%	-0.9%	-1.8%
δ_3	-2.3%	-2.7%	-2.2%	-2.9%	-2.5%	-2.1%	-3.2%	-2.2%	-1.3%	-2.3%	-1.2%	-2.4%	-2.2%	-3.7%
δ_4	-4.3%	-4.9%	-4.4%	-5.1%	-4.6%	-4.3%	-5.6%	-4.1%	-2.5%	-3.7%	-2.6%	-4.1%	-3.6%	-5.5%
δ_5	-6.7%	-7.2%	-6.9%	-7.5%	-6.9%	-6.9%	-8.2%	-6.5%	-4.2%	-5.4%	-4.3%	-5.8%	-5.8%	-6.6%
δ_6	-9.1%	-9.8%	-9.9%	-10.2%	-9.5%	-9.7%	-10.8%	-9.2%	-6.3%	-6.8%	-5.8%	-7.8%	-7.8%	-7.3%
δ_7	-12.0%	-12.8%	-12.7%	-13.1%	-12.3%	-12.6%	-13.7%	-11.9%	-6.8%	-8.8%	-7.5%	-9.6%	-9.9%	-7.8%
δ_8	-14.8%	-15.5%	-15.8%	-16.0%	-15.4%	-15.3%	-17.1%	-14.8%	-5.3%	-11.5%	-11.0%	-11.5%	-11.8%	-9.0%
δ_{max}	-17.7%	-18.4%	-18.7%	-19.2%	-18.4%	-18.4%	-24.7%	-9.7%	-8.8%	-14.1%	-14.1%	-13.1%	-13.9%	-10.3%

The overall consequence of introducing the abandonment possibility can be seen in table 2.13. The results are overwhelmingly negative, which implies that the positive effects for the firm do not compensate the loss in value for the government; there are some exceptions in this case (around S_0 = 55): this makes sense, as initial prices shift from being low (less expropriation when abandonment is introduced) to being high (early expropriation destroys value), there is a wedge where the abandonment possibility can be beneficial to both parties.

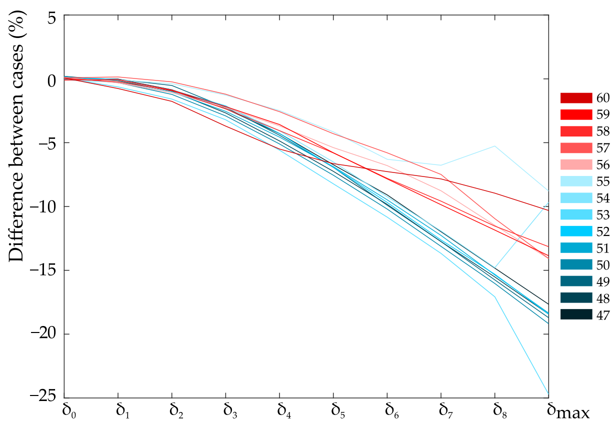
Table 2.13: Variation of the value of V_{tot}^{exp} with the introduction of an abandonment option on the oil exploitation model by Trolle and Schwartz (2009) varying S_0 (positive value means that the abandonment option increases **the overall value of the operations**)

	S_0 Initial Values													
	47	48	49	50	51	52	53	54	55	56	57	58	59	60
δ_0	0.2%	-0.2%	0.4%	-0.1%	0.1%	0.5%	-0.4%	-0.3%	1.0%	0.7%	0.9%	0.2%	-0.4%	0.0%
δ_1	0.2%	-0.3%	0.0%	-0.4%	-0.4%	0.0%	-0.7%	-0.2%	0.2%	-0.6%	0.9%	-0.2%	0.5%	-0.4%
δ_2	-0.3%	-0.5%	-0.3%	-0.8%	-0.7%	-0.4%	-1.2%	-0.5%	0.0%	-0.7%	0.1%	-0.7%	-0.4%	-1.9%
δ_3	-1.2%	-1.3%	-0.8%	-1.3%	-1.2%	-1.0%	-2.0%	-1.1%	-0.4%	-1.3%	-0.5%	-1.8%	-1.8%	-5.3%
δ_4	-2.1%	-2.3%	-2.1%	-2.3%	-2.1%	-1.9%	-3.0%	-1.8%	-0.3%	-1.8%	-0.3%	-3.1%	-2.5%	-8.4%
δ_5	-3.2%	-3.4%	-3.3%	-3.3%	-3.2%	-3.2%	-3.9%	-2.7%	0.4%	-1.9%	0.3%	-4.5%	-4.3%	-10.4%
δ_6	-4.2%	-4.5%	-4.6%	-4.4%	-4.3%	-4.4%	-4.4%	-4.2%	1.5%	-1.6%	2.2%	-6.6%	-5.6%	-9.5%
δ_7	-5.5%	-5.8%	-5.8%	-5.6%	-5.5%	-5.7%	-5.4%	-5.4%	6.5%	-2.5%	1.4%	-8.0%	-7.7%	-7.8%
δ_8	-6.7%	-6.9%	-7.1%	-6.8%	-6.8%	-6.8%	-7.8%	-6.6%	18.5%	-6.5%	-5.0%	-9.4%	-9.9%	-7.8%
δ_{max}	-7.9%	-8.0%	-8.3%	-8.0%	-8.0%	-8.1%	-24.1%	10.0%	9.6%	-11.3%	-11.1%	-11.1%	-11.9%	-8.8%

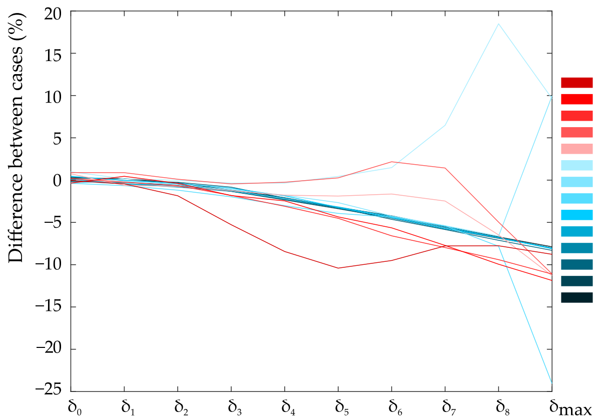
A graphic summary of these results can be seen in figure 2.9, here the percentage difference of V_{firm}^{exp} and V_{gov}^{exp} with and without abandonment option are clearly depicted. Finally, in figure 2.9c the evolution of the percentage difference of the sum of these two values, $V_{firm}^{exp} + V_{gov}^{exp}$, is shown; this last figure is relevant due the fact that if this *difference were positive* it would mean that the total value of the natural resources operations is increasing with the introduction of an abandonment option and therefore redistribution could take place so that values of the operations for the firm and the government were Pareto optimally increased with respect to the reference case, irrespectively of the individual variations of V_{firm}^{exp} and V_{gov}^{exp}.



(a) V_{firm}^{exp}



(b) V_{gov}^{exp}



(c) $V_{firm}^{exp} + V_{gov}^{exp}$

Figure 2.9: Percentage variation of V_{firm}^{exp}, V_{gov}^{exp}, and $\left(V_{firm}^{exp} + V_{gov}^{exp}\right)$ between the case with no abandonment and when the possibility to leave operations is included, using the oil exploitation model by Trolle and Schwartz (2009) varying S_0 (according to the colour scale on the right) and considering progressiveness in taxation being given by the parameter δ –for nonlinear equivalent taxes– values from δ_0 (no progressiveness) to δ_{max}.

Unfortunately, the effect of the abandonment option on the aggregated value of the operations is mostly negative. There is a slow decrease in the sum of the present value of the extractive operations if δ increases interrupted by a raise in value for middle initial prices, or in some other cases where δ is high by a sudden change in value: this can be traced back to the decrease in the relative rate of expropriation for scenarios where δ and the initial spot prices are high.

2.5.3 Impatience and reduced costs

In low risk environments, the fact that the expropriation probability increased as δ_i became larger was an unexpected result. In order to analyse the reasons behind it, we must revise the equations that determine the payoff function for the real option exercise decision. The modified equations that determine the payoff function, V_{cost}^{abn} and V_{gain}^{abn} are described in detail in Section 2.2 and are shown below.[37]

$$V_{cost}^{abn}(i,t_j) = \begin{cases} \left[\sum_{n=j+1}^{E_{t_n,i}[X_i-1]} e^{-r(t_n-t_j)}[(F_i(t_j,t_n)) - C_{firm})\,Tax(F_i(t_j,t_n),k))]Y_{t_n} \right] & \text{if } t_j < t_{X_i-1}, \\ + K_1 \cdot (E_{t_j,i}[t_{X_i-1}] - t_j) + K_2 & \\ & \\ 0 & \text{if } t_j \geq t_{X_i-1}. \end{cases} \tag{2.26}$$

$$V_{gain}^{abn}(i,t_j) = \begin{cases} \sum_{n=j+1}^{E_{t_n,i}[X_i-1]} e^{-r(t_n-t_j)}(F_i(t_j,t_n) - C_{gov})Y_{t_n} & \text{if } t_j < t_{X_i-1}, \\ 0 & \text{if } t_j \geq t_{X_i-1}. \end{cases} \tag{2.27}$$

As we can see from (2.26) and (2.27) the expectation of abandonment is present as an upper limit in both sum operators –in the form of the expression $E_{t_n,i}[X_i - 1]$ for each time t_n– so that there are fewer paths where the expected prices are negative; this elimination of less profitable paths should mean that both V_{cost}^{abn} and V_{gain}^{abn} are higher.

However, a higher progressiveness parameter, δ, would imply that the payoff function is comparatively lower in the abandonment case than in absence of that possibility, due to the fact that in this case low expected prices (i.e. low futures contracts prices) are discarded by abandonment, leaving only the higher expected prices. This affects V_{gain}^{abn} linearly and V_{cost}^{abn} in proportion to δF_i^2, which, if only higher prices are left in production, implies that V_{cost}^{abn} will increase proportionally more than V_{gain}^{abn}, and so the payoff function will

[37]Taken from equations (2.5) and (2.6) on page 77.

decrease.[38] This was the effect that was observed in the higher risk scenarios.

On the other hand, in order to explain the increased expropriation rate in the case of abandonment, the remaining expression that could be diminishing the costs in the payoff function of this expropriation model is the compensation payable in case the expropriation decision is taken: this is equivalent to $K_1 \cdot (E_{t_j,i}[t_{X_i-1}] - t_j)$ whereas in the reference case we had $K_1 \cdot (t_N - t_j)$. By definition $t_{X_i} \leq t_N$ for all cases and therefore the costs of compensating firms for expropriation *should be lower* in the case when the abandonment option is introduced.

This is the reason why there seems to be an increase in government's impatience with the introduction of the abandonment option for low risk environments, measured as the modification of the expropriation timing shown in figure 2.6. The relative variation of the cost of compensation between the cases with and without the abandonment option, $K_1 \cdot (E_{t_j,i}[t_{X_i-1}] - t_j)$, is maximised if expropriation takes place early and there are not enough prospects of a future increase in profits, given the fact that the operations are going to be abandoned earlier at time t_{X_i}. Therefore, in low risk environments with high values of δ there is more early abandonment (cf. figure 2.4), which motivates more expropriation as t_{X_i} becomes smaller. Therefore, an increase in early abandonment when δ is high motivates more expropriation on low risk environments as t_{X_i} becomes smaller and so does total compensation $K_1 \cdot (E_{t_j,i}[t_{X_i-1}] - t_j)$.[39]

2.6 How Producers Respond: Varying the rate of production using a multiple real option model

As we saw in the experimental setting in section 2.3, the paper by Aleksandrov and Espinoza (2011) introduced a multiple real option model to establish the optimal extraction rate for each period in the case of an oil field exploitation.[40] In this section we will present the results from introducing a similar multiple real option model that allows shifts in production in an environment where expropriation of the assets is feasible. We will thus see how this will affect the producer's perceived and effective political risk and how this enhanced productive flexibility will also affect the value of the operations for both the natural resources firm and the government. In the results from the original paper, this additional production flexibility increased

[38]The expression δF_i^2 comes from the use in this chapter of a nonlinear tax for $Tax(S, K)$.

[39]The expression $K_1 \cdot (t_{X_i-1} - t_{Z_i})$ could be a good approximation, but taking into account the accuracy of the conditional expected value is crucial in this case.

[40]As mentioned before, there are a couple of modifications in Aleksandrov et al. (2013), that don't alter substantially the results. However, the notation used in this chapter comes solely from Aleksandrov and Espinoza (2011).

the overall value of the operations, though governments there were only passive spectators. Here, firms can foresee the probability of expropriation, and so they will react by modifying production to maximise the expected value in presence of this risk; we thus introduce in this section an iterative procedure to model both the reaction of companies to existing risk and how this risk varies after the production schedule varies.

2.6.1 The intuition

According to Aleksandrov et al. (Aleksandrov and Espinoza, 2011; Aleksandrov et al., 2013), the introduction of production flexibility for the firms increases the overall value of the operations: they are now able to base their production decision on current and expected prices of the underlying commodity, delaying it if prices are too low and maximising it in good times.

On the other hand, we know that the production decision is taken by the firms, not the government; therefore the timing of production will be focused on maximising the value for the firm, irrespectively of the evolution of total social value: this becomes relevant as we take into account that governments can compensate for this optimisation by expropriation. Moreover, the total probability of expropriation is, to some extent, cumulative (i.e. once expropriated the operations do not revert to private ownership), for any given time t_b where $t_b > t_a$ the total probability of expropriation will necessarily be greater or equal than the probability at time t_a. This will generate incentives for producers to *displace production to the present*, skewing production decisions.

Finally, it is important to remember that this flexibility in the production decision is an addendum to the abandonment model, therefore the reference case to which we will introduce variations is the one reviewed in the previous section. There we saw that when progressiveness in taxation (or the parameter δ for the nonlinear tax) increased, there was a change in the expropriation timing (e.g. see figure 2.6 on page 109), therefore, we should expect that the reaction from the producers to expropriation should vary according to the progressiveness parameter, as the expected expropriation probability will vary not only in magnitude (e.g. see figure 2.5b on page 108) but also on its timing. Additionally, progressiveness in taxation skews the future stream of income for the company: in the case of low initial prices there would be a smaller incentive to postpone production given that the payoff, if the underlying commodity prices increases, is going to be diminished by the same progressiveness of the tax.

We will start first by choosing a suitable starting price to compare the effectiveness of the two heuristics for the iteration process that models the interaction between producers and the government. Then we will review the effectiveness of the heuristics that were presented on page 87; and which we called *naïve* and *non-naïve* production heuristics. In subsection 2.6.3 we will argue that the *non-naïve heuristic* is preferable for firms, and therefore it should be naturally chosen by them.

2.6.2 The initial conditions for this experimental setting

As it was discussed previously, we will focus the analysis on the oil production case, simulating oil prices and the associated futures curves using the dynamic price model by Trolle and Schwartz (2009). As in the previous section, firms have the option to abandon production, and taxation varies in its progressiveness using a nonlinear tax, where the progressiveness parameter goes from δ_0 (no progressiveness) to δ_{max} (where the value of the corporate income tax rate depends solely on the underlying commodity price). For the abandonment case, and also during the previous chapter, the analysis on oil production has been done varying the initial spot price S_0 from 47 to 60, however we will now start focusing on a more limited set of prices to analyse the evolution of the production decision with every iteration and the effects that different values of progressiveness have on this same production.

In the subsection below we will start comparing the two iteration heuristics, and therefore a suitable *interesting* initial spot price was selected to be shown here, so that the effects that happen at different values of taxation progressiveness can be illustrated. In figure 2.10, the price $S_0 = 55$, is the highest price in the shown interval where the increase in progressiveness in taxation eliminates the expropriation probability: this guarantees that we will avoid cases where rapid convergence is reached and a more varied set of effects can be observed.

This implies a small shift on the initial conditions used as reference values in the paper by Schwartz and Trolle (2010) (where $S_0 = 50$), for the sake of a greater variety of results without loss of generality. Finally, the parameters for the production model shown in Aleksandrov and Espinoza (2011) have already been described on page 86 of Section 2.3.

As an addendum, we can also make a definition of what constitutes a *low or high initial price*, for the underlying commodity as follows:

Definition 3. *An* ***initial low price*** *for an underlying commodity is defined as a price that, when progressiveness in taxation is introduced, there will be a level of such progressiveness where the overall risk of*

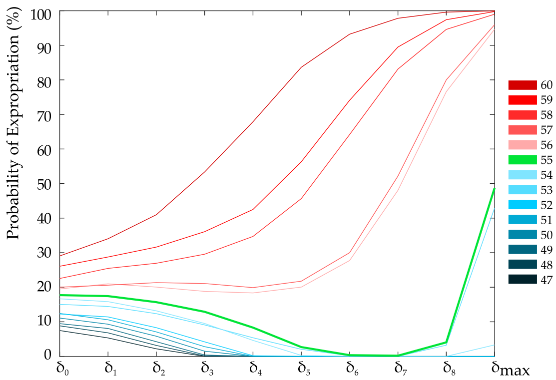


Figure 2.10: Total probability of expropriation in the case of oil exploitation with increased progressiveness in taxation – exemplified by δ_i– and different initial spot price S_0 (varying according to the colour scale on the right) and with a constant futures price parameter $x_0 = 0$ for the case where abandonment is possible. The selected price for comparison $S_0 = 55$ is highlighted in green.

expropriation disappears. On the contrary, an ***initial high price*** *is an initial price of the underlying commodity for which no level of progressiveness decreases the overall risk of expropriation.*

Thus, according to this definition prices from $S_0 = 55$ and below would be **initial low prices**, while prices close to $S_0 = 56$ or above this value would be **initial high prices**.[41]

We will now proceed to compare the different heuristics that modelled the interaction between firms and governments: the *naïve production heuristic* where the producer starts assuming a production schedule as if there were no initial risk of expropriation and the *non-naïve production heuristic*, where the producer assumes that there is going to be some political risk that needs to be taken into account even at a first approach.

2.6.3 Comparison of naïve and non-naïve production functions

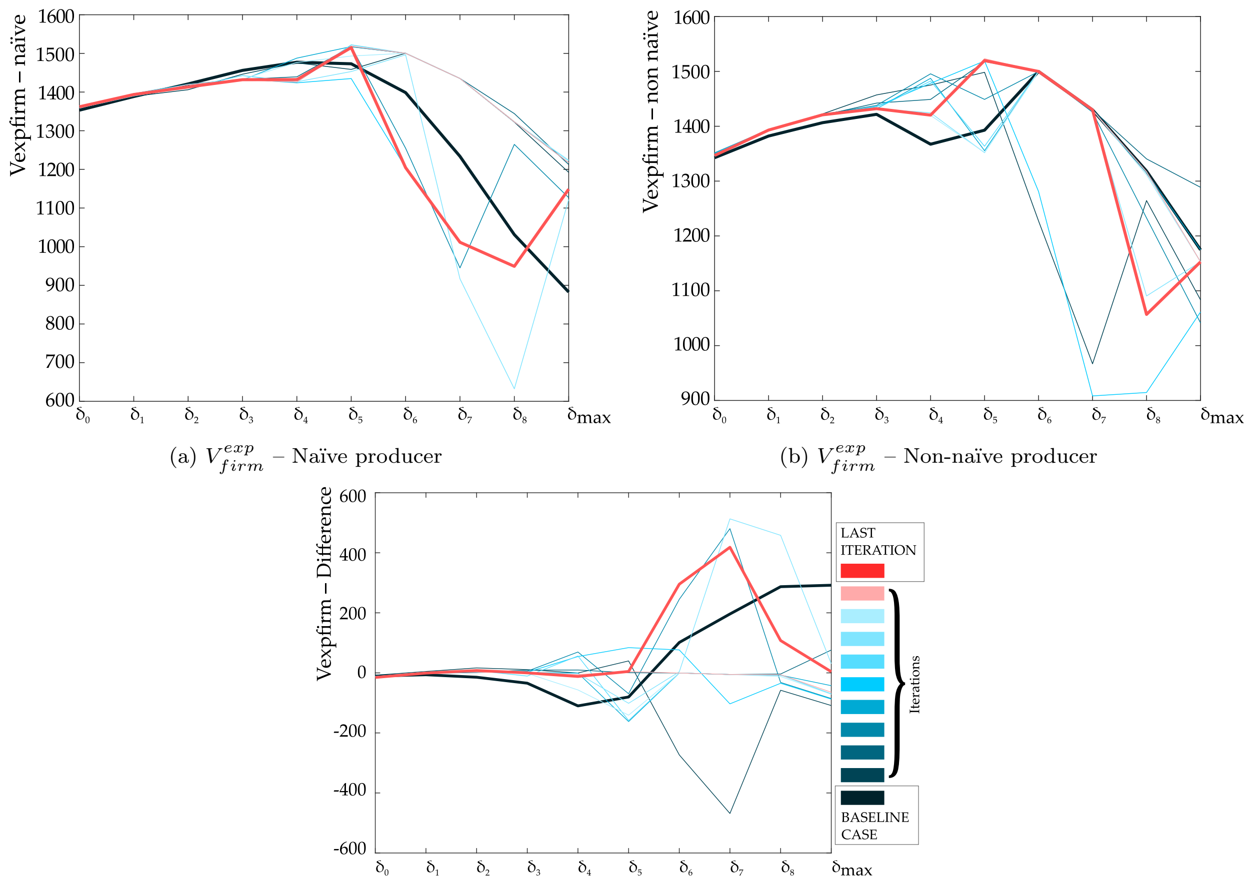
In figure 2.1 on page 89 we have seen two competing heuristics for the interaction between the firm and the government. In the *naïve production heuristic* the first production decision is taken without considering the possibility that the government might expropriate the operations. Whereas in the *non-naïve* case, the producer takes the expropriation probability from what would emerge from a hypothetical situation with constant rate of production. In order to assess the overall effect of each one of the heuristics, and to compare

[41] Note that there can be prices, such as $S_0 = 55$ in the no abandonment case that would be neither low nor high initial prices.

their relative efficiency we have done the following: first we have taken the standard case for this section, the oil production model with $S_0 = 55$, and then run iterations so that $N_{iterations} = 10$. As was discussed above, in the non-naïve case there is an additional –dummy– production function, which we have taken away to make the number of iterations comparable between each other. We have introduced the following comparisons:

- The evolution of the expected value of the operations for the firm, V_{firm}^{exp}, for a set of nonlinear progressive tax regimes when $S_0 = 55$ in the oil production case. This can be seen in figure 2.11.
- The evolution of the expected value for the government, V_{gov}^{exp}, for a set of nonlinear progressive tax regimes when $S_0 = 55$ in the oil production case. This can be seen in figure 2.12.
- And finally, the total expected value generated by each one of the heuristics in presence of expropriation and abandonment, $V_{tot}^{exp} = V_{firm}^{exp} + V_{gov}^{exp}$, under the same initial conditions. And which can be seen in figure 2.13.

For the value of the operations to the firm, V_{firm}^{exp}, it is interesting to note how the difference between the two heuristics evolves over time. At the first iteration (the thick blue line in figure 2.11c), we can see that the *naïve heuristic* offers a slightly better value for the firm when the values of δ are around the middle of the scale. However, as iterations progress we see a marked improvement of the non-naïve heuristic in terms of value for the firm, especially in those cases where there is high progressiveness in taxation (i.e. a high value of δ). Therefore we can argue that if it were the producer's decision, it would try to foresee the incentives of the government –choosing a *non-naïve heuristic*– which if it is sufficiently sophisticated, that is, if it considers a high number of iterations from both parties, will be more valuable for the firm.
Something similar happens for the case of the government, in figure 2.12c, we can see that after a few iterations for almost every taxation regime, the *non-naïve heuristic* dominates over the naïve case. Nevertheless, we must note that the absolute differences in value for the government are way smaller: as expected, the *non-naïve heuristic* tends to favour the firm over the government. Another interesting phenomenon is that the *naïve heuristic* tends to lower the value for the government with each iteration (see figure 2.12a), while the opposite seems to be the case in the non-naïve case.
Finally, when we see the total expected value of the operations, V_{tot}^{exp}, we can note two things. The first one is that there seems to be a decline in the overall value of the operations when tax is more progressive, and that factor is reinforced in the naïve heuristic (see figure 2.13a), where each successive iteration seems to



(a) V^{exp}_{firm} – Naïve producer

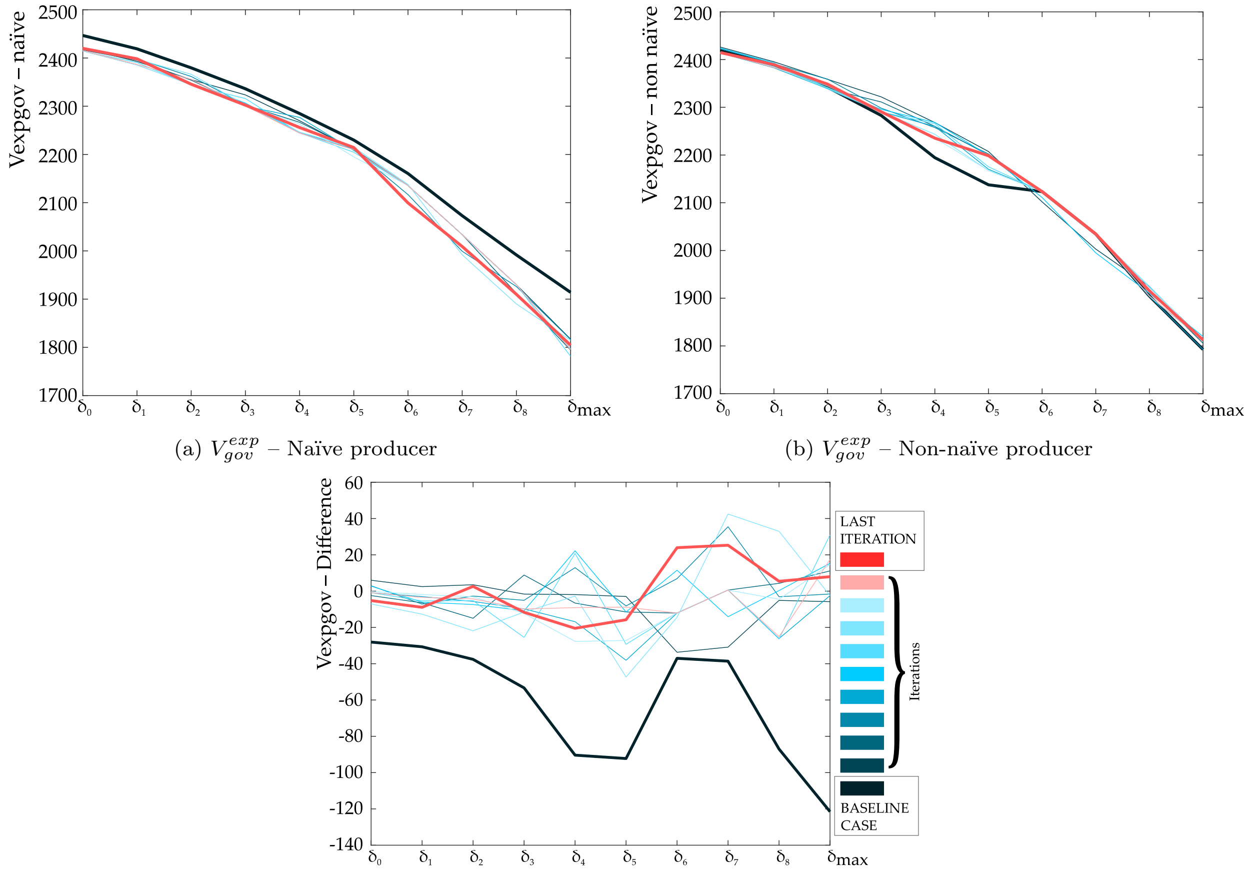
(b) V^{exp}_{firm} – Non-naïve producer

(c) Difference (Non-naïve minus naïve)

Figure 2.11: Total value of the operations for the firm considering flexible production determined using the Aleksandrov and Hambly (2010) multiple real option model for the oil exploitation case with initial spot price S_0 = 55, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}; where both heuristics –naïve and non-naïve– are shown, together with the difference between them. Curves vary for each consecutive iteration according to the scale on the right of figure (c), with the reference case –the **baseline production function for the naïve producer** and the **first iteration in the non-naïve heuristic**– in dark blue and the last iteration (with $N_{iterations}$ = 10) is in red.

be lowering the value of the operations. For this reason, the difference –if the firm and the government are sufficiently sophisticated– will favour the *non-naïve heuristic*.

To summarise, the *non-naïve heuristic* seems to dominate its counterpart both for the firms (which could be expected), but also for governments; which comes as a surprise. For this reason, we will focus the rest of the analysis on the results obtained with the *non-naïve heuristic*. The direction of the results is very similar in both heuristics, so there will not be a loss of generality by restricting the choice of results.

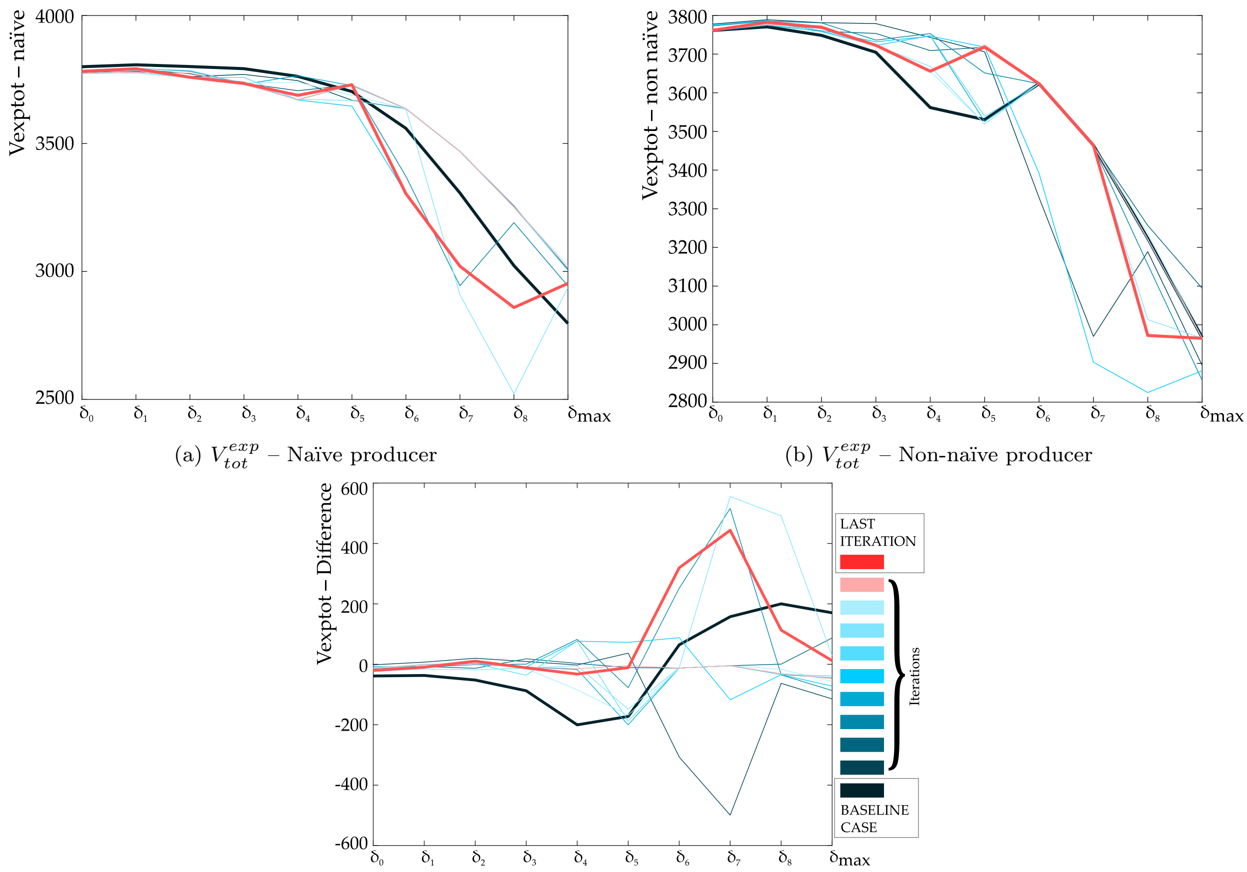


(a) V_{gov}^{exp} – Naïve producer

(b) V_{gov}^{exp} – Non-naïve producer

(c) Difference (Non-naïve minus naïve)

Figure 2.12: Total value of the operations for the government considering flexible production determined using the Aleksandrov and Hambly (2010) multiple real option model for the oil exploitation case with initial spot price $S_0 = 55$, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}; where both heuristics –naïve and non-naïve– are shown, together with the difference between them. Curves vary for each consecutive iteration according to the scale on the right of figure (c), with the reference case –the **baseline production function for the naïve producer** and the **first iteration in the non-naïve heuristic**– in dark blue and the last iteration (with $N_{iterations} = 10$) is in red.



(a) V_{tot}^{exp} – Naïve producer

(b) V_{tot}^{exp} – Non-naïve producer

(c) Difference (Non-naïve minus naïve)

Figure 2.13: Total value of the operations ($V_{firm}^{exp} + V_{gov}^{exp}$) considering flexible production determined using the Aleksandrov and Hambly (2010) multiple real option model for the oil exploitation case with initial spot price $S_0 = 55$, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}; where both heuristics –naïve and non-naïve– are shown, together with the difference between them. Curves vary for each consecutive iteration according to the scale on the right of figure (c), with the reference case –the **baseline production function for the naïve producer** and the **first iteration in the non-naïve heuristic**– in dark blue and the last iteration (with $N_{iterations} = 10$) is in red.

2.6.4 How Production Evolves: The Effects of flexibility

In figure 2.14 we can see the how the *average* of the production decision for $M = 10,000$ paths evolves with each iteration, when the *non-naïve heuristic* is applied for different values of progressiveness in taxation. In this case, each individual subplot represents the evolution of production for different values of the progressiveness parameter δ from δ_0 to δ_{max}. The first iteration[42] is in dark blue and each following iteration[43] is in a colour according to the chart of the left; the final iteration is in thick red colour.

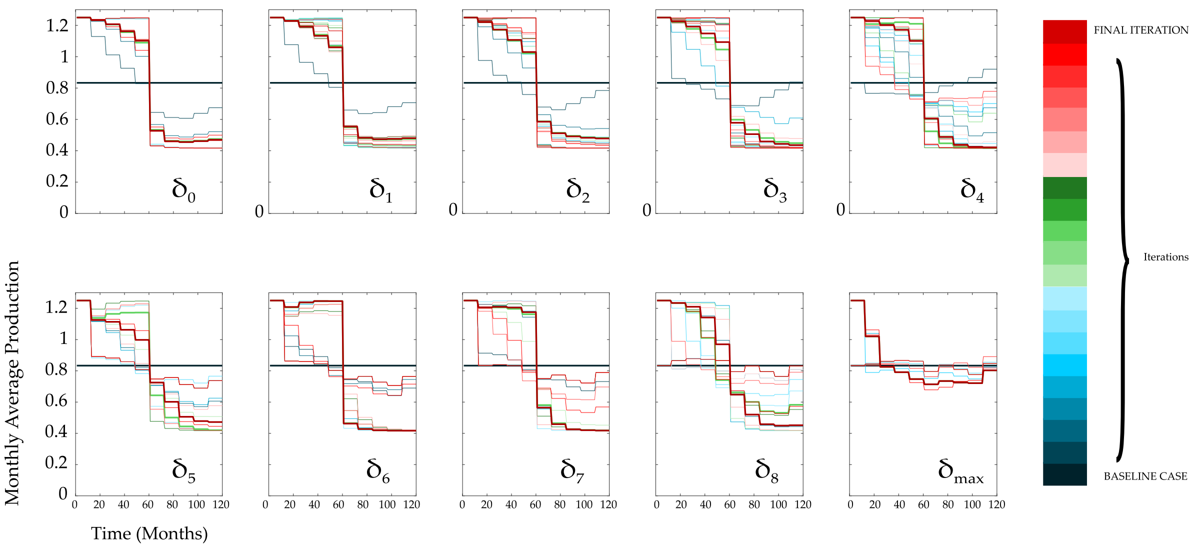


Figure 2.14: Average monthly production determined using the Aleksandrov and Hambly (2010) multiple real option model for the oil exploitation case with initial spot price $S_0 = 55$, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}. Curves vary for each consecutive iteration according to the scale on the right, with the reference case –**the 'dummy' constant production function**– in deep blue, and the final iteration traced thicker in red. The number of iterations in this figure ($N_{iterations}$) is 20.

After the first 'dummy' constant production function, the first iteration seen in figure 2.14, $l = 1$, corresponds to the initial response of the producer taking into account the expropriation probability that a government would generate if responding to a producer that has no choice over his schedule. Each following iteration is then generated taking into consideration the probability of expropriation generated by the government's response to the new production schedule.[44]

We can observe from this figure that only in those cases with mild taxation progressiveness, where the parameter goes from δ_0 to δ_3, we have a behaviour that clearly mirrors the intuition stated in 2.6.1. In these

[42]The **dummy production function** of 10m barrels per year that appears in figure 2.1b on page 89.

[43]Represented by each consecutive red box on the same diagram in figure 2.1b on page 89.

[44]The same dynamic that we observed for the simple three-period model between tables 2.8, 2.9, and 2.10, on pages 100 to 100.

cases, with each additional iteration, production concentrates more and more on the first five years as the profits coming from strategically allocating production in expectation of higher prices may not compensate an increase in the probability of expropriation.

When the taxation regime is more progressive –the parameter δ going from δ_4 to δ_8 in figure 2.14– we see an interesting phenomenon, the production schedule cycles with each iteration, as the firm and the government try to catch up with each other's evasive moves. This means that under certain number of iterations the second half of the extraction's time horizon would be more similar to the reference case.

Finally, when the maximum progressiveness is achieved we can see that extreme early expropriation (as seen in the previous chapter and in figure 2.6 in this one) renders all possibility of maximisation of revenue through scheduling of production pointless, so it will be mostly a flat production function.

We must remember that this iterative algorithm is a sequence of best responses from both the government (choosing expropriation timing) and from the companies (allocating production), so there is no guarantee that the iteration will converge on a value that is optimal for both the firm and the government,[45] and for that reason we are going to see some scenarios where the best responses cycle.

Looking at convergence of production

So far, we have seen convergence as how the different successive production regimes seem to vary through each iteration in figure 2.14 above. However, we can define a measure of how each one of the successive production schedules differs from the previous one; we will call it simply production convergence:

Definition 4. *We can define as* ***production convergence*** *the absolute difference between the production function at each successive iteration, l, where $l \in \{1, \ldots, N_{iterations}\}$, so that it is expressed as the following equation:*

$$Convergence_l = \sum_{q=1}^{Q} |Y_{t_q,l} - Y_{t_q,(l-1)}| \ , \tag{2.28}$$

So that $Convergence_l$ is defined for each iteration. Where $q \in \{1, \ldots, Q\}$ is each one of the production periods; $Y_{t_q,l}$ is the average production value at time t_q and iteration l, and finally, $Y_{t_q,0}$ is the dummy production function for the non-naïve heuristic, which, by definition is $Y_{t_q,0} = Constant \ \forall \ t_q, \ q \in \{1, \ldots, Q\}$.

[45] As was seen in the results of the iterations for the simple three-period model.

Using this definition, which takes the sum of absolute values in order to avoid that overproduction compensates for lower production in the next period, we can see the convergence figures for the 20 iterations of production seen on page 124, in the following figure 2.15.

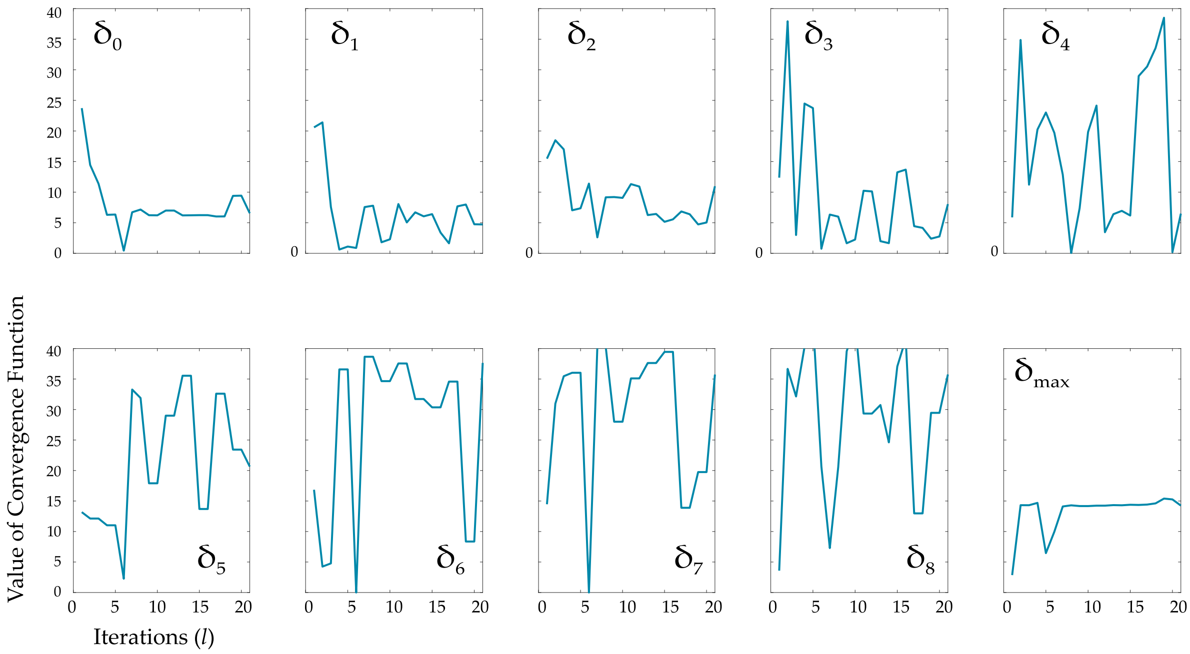


Figure 2.15: Absolute convergence of monthly production for each consecutive iteration l, determined using the Aleksandrov and Hambly (2010) multiple real option model for the oil exploitation case with initial spot price $S_0 = 55$, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}. When $l = 1$ the absolute difference is taken from the constant (dummy) production function.

In this figure, it becomes clear that our previous interpretation was correct: lower values for the convergence parameter imply fast convergence into a specific production schedule. For low values of progressiveness in taxation (i.e. low δ), this implies that the heuristics work in setting a production that does not change too much after a couple of iterations. For the median range of progressiveness we can see that there is a clear cycling of production –governments trying to catch up to the new production schedule and firms trying to escape from expropriation– while in values of δ that are too high we can see that expropriation is so sudden, when it happens, that the producers have not that many options left.

We will now broaden the analysis to a wider set of initial prices for oil production in the model of Trolle and Schwartz (2009), in order to see if there are more generalizable conclusions.

The results for a broader set of initial prices

To attain this, we look at the results from applying the non-naïve heuristic to the oil price mode from $S_0 = 53$ to $S_0 = 57$. This interval is chosen on purpose, because it marks the transition from *initial low prices* as defined on page 119 –that is, initial commodity prices, S_0, where the introduction of progressiveness in taxation lowers or eliminates perceived political risk[46]– to *initial high prices* (higher than $S_0 = 55$), where the introduction of progressiveness in taxation fails to lower the political risk.

As we have seen before, both the overall expropriation probability and the deadweight loss stemming from expropriation are closely correlated.[47] The evolution of these values for the different set of initial prices can be seen in figures 2.16 for the expropriation probability and 2.17 for the deadweight loss.

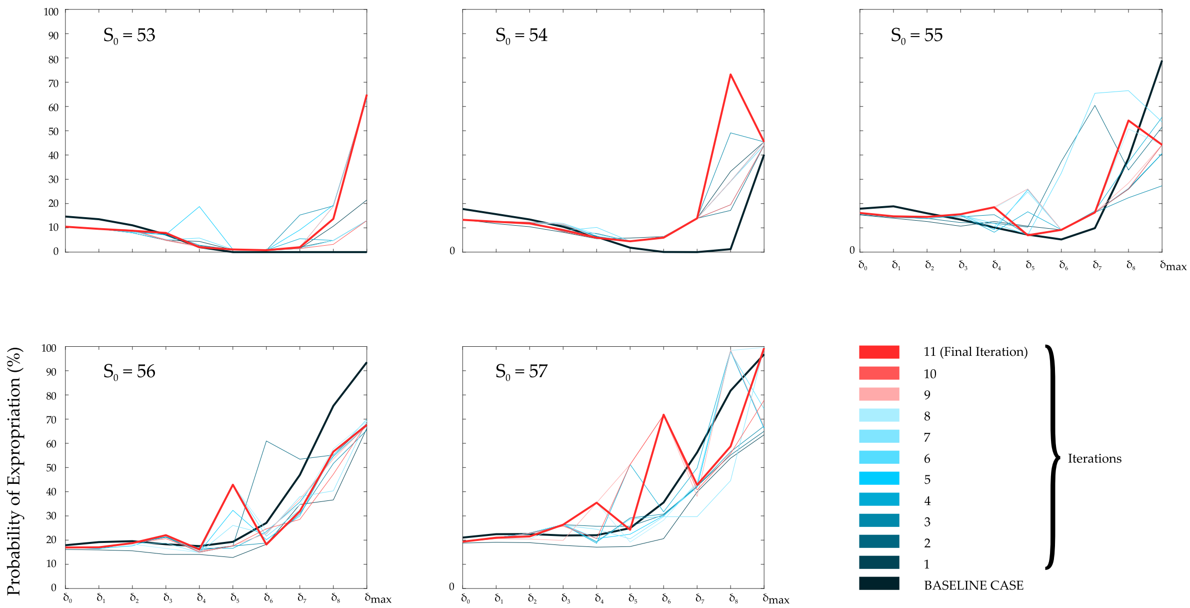


Figure 2.16: Variation of the **probability of expropriation** considering flexible production determined using the Aleksandrov and Hambly (2010) multiple real option model and the non-naïve heuristic for the oil exploitation case with initial spot prices varying from $S_0 = 53$ to $S_0 = 57$, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}. Curves vary for each consecutive iteration according to the scale on the right, with the reference case –**the 'dummy' constant production function**– in dark blue and the last iteration (with $N_{iterations} = 11$) in thicker red.

The first thing we can notice is that both graphs are almost indistinguishable,[48] which means that the timing of expropriation does not have a great effect on the overall deadweight loss. Secondly, we can notice that when the iterative algorithm tends to make the operations less risky and more efficient with each iteration,

[46]See figure 2.10 on page 118.

[47]In fact, correlation would be 1 if there were no differences in the timing of the expropriation decisions.

[48]Something that was stressed in Chapter 1.

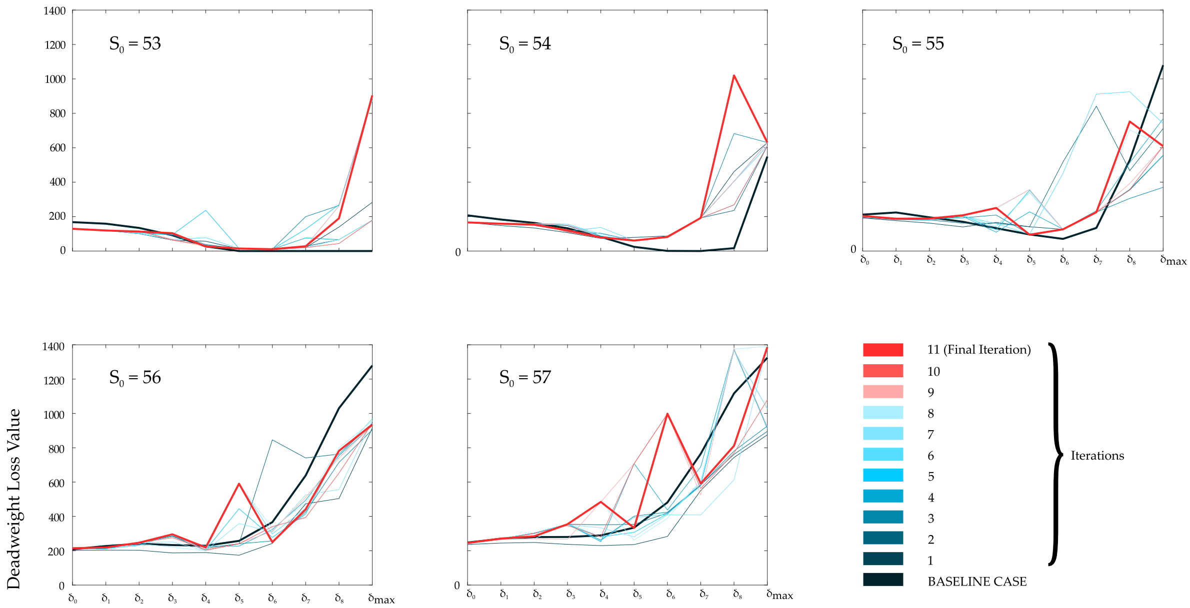


Figure 2.17: **Deadweight loss value** considering flexible production determined using the Aleksandrov and Hambly (2010) multiple real option model and the non-naïve heuristic for the oil exploitation case with initial spot prices varying from S_0 = 53 to S_0 = 57, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}. Curves vary for each consecutive iteration according to the scale on the right, with the reference case –**the 'dummy' constant production function**– in dark blue and the last iteration (with $N_{iterations}$ = 11) in thicker red.

two things happen:

- There are *low prices* at the beginning for the underlying commodity as defined above.
- Progressiveness in taxation is not too high.

When progressiveness in taxation is high (i.e. in this case, a high value of the parameter δ) or when there are *initial high prices* the results are not so clear. There is a substantial amount of cycling of production schedule, which, in its turn, tends to increase the overall expropriation risk and the deadweight loss of the operations.

We must remember, though, that the overall expropriation risk is not the only parameter under which we can evaluate the performance of the producer's response. More important than the effect that the introduction of a flexible production function has on the riskiness of the operations is the effect that it has on the value of the operations for the firm and for the government: an increase in riskiness can be compensated by a higher expected value, either for the firm, for the government or for both.

The effects for the firm, in the form of the value of V^{exp}_{firm} can be seen in figure 2.18. It is interesting to note that in this case the introduction of production flexibility is good for the firm as long as progressiveness is low. This confirms the intuition based on the results obtained by Aleksandrov and Espinoza (2011) and Aleksandrov et al. (2013);[49] where this holds when progressiveness is zero (δ_0 in this case), but it also means that these results are robust to the presence of political risk (expropriation) from the government. When progressiveness is higher results are mixed: if production cycling is **not too large** it holds that even if progressiveness in taxation might decrease the value for the firm, the flexibility in production ameliorates the initial situation (the dark blue line that assumes constant production).

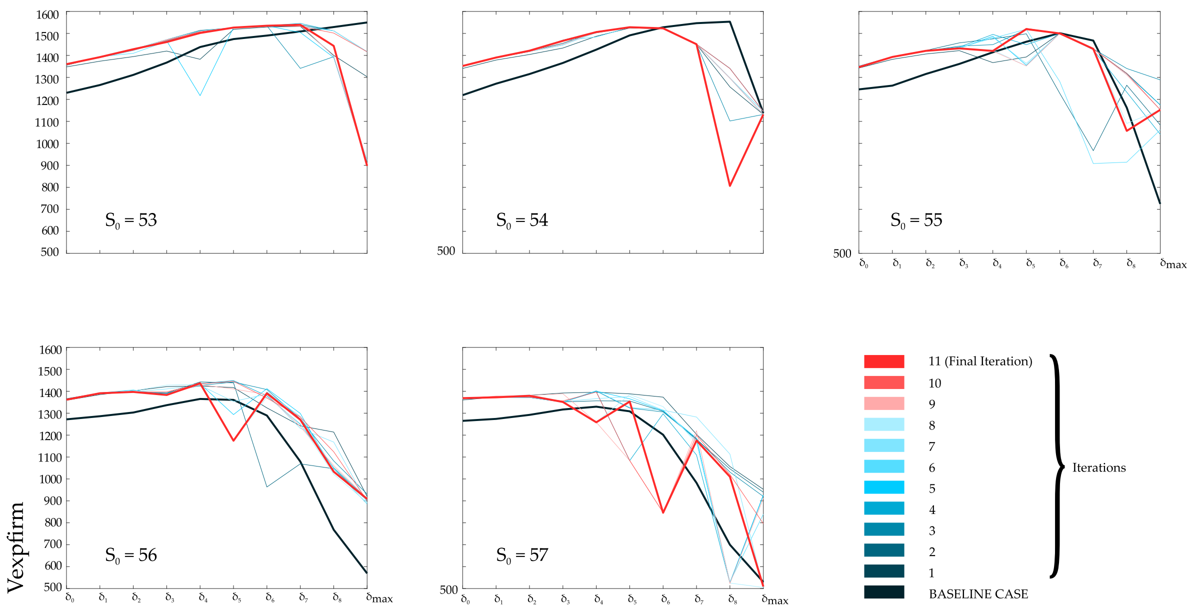


Figure 2.18: Total value of the operations for **the firm** considering flexible production determined using the Aleksandrov and Hambly (2010) multiple real option model and the non-naïve heuristic for the oil exploitation case with initial spot prices varying from S_0 = 53 to S_0 = 57, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}. Curves vary for each consecutive iteration according to the scale on the right, with the reference case –**the 'dummy' constant production function**– in dark blue and the last iteration (with $N_{iterations}$ = 11) in thicker red.

It is interesting to note that irrespectively of the effects that introducing flexible production have on the probability of expropriation and deadweight loss, operations become immediately more valuable for both the government and the firm after this flexibility is allowed.

When we look at the effect of production flexibility for the government, in the form of the value of V^{exp}_{firm} (see figure 2.19) the results are qualitatively different: for every initial price and progressive taxation regime being analysed, the introduction of production flexibility increased the value of the operations for the government.

[49] Although in those papers only the variation in value for the whole extractive operation was discussed.

Even in those cases where production cycled heavily, the advantage of being able to *catch-up* the producer, and to expropriate if considered necessary gives the host country an edge.

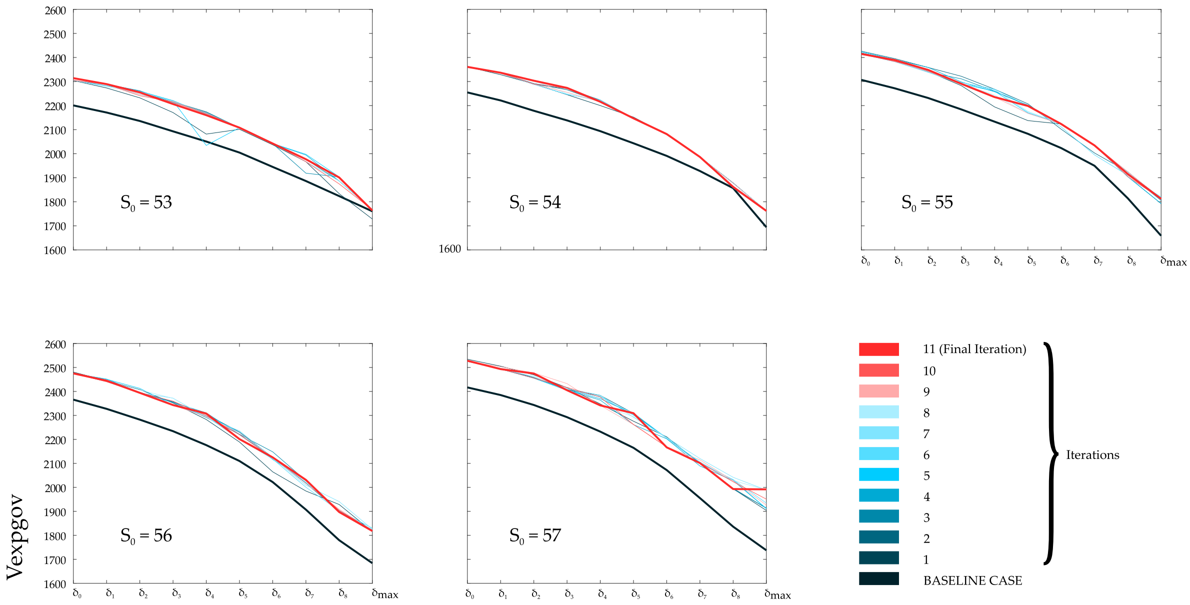


Figure 2.19: Total value of the operations for **the government** considering flexible production determined using the Aleksandrov and Hambly (2010) multiple real option model and the non-naïve heuristic for the oil exploitation case with initial spot prices varying from S_0 = 53 to S_0 = 57, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}. Curves vary for each consecutive iteration according to the scale on the right, with the reference case –**the 'dummy' constant production function**– in dark blue and the last iteration (with $N_{iterations}$ = 11) in thicker red.

Finally, when we consider the total value of the exploitation, seen in figure 2.20, we can observe that for *low initial prices* the introduction of production flexibility is advantageous over the constant 'dummy' production, except in those cases of maximum progressiveness in taxation. For the rest of the cases the effect is mostly positive except if production cycles heavily, as can be seen at the values for middle progressiveness in taxation for *high initial prices.*

To sum it up, the introduction of production flexibility increases the value of the operations when progressiveness in taxation is not extreme, which is a similar result to what it was stated in Aleksandrov and Espinoza (2011) and Aleksandrov et al. (2013); with two caveats, here we have shown that those improvements are robust in the presence of a state that is able to expropriate assets, and, unlike in these previous papers, we could see who were the main net beneficiaries of allowing flexible production: the government being always better off by allowing flexible production if we assume that it cannot refrain from expropriating assets when the conditions are too favourable; which was the same assumption used in the previous chapter.

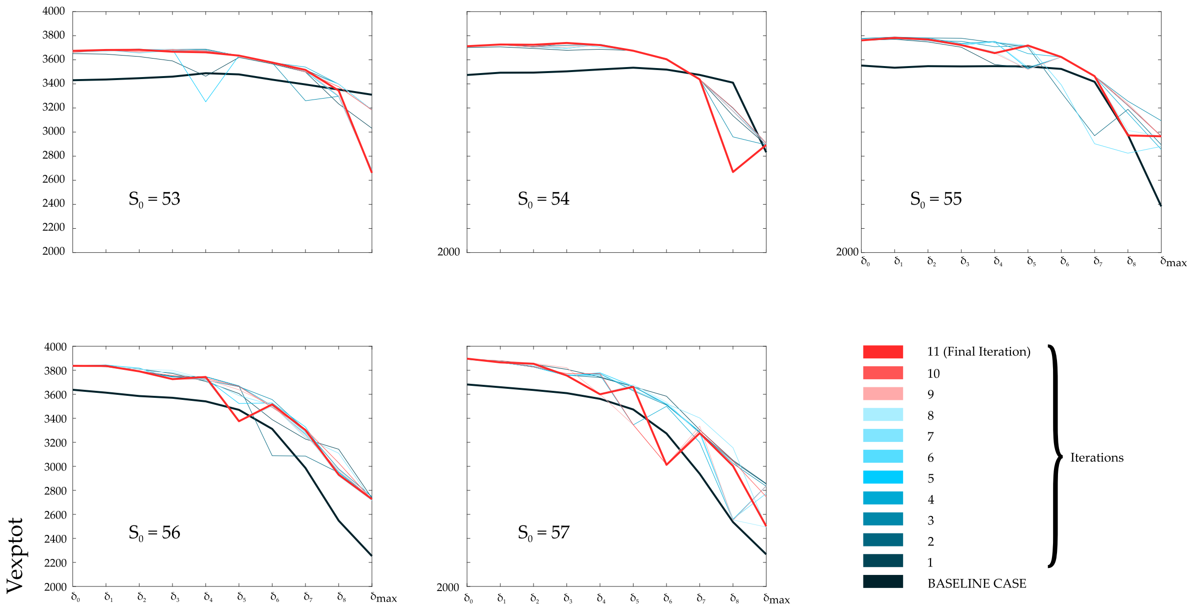


Figure 2.20: **Total value of the operations**, $V^{exp}_{firm} + V^{exp}_{gov}$, considering flexible production determined using the Aleksandrov and Hambly (2010) multiple real option model and the non-naïve heuristic for the oil exploitation case with initial spot prices varying from $S_0 = 53$ to $S_0 = 57$, for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}. Curves vary for each consecutive iteration according to the scale on the right, with the reference case –**the 'dummy' constant production function**– in dark blue and the last iteration (with $N_{iterations} = 11$) in thicker red.

Observations on convergence for this broader set of prices

We can also see how the convergence parameter evolved, as it was shown on page 126 for the case where $S_0 = 55$; in this case with only 10 iterations. And using the formula for convergence stated on page 125.

As can be seen in figure 2.21, the cycling of production becomes evident for high initial prices of the underlying commodity, whereas when the initial prices are low we see limited cycling (when tax progressiveness parameters are δ_3 and δ_4), and a sort of constant divergence for extreme values of δ.

We explained this before as a consequence of early expropriation when progressiveness is too high, something that we will consider in the paragraphs below.

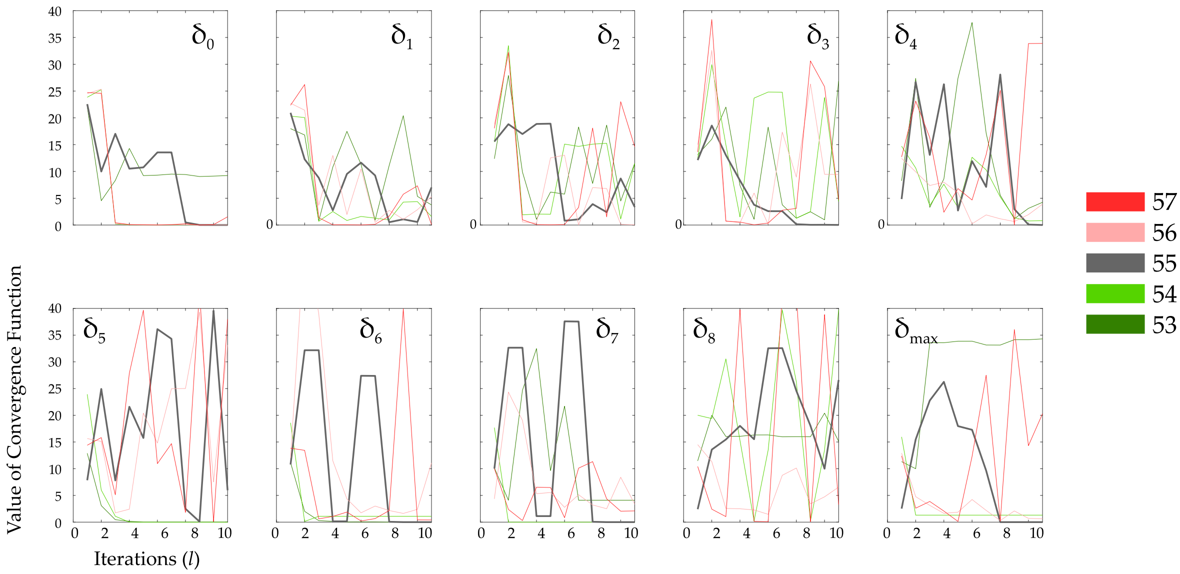


Figure 2.21: **Absolute convergence** of monthly production for each consecutive iteration l considering flexible production determined using the Aleksandrov and Hambly (2010) multiple real option model and the non-naïve heuristic for the oil exploitation case with initial spot prices varying from S_0 = 53 to S_0 = 57 (see scale on the right), for varying degrees of taxation progressiveness expressed by the nonlinear taxation parameter δ, between δ_0 (no progressiveness in taxation) to δ_{max}. When l = 1 the absolute difference is taken from the constant (dummy) production function.

A note on increased risk for some high δ values

Even though the iterative algorithm raises the value of the operations for most of the values of δ (see figure 2.20), this improvement tends to disappear when the taxation parameter δ is too high. In order to explain this phenomenon is necessary to go through the multiple real option model again. One of the characteristics of this model is that it is assumed that the producer chooses to produce or not, that is, he chooses to exercise one of the stopping times of his multiple real option model, based on an unbiased estimation of how this exercise will affect the value of his operations, an estimator that uses current prices and the futures curve as parameters. As in the case of the LSM model, the value of this expectation is done with data that is available *ex-ante*, regressing simulated values from next period to current prices,[50] however at time t_0 there is only one price and one futures contracts curve (the initial conditions), and thus a regression cannot be built.

For this reason, the initial expectation of the values that determines every possible production choice for the

[50] The regressors used are the spot price S, S^2, and the parameters that determine the shape of the futures curve: $x, v, x^2, v^2, Sx, Sv, vx$ in the Trolle and Schwartz (2009) price model for oil production and $\hat{v}, \hat{y}, \hat{v}^2, \hat{y}^2, S\hat{v}, S\hat{y}, \hat{v}\hat{y}$ for the Cortázar and Schwartz (2003) price model for copper production which was analysed separately with similar results than those obtained for the oil price model shown in this dissertation.

first period ($E_{t_0}[V_{t_1}^{*,m_p-i}]\ \forall i \in \{0,\dots,k_1\}$, according to the notation in Section 2.3) is calculated not with a regression as in the LSM model, but with the average values at period 1 for each production possibility, an unbiased indicator that has limited predictive power. As a consequence, production in the first period **is largely insensitive to varying expropriation probability**, expectations do not vary with the price path as in later cases, and therefore the flexible production model is less efficient **when there is a larger probability of expropriation in that first period**. As we have seen for the case of oil exploitation in figure 2.6 on page 109 when the initial price S_0 is between 53 and 57 there is an increased risk of early expropriation at year 1 when the progressiveness parameter δ is larger,[51] therefore, it is the insensitivity of the multiple real option model to the conditions on that same first period what makes that the adaptation to the high values of tax progressiveness, δ, to be less efficient, decreasing the overall value for the firm after the first iteration.

2.7 Conclusions

We thus end up this chapter on a similar note than on the previous one, the hypothesis we posited is only partially true and there are many caveats to it.

In the hypothesis we stated that the introduction of production flexibility would give an edge to producers, compensating the political risk that was either already present or could be introduced by negotiating more progressive taxation regimes. Flexibility seemed to be favoured in the literature: the ability to abandon a project was especially stressed in the early papers by Cortázar and Casassus (1998) and Cortázar et al. (2001). However, as we saw in figure 2.9 on page 114, the sole addition of abandonment provided negligible advantages for the firm in the case of low progressiveness and some potential major advantages if the initial conditions were right: for firms it might be a risky strategy if they do not know the nature of the initial conditions to which they would be subject.

When production flexibility was introduced, the evidence from Aleksandrov and Espinoza (2011) seemed to be confirmed for tax regimes with low progressiveness (see figure 2.18 on page 129), although the gains were much more modest than reported in the original paper: an increase of around 8% ~ 10% with respect to the baseline scenario. For higher progressiveness (i.e. higher values of δ in this specific case), production converged on a limited number of cases, when that happened the valuation of the operations was enhanced for

[51] In reality, this happens in the whole interval, S_0 from 47 to 60 as it was analysed in the *pure abandonment* case in sections 2.2 and 2.5.

the firm, whereas if there was a cycling of production the results were unpredictable, but usually detrimental for the investor.

In these two cases we focused on the effect over the producers (V_{firm}^{exp}), rather than on the host government given that what we analysed here were decisions made by producers themselves to protect from predatory governments; and therefore they would be implemented or not based on their effect on the value for the investing firm.

Is taxation progressiveness a good idea?

After these two chapters we might have an idea of why Stroebel and van Benthem (2013) failed to find much innovation among the 2,466 oil contracts that they revised: introducing progressiveness in taxation is fraught with risks. In the previous chapter we found that it was an effective means to reduce the political (expropriatory) risk when initial prices of the underlying commodity were low; but depending on the kind of tax regime, we also saw that the jump towards a *bad* equilibrium could be quite abrupt.

In this chapter, we saw that after introducing the possibility of abandonment every scenario for the government deteriorated when taxation progressiveness was introduced (see figure 2.9b on page 114). In absolute terms, even when production remains constant, this implied that the sole consideration that abandonment could be an option lowered the expected value for the government of the operations (the constant production function with abandonment is the thick blue line of figure 2.19 on page 130).

We can thus appreciate the risks involved, when even a small modification to the previous chapter scenario –just introducing abandonment– could make all kinds of tax progressiveness to be harmful for government's tax capture. This is similar to with what Løvås and Osmundsen (2009) say about the Norwegian tax regime when they compare it with the usual production sharing agreements employed in the industry: the robustness to price changes greatly compensates the perceived "fairness" of the production deals that are commonly used in the industry.

For these reasons, and for the damaging failure to converge of production when tax regimes are progressive is that we must issue a further note of caution against the use of pure progressive taxation regimes in order to minimise risks.

Flexibility in production can be a sort of deterrent

Vernon (1983) cites an extensive list of measures that companies can take in order to minimise their risk when facing an unstable host government. To these measures we could add the credible introduction of abandonment measures: as we saw above,[52] the threat of establishing abandonment protocols could very well work as a deterrent for the government to modify the taxation regime. The combination of no progressiveness in taxation together with flexibility in production seem to maximise the value for both the firm and the government, as can be seen in figure 2.20 on page 131.

Further extensions of the model

As has already been said, the initial model shown in the previous chapter and the one detailed here rely only on corporate income tax, so that the progressiveness in taxation remained monotonically increasing as we changed the parameters. The introduction of royalties, coupled with this model, could yield interesting results. In the next chapter we will review a special case where royalties are used in conjunction with corporate income tax to maximise the tax capture in the presence of tax evasion, but a coherent integration of both models could be even more productive.

Finally, this model assumes that the taxation regime will remain constant throughout the operation of the mine/oil field, and that the only tool available is that of expropriating the assets. This leaves open an opportunity to explore what can happen when taxes can dynamically respond in order to minimise expropriation risk and to maximise tax capture.

[52] Cf. figure 2.9b on page 114.

Chapter 3

Institutional Frameworks and the Taxation of Natural Resources: Escaping the Royalty Trap

This chapter explores how the capacity of a state –its ability to levy taxes and to offer a credible national-owned alternative to foreign investment– is going to affect the kind of taxation regime that a mine or oil field is going to face; private investors are assumed to be multinational firms that can costly divert part of their rents to jurisdictions with different tax regimes. The initial capacity of the host government, its technology and the quality of its institutions will determine both the nature of the ownership of the resources and the path that the tax code is going to follow. It is also argued that certain initial conditions can effectively trap *a country into a suboptimal tax regime. Finally, the evolution of mining taxation in Chile during the 20^{th} century is presented to illustrate the main drivers of the model.*

JEL Classification: D82, H25, H26, H30, N50, Q38.

Keywords: Non-renewable resources, taxation, income shifting, royalties, evolution of institutions.

3.1 Introduction

Both in the past and in current times, several economic voices have argued for the healthy promotion of native industrial development as desirable in itself:[1] however it is important to consider the effects that weak institutions can have on the stability of private investment; more so when there are changes in the degree of technological development of a country.

For this purpose, we will analyse what happens with investment in the natural resources industry when what we call the "state capacity" of a jurisdiction changes. In this chapter, this capacity is going to be separated into two dimensions. The first one is the *technological capacity* and the second one is the *institutional or tax capacity*, which resembles the *fiscal capacity* shown in Besley and Persson's (2011) *Pillars of Prosperity.* We will define technological capacity as how competitive government-owned natural resources companies are in relation to the productivity of private firms (using the same definition and parameter, ρ, as is defined in Opp (2012)); while the institutional or tax capacity is going to be the ability of the state to capture rents from the private sector through corporate taxation.

The existence of two, independent, parameters is relevant, as these capacities do not necessarily evolve in parallel: the government can usually influence the tax capacity more directly, whereas the technological capacity is more of a consequence of long-term planning or mere chance (i.e. it can sometimes be treated as an exogenous factor). How these parameters can vary will be shown at the end of the chapter using the evolution of mining taxation regimes through time.

In this chapter we conclude on some effects that the technological capacity, ρ, and the institutional capacity, χ, have on the tax regime and on the stability of private investments in the natural resources industry. Two of them are:

- Conditional on the initial fiscal capacity of a country, the government might choose a simpler taxation regime –just royalties or corporate income taxes– without much loss; a finding that confirms what we see in reality (simple taxation regimes in most jurisdictions), and which might have the added benefit of fostering investment due to added simplicity.

- When the initial institutional capacity of a state is low, this chapter finds that there might be few or no incentives to invest in the improvement of this situation: leaving countries stuck in a position where

[1] An example of this view is the historical view of *dependency theory* (or *dependencia*) as mentioned by Moran (1974), which was spearheaded by Raúl Prebisch and the ECLAC in the Americas. A more contemporary overview can be found in Mazzucato's (2013) *The Entrepreneurial State.*

any increase in the tax capacity will be detrimental for the total tax take.

These findings put an additional weight on the improvement of tax legislation at the multinationals' home jurisdictions; if costs become more difficult to divert both at home and abroad, the least developed countries might face an exogenous increase in their tax capacity, which –while detrimental and unwanted in the short term– might prove advantageous on the long run.

3.1.1 Motivation

This chapter aims to explore how the trade-off between the technological capacity of a country and the quality of its institutions determines the country's taxation regime and, more specifically, how the taxation of the natural resources industry evolves when economic or political conditions change.

The motivation is that although there seems to be a link between the quality of institutions (including the tax authority) and the potential productivity of the state sector, this correlation is far from perfect, and the interaction between these two quality dimensions will affect the institutional stability of a given region.

If a government makes a clear development in its technical capacity to exploit natural resources, but it does not have the institutions to effectively increase the tax capture over the incumbent firms, there will be more pressure to nationalise the corresponding mines or oil fields, and a push to attract investments would be counterproductive. On the other hand, when the state does not have the technological capacity to create its own national resources companies, or to operate the existing ones on its own, it can sustain foreign investment even when this is contributing little to the state: there is no realistic outside option.

In the literature we can find examples of both cases: countries that tolerate foreign investment because there is a technology shift that leaves their national natural resources companies obsolete,[2] and cases where the poor quality of institutions prompts inefficient tax regimes (or government ownership) as an alternative to neutral taxation.

Moreover, there is ample evidence that, being subject to multiple and conflicting principals, the state-owned firms have lower efficiency, and generate smaller rents than privately-owned operations. Nevertheless, they are highly relevant for the industry as a whole, as can be seen in figure 3.1 which shows the **oil output** from the 50 largest producers: a staggering 69% of it comes from state-owned companies (or NOCs), this highlights the difficulty to sustain private investment even if theoretically it would be the most efficient

[2]This could be –for example– the case of an oil producer like the Mexican PEMEX, who needed to find suitable alliances in order to extract oil from deepwater fields in the Gulf of Mexico.

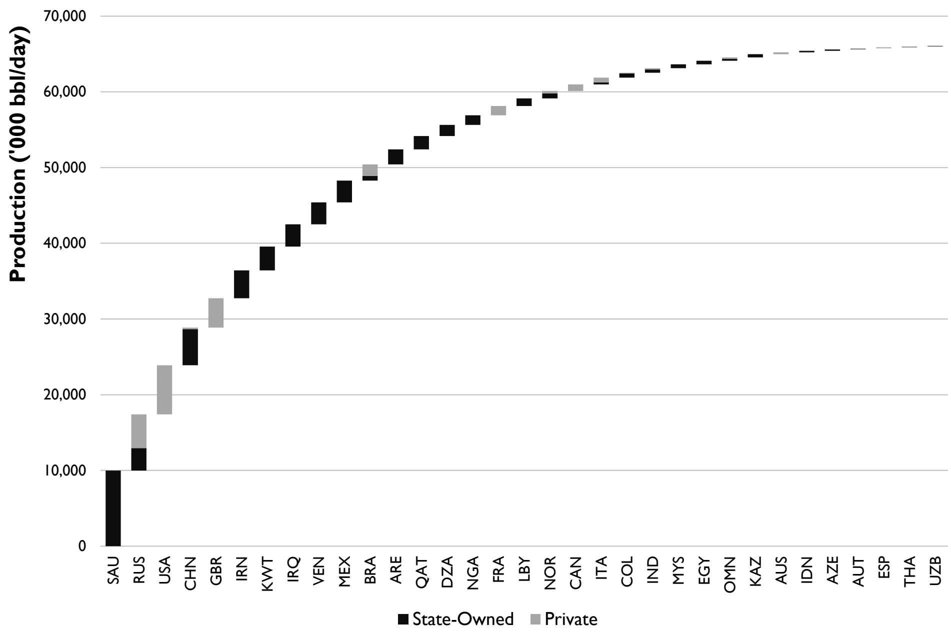


Figure 3.1: The 50 largest oil producers, arranged by country and ownership regime. *Source: Energy Intelligence (2013).*

course of action; we would expect the technological capacity of the state, ρ, to be less than 1 and therefore, that there should be less rents available when the property of the mine/oil field, is held by the state.[3]

Hypothesis: Corporate income tax is not always desirable, and governments should foresee this

While the taxation literature stresses the importance that taxes should not be distortive (e.g. see Boadway and Keen, 2010), in this chapter we argue that the fact that companies can respond to taxation by engaging in costly income shifting, can render an efficient tax –like corporate income tax with complete capital allowance for depreciation– as a second best to the use of a mixed taxation regime that includes royalties. Moreover, depending on their starting point, governments should take different decisions on how to develop their institutions in order to avoid getting trapped in inferior taxation regimes.

[3] Ample evidence for the renewed vigour of state-owned companies, especially in the natural resources industry can be found in the book by Kurlantzick (2016).

3.1.2 Literature review

A comprehensive review of the existing literature on rent taxation for natural resources can be found in Lund (2009); there, the author explains the choices between models that consider different degrees of uncertainty, and how the decision being made by the policy maker needs to be a compromise between *the attainable level of taxation and the distortions brought by different taxation regimes.* For a detailed review of the theory behind the different applicable taxes, Boadway and Keen (2010) provide us with an extensive analysis, though strongly advocating the use of non-distorting taxes.

After publishing *The Taxation of Petroleum and Minerals: Principles, Problems and Practice* where Boadway and Keen (2010) appears, the IMF has published two related books: one by Calder (2014) –*Administering Fiscal Regimes for Extractive Industries: A Handbook*– and more recently another one called *International Taxation and the Extractive Industries*, where Calder (2017) deals with current issues regarding transfer pricing and Mintz (2017) explores the trade-offs between royalties and corporate income taxes, Mintz also reminds us that a resource-rich government has two conflicting but not necessarily antagonistic objectives: one is the need to promote investment and the other is the need to extract taxes from that same investment.

In general, the literature that deals with taxation of natural resources needs to explain why economic rents are not taxed in its entirety –for example, using resource rent taxes– in the real world. One possible way of justifying this fact is through the asymmetry of information when it comes to knowing the true cost of exploration, as mentioned by Osmundsen (1995). Another source of distortion is the fact that exploitation of a mine or oil field can span for several periods, and therefore companies will try to engage in practices that will obscure their true cost up until the end of their participation as they might fear that once the cost is known, all the rents are going to be extracted (see Osmundsen (1998) for an application of the ratchet effect in the context of natural resource taxation).

Even if costs are not unknown, they might remain unverifiable for tax purposes, which is the basis for classical income shifting models as the one presented in this chapter. And as Raskolnikov (2013) thoroughly exposes; there are limits to the taxation we can impose to a mine or an oil field: unless production responses to taxation are impossible (like shifting production to the future), those being taxed are going to engage in measures to decrease their tax burden. When this happens, firms choose a production function q that is going to differ from the optimal value q^*. We should also bear in mind that the law's attitude towards tax evasion is going to be proportional to the amount being evaded, and this justifies the existence of limits to the possible penalties: these are characterised in this chapter by the institutional parameter χ.

The range of attainable taxation regimes also needs to consider the constraints in policy-making, as Dixit (1996) in *Lawlessness in Economics* rightly mentions: if there are weak incentives in bureaucracies, these should be understood as a response to them being subject to multiple principals (and so, no single instrument can be sufficiently aligned). On the other hand, we usually see in the literature that incentives that privately-owned companies have when investing abroad are quite straightforward, and so a couple of indicators should suffice to keep performance aligned.

Dixit also shows us why under certain conditions both parties involved would prefer opacity over full disclosure of production information: when looking at a model of repeated interactions, uncertainty keeps both parties disciplined, of course this will only happen if the future is sufficiently important. Such insights can be linked to Hart and Moore (2008) and other related literature which shows that relying purely on the formal mechanisms of contract enforcement can be detrimental. Additionally, Dixit stresses that in repeated interaction scenarios there is a rationale for graduated punishments (as opposed to what he calls *grim-trigger* strategies): once we introduce the possibility of miscalculation or error, a grim-trigger strategy seem unrealistically harsh. Finally, he mentions how reputational concerns can broaden the range of private investment that can be sustained.

The fact that direct investment is going to be affected by the capacity of the state, and how this evolves was identified by Vernon under the name of 'planned obsolescence' (in Vernon, 1971).[4] According to him, multinational firms invest in less developed countries because they have a technological advantage that protects their investment. Eventually, the technology diffuses to the rest of the country rendering the original negotiating power obsolete.

The persistence of this technological gap is behind the model by Opp (2012); where a company is able to sustain an investment through time even if the government cannot offer any credible commitment.[5] Another variation is the one suggested by Eaton and Gersovitz (1983), where a multinational firm plans its investment in such a way that the technological gap is kept constant through a careful renovation of the technology in the host country: obsolescence is paced to maintain the technology parameter, ρ, constant.

Another mechanism to promote investment while in presence of information asymmetries is to promote direct investment through joint ventures with local partners. Two complementary models that show a strong resemblance to the model presented here are the ones shown by Karabay et al. (2009) and Karabay

[4]Cf. also Vernon (1981) and Vernon (1998) for further discussion of this concept and its historical application, the latter is especially relevant as it deals with how the technological obsolescence impacts on cost transfers for multinational firms.

[5]In some ways, Opp's model is a dynamic version of the model presented by Dixit (2004).

(2010), as in this chapter, in these models the state has a limited ability to know the true costs (or to avoid tax evasion), but in these two papers the mechanism relies on the fact that the local partner is going to be better informed about the cost structure of the multinational company once the joint venture is established. This, together with the fact that total repatriation of rents is not feasible under these conditions, is sufficient to create mechanisms that provide truthful revelation of the cost structure by foreign investors: as mentioned previously, these models are comparable to assume that there is a certain mechanism (joint-ventures) that can immediately increase the tax capacity, χ.

Finally, we have models that consider the constraints to the design of taxation systems when there is more than one mine or oil field being exploited. These range from those where the expectation is that there is going to be conformity to emerging norms, as in Young and Burke (2001), to those problems with more than one type of contract, mentioned by Sunnevåg (2000).

In this chapter, rents will not be fully taxed due to the ability of investors to shift their income to their home jurisdiction, this income shifting process is akin to the transfer pricing model by Devereux, Lockwood and Redoano (2008), though in that case the tax authority did not impose royalties but could change the depreciation rules; we use here the approach taken by Lund (2002), where the tax authority can choose between a corporate income tax and a royalty to minimise the evasion through income shifting: this chapter also takes elements from a historical analysis for copper taxation co-authored in Biehl and Vera Concha (2014); to which substantial improvements have been made in order to update it with current knowledge of evasion mechanisms and retaliation tools as mentioned in *The Empire Trap*, the book by Maurer (2013).

3.1.3 About the structure of this chapter

This chapter starts with a rent taxation model based on the one proposed by Lund (2002), which we use to analyse the trade-off between the ability of a government to tax the rents of a foreign investor and the capacity of a multinational firm to evade taxes through income shifting. The structure and solution of this model, which also takes elements from Devereux et al. (2008) is presented in **Section 3.2**.

Following the introduction to the model, we consider how the institutional parameters will determine the tax take of the government, and how this might affect the ownership of natural resources assets. In search for a better name, we call the relative tax capture the 'investment frontier'. This is shown in **Section 3.3**, where the incentives that condition the evolution of tax rates and some limiting cases are also taken into consideration.

In **Section 3.4** we explore the implications of the shape of the gradient of the investment frontier –how the tax capture changes when there is a modification in the tax capacity of the country– and from this result we argue for the existence of a *Royalty Trap*[6] that might leave less developed countries stranded in inefficient tax regimes when certain initial conditions are found.

Sections 3.5 and **3.6** observe and fiddle with the assumptions of the model and its consequences. First, we observe how the tax rates evolve when there is a change in the tax capacity parameter, χ; then we vary the assumptions of fixed mine/oil field size or productivity and we introduce investment costs (and how these changes affect the stability of ownership regimes).

In **Section 3.7** there is a historical review of Chile's mining taxation regulation as an example of the applicability of this model, in particular how the technological and institutional capabilities of the country influenced the discussion on the taxation of natural resources throughout the 20$^{\text{th}}$ century.

Finally, **Section 3.8** concludes, with recommendations for further research.

The results in a nutshell

Once we contrasted the hypothesis –that some governments should realise that is preferable to have some degree of tax inefficiency to curb evasion– with the results from this paper, we could make the following observations.

Combining royalties and corporate income tax is better than using a single tax: The simultaneous combination of taxes generates an additional area of tax stability than if each tax was used sequentially, though the range of institutional capacity indicators for which these advantages are relevant is quite modest.

If the tax capacity is too low, royalties will be minimally distortive: When governments know that the potential for tax evasion is too high, they will set a low corporate income tax; and so, the evasion will be minimised. In these conditions the royalties decrease its effect on the investment decision compared with a scenario where parameter χ is large, because most of their distortive effects will be compensated through evasion and through the incentives provided by low corporate income taxes.

Less technologically developed governments get trapped in low tax regimes: This is what we call a *Royalty Trap*, where the improvement of the tax capacity starts creating distorting effects on the

[6] We define a *Royalty Trap* as a situation where the gradual improvement of a taxation technology goes against the short-term objectives of the maximisation of tax capture by a government.

royalties, while tax evasion is sufficiently strong so that higher tax rates do not capture more money for the government. In these cases, the short-term incentive for the government is to limit investment in improving their fiscal capacity so as to maximise (locally) their tax take.

These three conclusions complement what we already know about the *Natural Resources Curse* and emphasise that –for some states– second-best tax regulations are the only option unless there is a massive discrete jump in their tax capacity.

3.2 A Model to Determine an Adequate Tax Regime Considering Asymmetric Information and the Probability of Tax Evasion

The model presented in this chapter will focus its analysis on how taxation and institutional stability evolves. To determine the overall capacity of the state we rely on a pair of independent parameters; first, a technological capacity (the ability of the state to replace –up until a degree– private entrepreneurship) which is based on the definition of technological capacity mentioned by Opp (2012);[7] and secondly, the quality of tax institutions as defined by Devereux et al. (2008). These parameters will be fed into a variation of the model of imperfect monitoring costs presented by Lund (2002), from which the basic setup of this model is taken: this will give us the tax decisions and production indicators conditioned on the overall capacity of the country.

This is a model of tax setting with asymmetric information and monitoring costs.[8] We will start with a two-period model (see figure 3.2), that is characterised by the following elements:

- A mine or oil field is exploited for a single period.
- The government –taking into account its technological and taxation capabilities– takes an *ex ante* decision about the tax regime and abides by it. We assume that the government can foresee the best response functions of the firms and will act accordingly to maximise its tax revenue. In this model, this decision implies to select a corporate income tax, 't', over profits, and a royalty 'r' over the value of sales.

[7] Which is closely related to the idea of a narrowing 'technological gap' featured in Moran (1974) when he discussed the evolution of taxation of copper in Chile during the 20$^{\text{th}}$ century.

[8] Or a model with symmetric information but unverifiable costs for tax purposes.

- A multinational firm decides whether to invest or not. If it invests, it should choose the production level, 'q', that is going to determine part of the remaining economic surplus available after taxation. And, equally important, it should decide the amount of rents that are going to be transferred, 'a', unbeknownst to the host government, to its home jurisdiction.

- A consequence of the state being able to foresee the best responses from producers is that it will always propose a tax regime that would, at least, make the firm indifferent with respect to investing, and as such, we can safely assume that firms will always invest if proposed a tax deal.

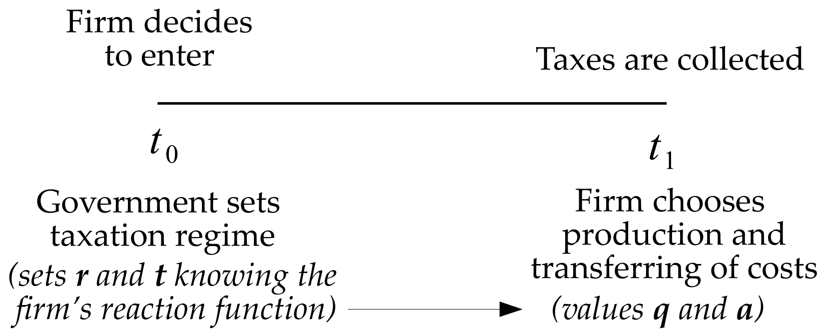


Figure 3.2: Sequence of events and decisions.

The host country is defined by its technological and taxation capacities. In the model the parameter ρ describes the technological capacity, while χ describes the institutional (tax) capacity of the state. In the case of ρ, the technological capacity is defined as the ratio between the optimal profit of a state-owned firm and the theoretical, pre-tax, profit that a foreign investor with world-class technology would have under non-distortive taxes,[9] so that it can be written as:

$$\rho = \frac{\hat{\pi}_G}{\hat{\pi}_F} \tag{3.1}$$

Where $\hat{\pi}_G$ is the optimal profit of a field under government operation, and $\hat{\pi}_F$ is the corresponding profit if the mine or oil field were being operated by an efficient private firm under no taxes. Thus, if $\rho = 1$ the state can costlessly replace private investors, and no loss of efficiency would be perceived. Whereas if $\rho = 0$, there would be no economic activity at all if the private investor were not present, as the government would

[9] The definition of the parameter ρ has been taken from Opp (2012); and has been confirmed in practice by the differential between public/private practice. See, for example, Titelman Goren (2007) for evidence of this differential for the case of the copper industry in Chile, and Çakir-Melek (2011), for evidence on the Venezuelan oil nationalisation experience in the 70s.

be unable to operate the mine or oil field. On the other hand, the tax capacity of the state is going to be represented by a parameter χ, which is going to be equal to 0 if the state has no ability to avoid the transfer of profits from the host jurisdiction to the firm's headquarters, and it is going to be 1 if there is perfect monitoring capacity.[10] In this way, the host government capacity is going to be described by a pair (ρ_0, χ_0) where $\rho \in [0,1]$ and $\chi \in [0,1]$.

Taxes and the production function

Following Lund (2002), we will assume that the production function for a mine or an oil field will be deterministic, and the gross profits are going to be characterised by the price of the commodity and the cost structure. For the firm, this will mean that rents before taxes are going to be:

$$pq - bq^2 \tag{3.2}$$

Where q is the production, p the price of the commodity and b a parameter in the production cost, a function that satisfies Inada conditions, where q^* is the optimal production function.[11]

So, the government, knowing the producers' best response to taxation is going to choose a tax regime made from a combination of corporate income taxes, t, and royalties, r, where $\{t,r\} \in [0,1] \times [0,1]$. With these taxes, the total tax collection would be

$$T = t(pq - bq^2 - a) + r(1-t)pq \ , \tag{3.3}$$

where the royalty tax rate is a direct tax over sales or gross revenue.

Then, the investor, is going to act accordingly to its foreseen best response and will try to maximise its after-tax profits, by choosing the produced quantity, q, and the cost to transfer to its home jurisdiction –that will not affect production– by an amount a. If this happens the after-tax profits will be given by the expression:

[10] The tax capacity is taken from the ability to penalise transfer costs as it appears in Lund (2002) and Devereux et al. (2008), and can be interpreted as a proxy for the heightened probability of being caught evading taxes; which, of course, would be larger if the sums being evaded are correspondingly bigger.

[11] This production function is of the same form as in Opp (2012), where rents from production were given by the equation: $\pi = AI^\alpha - I$; with I being the investment and α and A parameters. Equation (3.2) above is equivalent to the case where the parameter $\alpha = \frac{1}{2}$. And, of course, Inada conditions assume that there will be no overproduction, so that when $q \to \infty$ the profit will be equivalent to $\lim_{q \to q^*} pq - bq^2$.

$$\Pi = (pq - bq^2)(1 - t) - r(1 - t)pq - \frac{\chi}{1 - \chi}a^2 + a(t - s). \tag{3.4}$$

Where the costs to incur in this transfer of rents outside the host country are going to be given by the expression $\frac{\chi}{1-\chi}a^2$. So that there will be no costs if $\chi = 0$ but these will monotonically increase as it approaches $\chi = 1$, where the transfer of rents is impossible at a finite cost.[12]

We must note that the net profits that the multinational firm is going to receive due to the transfer of costs to its home jurisdiction, a, is going to be given by the expression at the end of equation (3.4): $a(t-s)$, where s is the corporate income tax on the home jurisdiction of the multinational firm: so this model assumes that it only makes sense to transfer profits abroad if there is a tax differential between the host country, where operations are based, and the home jurisdictions. where the rest of the profits are taxed.

Setting limits to tax avoidance

As the value of parameter χ decreases, it becomes easier for investors to engage in costs transfers (i.e. they are less likely to be punished); while their incentives to avoid taxes are going to remain proportional to the differential $(t - s)$. For this reason, we can expect that in these cases the host government will aim to lower this differential between the corporate taxes at home and abroad in order to deter, at least partially, the transfer of costs. Eventually, when χ is very low, t will become **lower** than the international tax rate, s, and the firm's profit –as it appears in equation (3.4)– will be maximised with a *negative* value of the parameter a. That is, as corporate income taxes are going to be too low, there will be incentives to *decrease the declared costs of the operations*. Here we depart from Lund (2002), and assume that, as a reasonable minimum, in no case the firm's net taxable income, $(pq - bq^2 - a)$ can be larger than the (verifiable) proceeds from sales, (pq). Therefore, we will set a minimum value for the parameter a, that will call the *tax evasion boundary* so that it is defined as:

Definition 5. *We can define the* ***tax evasion boundary*** *as the minimum value of* **a** *that can be credibly incurred by the investing firm, and which makes the perceived taxable costs to go to 0; so that it is equivalent to*

[12] The rationale of this expression is that the risk of being caught is going to be proportional to the diverted rents, while the potential penalties would also be proportional to these transferred costs. Thus, the penalty for tax evasion will be equivalent to $\frac{\chi}{1-\chi}aK$ and the probability of being caught would be represented by $(\frac{a}{K})$; K being a positive parameter.

$$a \geq -bq^2. \tag{3.5}$$

Of course, this is an arbitrary limitation for the parameter a; a more conservative approach would be –for example– that χ_d, the tax capacity at the home jurisdiction, is one, and therefore a should always be positive. Now that the incentives of both investing firms and host governments are clearer, we can proceed to solve the model. First, by defining the producer's best response to a specific tax, and then letting the government to establish a tax rate given that information.

3.2.1 Solving the Model

The presence of a tax evasion boundary to the transfer of costs modifies the solution from what was shown in Lund (2002). Nevertheless, it is still possible to find a pair of taxes, $\{t, r\}$ that will maximise the overall tax take for a given value of the parameter χ, so that $t = t^*(\chi)$ and $r = r^*(\chi)$: t^* and r^* being the values that maximise the tax take for a given value of χ. The role of the government, then, is to find those values, $\{t^*, r^*\}$, that will maximise tax capture, and propose them to firms so that they commit their investment.
In order to achieve this, we will follow the aforementioned model by Lund (2002) with the addition of boundaries to tax evasion. The procedure to solve it is going to be almost the same seen on Lund's paper until we reach the conditions where the best response conflicts with equation (3.5). However, it is relevant to note that our main focus will not be in the parameters obtained from the result, but on the tax capture that will arise from it: the total tax capture compared against the parameter χ as it is presented, for example, in figures 3.7 and 3.8 on pages 163 and 164, respectively.
In order to set a tax regime, first, the government needs to take into account the producer's reaction function to a certain level of taxes, in both parameters q and a.
This can be done taking the first order conditions from the after-tax profit equation for the firm, equation (3.4), which gives us

$$\frac{\partial \Pi}{\partial q} = (1-t)(p-2bq) - r(1-t)p = 0 \ , \tag{3.6}$$

and

$$\frac{\partial \Pi}{\partial a} = t - s - 2a\frac{\chi}{1-\chi} = 0 \ . \tag{3.7}$$

Which satisfy second order conditions when $t < 1$, and so are optimal responses for a specific tax combination $\{t, r\}$ in the solution range $[0,1] \times [0,1]$.

Then, solving these equations leads us to the producer's optimal responses, which are

$$q = \frac{p(1-r)}{2b} \ , \tag{3.8}$$

and

$$a = \frac{(t-s)(1-\chi)}{2\chi} \ . \tag{3.9}$$

These would be the optimal quantities as long as the solution does not lie inside the tax evasion boundary. Lund (2002) notes that the value for q is not unique when $t = 1$, however, as equation (3.8) is the limiting case when $t \to 1$ we will also use it in those circumstances without loss of generality.

Now, knowing these best response functions the government is able to choose t and r to maximise its tax collection, and therefore will select a corporate tax and a royalty that reflect this and elicit the best response from the firms. Taking the tax capture from equation (3.3) and inserting the values for q and a as the responses of the producer –equations (3.8) and (3.9)– we obtain the following,

$$T = \frac{p^2(1-r)}{4b}(t - rt + 2r) - \frac{t(t-s)(1-\chi)}{2\chi} \ . \tag{3.10}$$

Which has, as first order conditions, the following equations,

$$\frac{\partial T}{\partial t} = \frac{1-\chi}{\chi}\left[\frac{p^2\chi}{4b(1-\chi)}(1-r)^2 + \frac{s}{2} - t\right] = 0 \ , \tag{3.11}$$

and

$$\frac{\partial T}{\partial r} = \frac{p^2}{2b}(2-t)\left[\frac{1-t}{2-t} - r\right] = 0 \ . \tag{3.12}$$

Lund (2002) rightly points out that $\frac{\partial T}{\partial t}$ from equation (3.11) will always be positive if $t < \frac{s}{2}$, so the solution to equation (3.11) will be in $t \in [\frac{s}{2}, 1]$. In the same way, from the expression $\left[\frac{1-t}{2-t} - r\right]$ at the right of the equation (3.12), we can also note that $\frac{\partial T}{\partial r}$ will always be negative if $r > \frac{1}{2}$, so the solution to the equation (3.12) will be in $r \in [0, \frac{1}{2}]$.[13] So the solution to the intersection of these two conditions (valid for the cases where the tax evasion boundary is not binding) is well defined, $\{t, r\} \in [\frac{s}{2}, 1] \times [0, \frac{1}{2}]$, a subset of the complete range of possibilities, $\{t, r\} \in [0, 1] \times [0, 1]$, so it is feasible to search for the optimal values looking at the stationary points of the solution range.

In order to find these points, Lund (2002) first solves equation (3.12) for r and defines a solution in the form of the function $g(t)$,

$$r = \frac{1 - t}{2 - t} \equiv g(t) \ , \tag{3.13}$$

and then solves equation (3.11) for r, getting $f(t; p, b, \chi, s)$.

$$r = 1 - \sqrt{\frac{4b(1 - \chi)}{p^2 \chi} \left(t - \frac{s}{2} \right)} \equiv f(t; p, b, \chi, s) \ , \tag{3.14}$$

it is important to note that these functions, $g(t)$ and $f(t; p, b, \chi, s)$ represent points where either $\frac{\partial T}{\partial t}$ or $\frac{\partial T}{\partial r}$ are equal to zero, and therefore divide the possible solution range in areas according to the following rules:

- The values of $\{t, r\}$ that are above (i.e. to the north east) of curve $g(t)$, plotted on the solution range $\{t, r\} \in [\frac{s}{2}, 1] \times [0, \frac{1}{2}]$, are those where $\frac{\partial T}{\partial r} \le 0$. Those who are below (i.e. to the south west), are those where $\frac{\partial T}{\partial r} \ge 0$.
- The values of $\{t, r\}$ that are above (i.e. to the north east) of curve $f(t; p, b, \chi, s)$, plotted on the solution range $\{t, r\} \in [\frac{s}{2}, 1] \times [0, \frac{1}{2}]$, are those where $\frac{\partial T}{\partial t} \le 0$. Those who are below (i.e. to the south west), are those where $\frac{\partial T}{\partial t} \ge 0$.

These results are encouraging, because they imply that there is the possibility that the intersection of $g(t)$ and $f(t; p, b, \chi, s)$ represent a global maximum, as can be seen in figure 3.3.

In this figure[14] we can see how the gradients point up to the stationary point, in this case where $t = 0.42$ and $r = 0.37$, which is going to represent the solution of the problem for this set of parameters. From t and

[13] This is a consequence of the nature of the production function, a different value would be found with a production function that shares the Inada condition but has a different slope: we must remember that the production function in this case is equivalent to Opp's (2012), where the production function $\pi = AI^{\alpha} - I$, has a parameter $\alpha = 0.5$.

[14] It is important to note that the graphs and examples shown in this chapter use –unless explicitly told otherwise– the following parameters: $p = 1$, $b = 0.25$, and $s = 0.3$. The value of parameters p and b are given so that the efficient firm rent will be $\hat{\pi}_F = 1$, whereas the value of the international tax rate, s, is going to be 0.3, in order to keep comparability with the results by Lund (2002). However, the conclusions of this chapter were tested with a wide array of parameters, and these did not change the nature of the results.

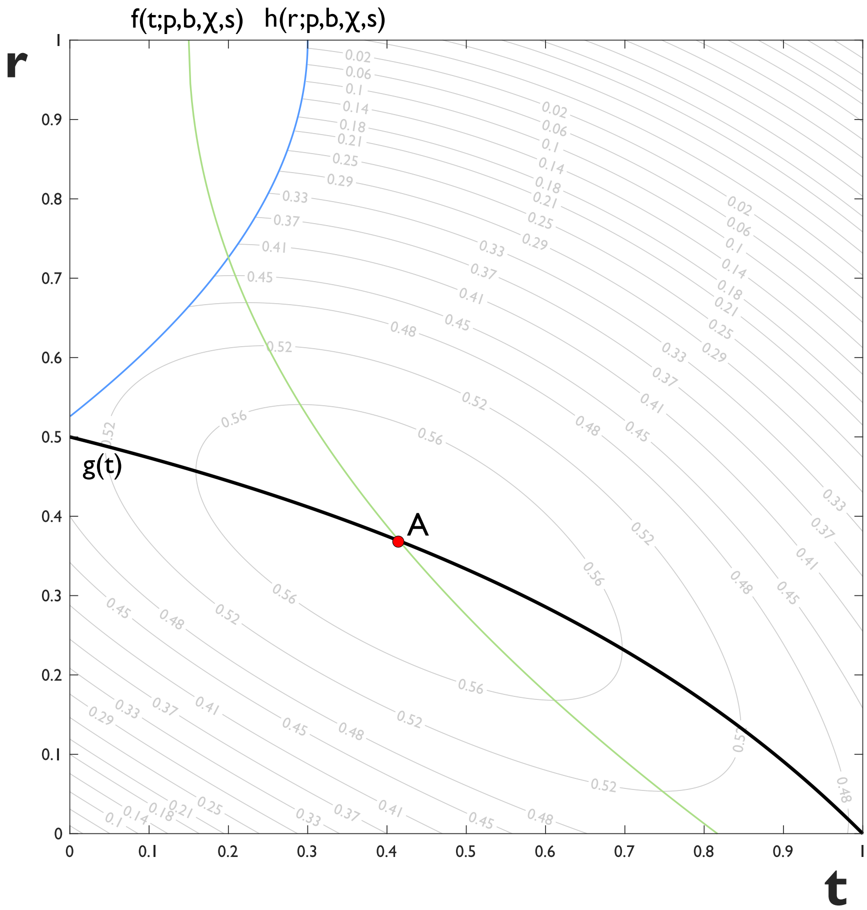


Figure 3.3: The solution range for the tax maximisation problem when $\chi = 0.4$, with $g(t)$ as a black thick line, $f(t;p,b,\chi,s)$ as a thin green line, and $h(r;p,b,\chi,s)$ –the tax evasion boundary– as a blue line. The contour plot represents the varying level of the objective function T (where positive values for T are labelled), which in this case finds its maximum at the stationary point A, where $t = 0.42$ and $r = 0.37$.

r it is possible then to get the best responses q and a, and from those, the tax capture by the government and the profits for the company.

Solving the problem when the tax evasion boundary is binding

We can see on the upper left corner of figure 3.3 the tax evasion boundary, it is located where the production cost is equal to the negative value of the money diverted (as it represents an inflow of money due to low values of t), $bq^2 = -a$. In order to display it on the graph we use the values for the producer's best response in equations (3.8) and (3.9) to replace the values for q and a and then put the boundary in the solution range $\{t, r\} \in [0,1] \times [0,1]$, where it will be represented by the equation

$$t = s - \left(\frac{\chi}{1-\chi}\right) \frac{p(1-r)^2}{2b} \equiv h(r; p, b, \chi, s) \ , \tag{3.15}$$

which is a parabola with its maximum value in $r = 1$ as can be seen from its derivative:

$$\frac{dt}{dr} = \left(\frac{\chi}{1-\chi}\right) \frac{p(1-r)}{b} \ , \tag{3.16}$$

which is positive whenever $r \leq 1$.

As the previous functions, the tax evasion boundary, $h(r; p, b, \chi, s)$, also divides the solution range in two: to the left of it, it is binding, so any stationary point located there will not represent a solution. In figure 3.4 we can see one of such cases.

So, in this case the optimal value is going to be located somewhere over the tax evasion boundary, but we cannot infer more than that from the graph.

At the boundary, what happens is that both the tax collection and the profit from the company cease to depend from the type of tax regime being used, as $bq^2 = -a$, we have that all taxes will depend on a composite value given by the equation,

$$u = t - rt + r \ , \tag{3.17}$$

which behaves like a royalty tax.

Thus, the tax collection for the government will be

$$T = tpq + r(1-t)pq \ = \ (t - rt + r)pq \ = \ upq \ , \tag{3.18}$$

doing the same exercise for the profits of the multinational firms, leave us with

$$\begin{aligned} \Pi = &\ (pq(1-r) - bq^2)(1-t) - \frac{\chi}{1-\chi}(bq^2)^2 + bq^2 t - bq^2 s \\ = &\ -\left(\frac{\chi}{1-\chi} b^2\right) q^4 - (b+s)q^2 + p(1-u)q \ . \end{aligned} \tag{3.19}$$

A fourth-degree polynomial in q which depends linearly on the composite tax, u. So, when the stationary points are inside the area delimited by the boundary constraint, the maximisation problem changes to one

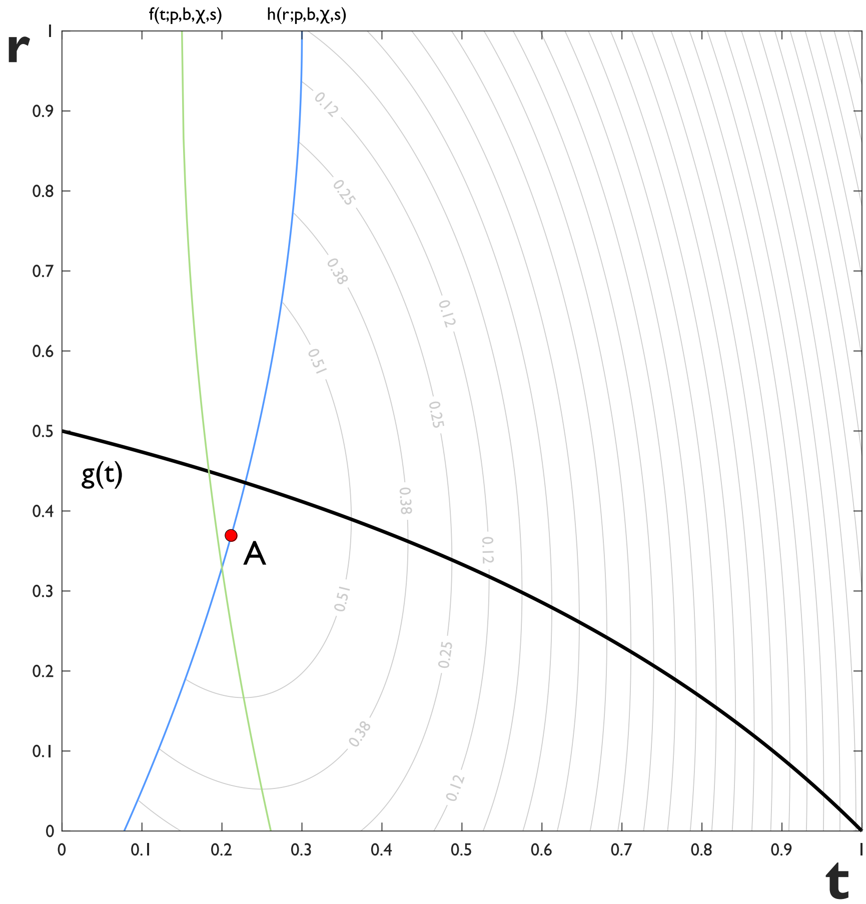


Figure 3.4: The solution range for the tax maximisation problem when $\chi = 0.1$, with $g(t)$ as a black thick line, $f(t;p,b,\chi,s)$ as a thin green line, and $h(r;p,b,\chi,s)$ –the tax evasion boundary– as a blue line. The contour plot represents the varying level of the objective function T (where positive values for T are labelled). In this case the stationary point is to the left of the tax evasion boundary, so one of the maximum values of the function is at a point on the blue line, $h(r;p,b,\chi,s)$, the others are combinations that yield the same value for u. Over the boundary, the maximum value is at point A, where $t = 0.21$ and $r = 0.37$.

where the government sets a combination of taxes equivalent to u on the boundary of production,[15] taking into account the best response by the firm –which sets q with parameter a fixed by the tax evasion boundary, $a = -bq^2$.

As both $t \geq 0$ and $r \geq 0$; when we consider that the composite tax u needs to touch the tax evasion boundary (itself on the same solution range $[0,1] \times [0,1]$) we find that it has a lower bound, so $u \in [u_{min}, 1]$. The value u_{min} is defined by the point where the tax evasion boundary parabola touches the boundary of the solution range and $r \neq 1$ (i.e. not the upper interception of the parabola with the solution range). So that its value is

[15]We will discuss in Section 3.5 which set of combinations for u look more plausible.

$$u_{min} = \begin{cases} 1 - \sqrt{\frac{2bs}{p^2}\frac{1-\chi}{\chi}} & \text{if } \chi > \frac{2bs}{p^2+2bs} \ , \\ 0 & \text{if } \chi = \frac{2bs}{p^2+2bs} \ , \\ s - \frac{p}{2b}\frac{\chi}{1-\chi} & \text{if } \chi < \frac{2bs}{p^2+2bs} \ . \end{cases} \tag{3.20}$$

To get the producer's best response, we look at the first order conditions,

$$\frac{\partial \Pi}{\partial u} = -pq < 0 \ , \tag{3.21}$$

$$\frac{\partial \Pi}{\partial q} = p(1-u) - 2(b+s)q - 4\left(\frac{\chi}{1-\chi}b^2\right)q^3 = 0 \ . \tag{3.22}$$

From equation (3.19) we realise that a best response will not have $q = 0$ and that if $q \to \infty$ then $\Pi \to -\infty$, so we know that one of the zeroes of equation (3.22) is going to be a best response for a given tax u.

Thus, the government will choose, in those cases, a taxation by maximising the value of equation (3.18), replacing the first order conditions from (3.22)

$$\begin{aligned} T &= pq\left(1 - \frac{2(b+s)q + 4\left(\frac{\chi}{1-\chi}b^2\right)q^3}{p}\right) \ , \\ &= -4\left(\frac{\chi}{1-\chi}b^2\right)q^4 - 2(b+s)q^2 + pq \ . \end{aligned} \tag{3.23}$$

And in consequence, the first order conditions for the tax collection in this situation will be

$$\frac{dT}{dq} = -8\left(\frac{\chi}{1-\chi}b^2\right)q^3 - 4(b+s)q + p = 0 \ . \tag{3.24}$$

Solving this third order polynomial, subject to $u \geq u_{min}$ (if not u_{min} should be used in both profit and tax collection equations), would get the appropriate taxation and production decision when the stationary point lies to the left of the tax evasion boundary.

We have already seen one type of solution where the stationary point represents a maximum, and another case where the tax evasion boundary is binding. Now we will see the remaining two kinds of solutions that the stationary point analysis gives us.

The remaining non-binding equilibria with its stationary points

When we characterised the stationary points on the solution range we relied on the functions $g(t)$ and $f(t;p,b,\chi,s)$.[16] However, only $f(t;p,b,\chi,s)$ varies with the parameter χ, its partial derivative being

$$\frac{\partial f}{\partial \chi} = \frac{1}{2}\left(\frac{4b}{p^2\chi}\left(t - \frac{s}{2}\right)\right)^{\frac{3}{2}} (1-\chi)^{\frac{1}{2}} \ , \tag{3.25}$$

which means that $\frac{\partial f}{\partial \chi} \geq 0$ if $0 \leq \chi \leq 1$.

This implies that the function f will move upwards in the solution range $\{t, r\} \in [\frac{s}{2}, 1] \times [0, 1]$ as χ increases, and motivates the next two kind of cases that complement the ones we saw above, and which are mentioned as well in Lund (2002). When χ continues increasing (from 0.4 in figure 3.3 to 0.47 in the following figure 3.5) there is a short interval where we will see two stationary points.

When we look at the rules related to the behaviour of the tax capture T relative to $g(t)$ and $f(t;p,b,\chi,s)$ on page 150, we realise, however, that only one of those points, the one at the north west, represents a maximum value; in this case to the values $t = 0.61$ and $r = 0.28$.

If χ continues increasing there will be a moment when there will be no intersection between $g(t)$ and $f(t;p,b,\chi,s)$. This is what is shown in figure 3.6: if we look at the contour lines on the figure, or refer to the rules for the gradient of T on page 150, we realise that the values of taxation will find its maximum in the corner solution, where $t = 1$ and $r = 0$.

[16] See equations (3.13) and (3.14) on page 150.

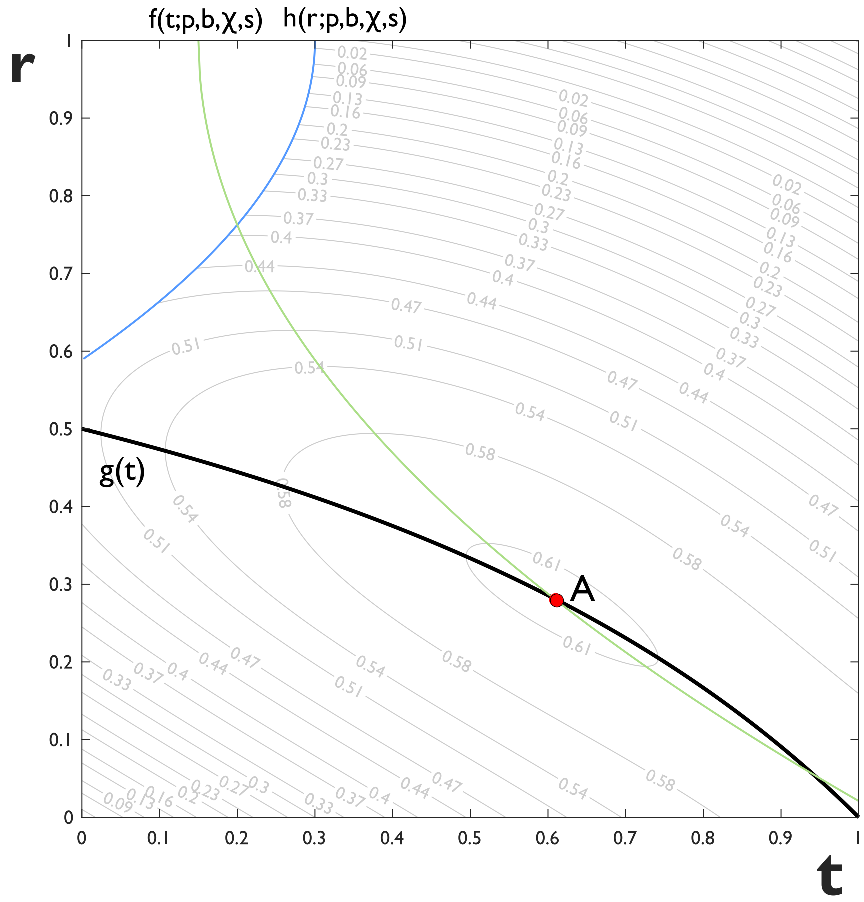


Figure 3.5: The solution range for the tax maximisation problem when $\chi = 0.47$, with $g(t)$ as a black thick line, $f(t; p, b, \chi, s)$ as a thin green line, and $h(r; p, b, \chi, s)$ –the tax evasion boundary– as a blue line. The contour plot represents the varying level of the objective function T (where positive values for T are labelled). In this case there are two stationary points, but only the one located on the north west (point A) represents a global maximum: where $t = 0.61$ and $r = 0.28$.

These cases, plus the two ones seen before, complete the whole set of equilibria that are to be found when we limit the space of possible taxes to $\{t, r\} \in [0, 1] \times [0, 1]$.

Now we will limit the analysis to those cases where there is only one type of tax available, either corporate income tax, t, or royalties, r. We will start with the cases where only t is available below.

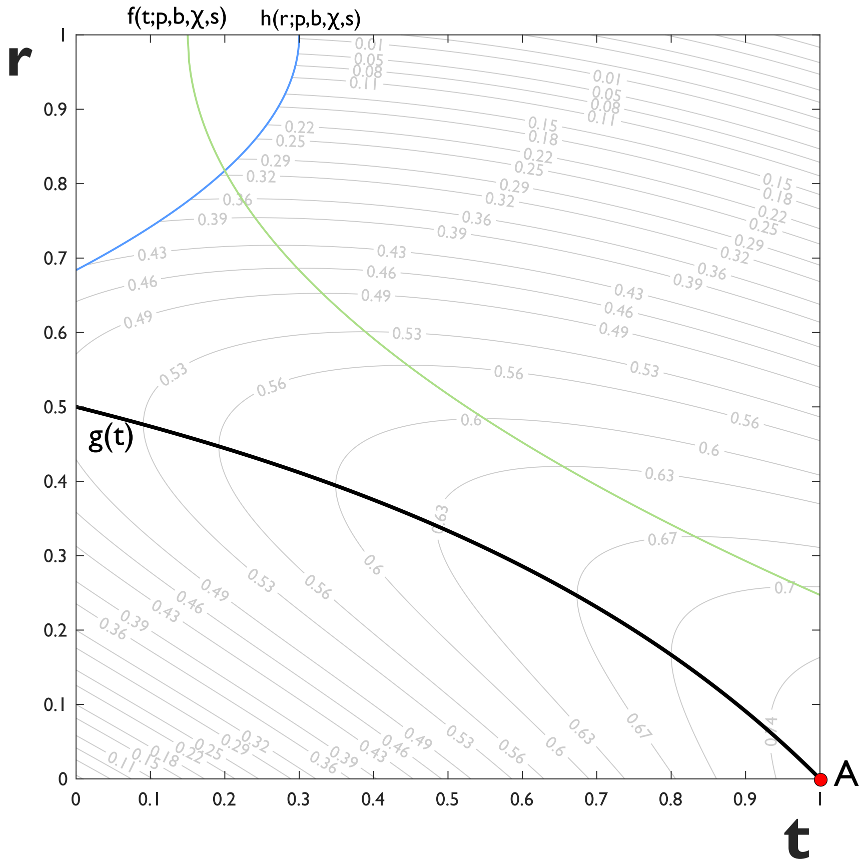


Figure 3.6: The solution range for the tax maximisation problem when $\chi = 0.6$, with $g(t)$ as a black thick line, $f(t;p,b,\chi,s)$ as a thin green line, and $h(r;p,b,\chi,s)$ –the tax evasion boundary– as a blue line. The contour plot represents the varying level of the objective function T (where positive values for T are labelled). In this case there is no stationary point, and the gradients of the objective function take the equilibrium to the case where $t = 1$ and $r = 0$, marked with a red dot.

Solutions where only one tax is available: Corporate Income Tax

At the beginning of Section 3.3, we will start reviewing a scenario where just royalties or corporate income taxes are available in exclusion to the other (see figure 3.7 on page 163).

The solution to such a problem is going to be simpler than before: *when the tax evasion boundary is not binding* it is just a matter of using the best response from producers, the equations (3.8) and (3.9).

For the case where one uses just corporate income tax, t, the best responses will be

$$q_{corp} = \frac{p}{2b} \,, \tag{3.26}$$

a constant,[17] and

$$a_{corp} = \frac{t-s}{2}\left(\frac{1-\chi}{\chi}\right) \ . \tag{3.27}$$

These best responses are going to be valid whenever the tax evasion boundary, $a \geq -bq^2$, is not binding, replacing the values of equations (3.26) and (3.27) in the boundary we get the restriction

$$t \geq s - \frac{p^2}{2b^2}\left(\frac{\chi}{1-\chi}\right) \ . \tag{3.28}$$

We should note that the right hand side of this restriction monotonically increases as χ decreases, this fact is going to be useful later when finding the point where this restriction binds.

The function that the government needs to maximise is taken from equation (3.3), the standard definition of tax capture, but this time with $r = 0$ and with the values of equations (3.26) and (3.27) replacing q and a and the tax boundary restriction from (3.28), so we get:

$$\begin{aligned} T_{corp} &= \max_t -\frac{1}{2}\left(\frac{1-\chi}{\chi}\right)t^2 + \left(\frac{p^2}{4b} + \frac{s}{2}\left(\frac{1-\chi}{\chi}\right)\right)t \\ s.t.& \\ &t \geq s - \frac{p^2}{2b^2}\left(\frac{\chi}{1-\chi}\right) \ , \\ &0 \geq t \geq 1 \ . \end{aligned} \tag{3.29}$$

The first order conditions for this problem, are

$$\frac{dT}{dt} = -t\left(\frac{1-\chi}{\chi}\right) + \left(\frac{p^2}{4b} + \frac{s}{2}\left(\frac{1-\chi}{\chi}\right)\right) = 0 \ , \tag{3.30}$$

which gives us a value for t,

$$t = \frac{p^2}{4b}\left(\frac{\chi}{1-\chi}\right) + \frac{s}{2} \ , \tag{3.31}$$

that is going to be valid as long as $0 \leq t \leq 1$, and while equation (3.28) is not binding.

As t in equation (3.31) is increasing in χ ($t \to \infty$ as $\chi \to 1$), there is going to be a maximum value of χ for which $t = 1$; we will call this χ^{max}_{corp}. So, replacing $t = 1$ in equation (3.31) will give us

[17] It is logical that q_{corp} is not affected by t and it is a constant, as the corporate income tax is defined as a non-distortive tax in this case.

$$\chi_{corp}^{max} = \frac{2b(2-s)}{p^2 + 2b(2-s)} \in [0,1] \ , \tag{3.32}$$

the value of $\chi_{corp}^{max} \in [0,1]$ as $0 \leq s \leq 1$, $b \geq 0$, and $p > 0$, the usual conditions.

On the other hand, as t in equation (3.31) decreases when χ decreases, there is going to be a lower value for χ, under which the tax evasion boundary starts binding,[18] let's call it χ_{corp}^{min}, and we obtain it from replacing t from equation (3.31) in the restriction of equation (3.28). Replacing the values we get,

$$\chi_{corp}^{min} = \frac{2bs}{3p^2 + 2bs} \ . \tag{3.33}$$

Simple examination of equations (3.32) and (3.33), show us that if $b > 0$ (i.e. there are production costs), $p > 0$, and $0 \leq s \leq 1$, we will always have that:

$$\chi_{corp}^{min} < \chi_{corp}^{max} \ , \tag{3.34}$$

implying that there is going to be an interval of values for $\chi \in [\chi_{corp}^{min}, \chi_{corp}^{max}]$ where the tax maximisation problem is not going to be bounded by the tax evasion boundary and where t is going to be less than $t = 1$, the corner solution.

When the parameter χ is such that $\chi < \chi_{corp}^{min}$, the tax evasion boundary hits, and the solution becomes equivalent to that presented above for the general bounded condition (see page 151), the only difference is that u becomes t, so equation (3.18) becomes, in this case

$$T = tpq \ , \tag{3.35}$$

and equation (3.19), becomes

$$\Pi = -\left(\frac{\chi}{1-\chi} b^2\right) q^4 - (b+s)q^2 + p(1-t)q \ , \tag{3.36}$$

from which we get the first order conditions for q,

$$\frac{\partial \Pi}{\partial q} = p(1-t) - 2(b+s)q - 4\left(\frac{\chi}{1-\chi} b^2\right) q^3 = 0 \ . \tag{3.37}$$

[18] Remember the right hand side of equation (3.28).

From this equation –a third order polynomial, so it has at least one real solution– we can get $q^*_{corp}(t)$, the producer's best response when bounded, and we use it to maximise the equation (3.35):

$$\begin{aligned} T_{corp} &= \max_t pq^*_{corp}(t)t \\ s.t. & \\ 0 \geq t &\geq 1 \ . \end{aligned} \tag{3.38}$$

A maximisation problem that is identical to the one analysed before in the border case with r and t and where the composite tax, $u = t - rt + r$, was used.

Solutions where only one tax is available: Royalties

When we consider *only the use of royalty taxes*, the problem does not change substantially; as before, we start by defining the best response from producers[19] when the tax evasion boundary is not binding,

$$q_{roy} = \frac{p(1-r)}{2b} \ , \tag{3.39}$$

and

$$a_{roy} = -\frac{s}{2}\left(\frac{1-\chi}{\chi}\right) \ . \tag{3.40}$$

And we have the same criteria as with the corporate income tax to limit the validity of these best responses, which is whenever the tax evasion boundary, $bq^2 \geq -a$, is binding. So, if we replace the values of equations (3.39) and (3.40) in the boundary we get the restriction

$$r \leq 1 - \sqrt{\frac{2bs}{p^2}} \cdot \sqrt{\frac{1-\chi}{\chi}} \ . \tag{3.41}$$

As we repeat the criteria used for the maximisation in the case limited to just corporate income taxes (equation (3.29)), when we use royalties we get:

[19] The same equations (3.8) and (3.9), but now with $t = 0$.

$$
\begin{aligned}
T_{roy} &= \max_{r} \frac{p^2}{2b} r(1-r) \\
s.t. & \\
& r \leq 1 - \sqrt{\frac{2bs}{p^2}} \cdot \sqrt{\frac{1-\chi}{\chi}} \ , \\
& 0 \geq r \geq 1 \ .
\end{aligned}
\tag{3.42}
$$

When the restriction is not binding this problem has a trivial solution of $r = 0.5$, which –again– is going to be valid as long as equation (3.41) is not binding.

We can see that in this case r remain constant until the tax evasion boundary hits, but the right hand side of equation (3.41) is decreasing in value as χ decreases (goes from $1 \to -\infty$ as χ goes from $1 \to 0$), which means that there is going to be a lower bound for χ where the tax evasion boundary is going to be binding. Using the same notation as above, we call it χ_{roy}^{min}, and obtain it from replacing $r = 0.5$ in equation (3.41), so that χ_{roy}^{min} can be expressed as,

$$
\chi_{roy}^{min} = \frac{8bs}{3p^2 + 8bs} \ . \tag{3.43}
$$

When we compare χ_{roy}^{min} with χ_{corp}^{min}, from equation (3.33), we get that,

$$
\chi_{corp}^{min} < \chi_{roy}^{min} \ , \tag{3.44}
$$

if $\{b, s, p\} > 0$. This implies that in the case of pure royalty, the tax evasion boundary will limit evasion for a broader range of the parameter χ.

Now, as before, when the parameter χ is such that $\chi < \chi_{roy}^{min}$ the tax evasion boundary will hit, and the solution becomes exactly the same as it was the case with the case of only corporate income tax –equations (3.35), (3.36), (3.37), and (3.38)– just changing the existing t for r. The only difference is that in the pure royalty case, this maximisation problem will be used over a much broader range of $\chi \in [0, \chi_{roy}^{min}]$.

3.2.2 The technology parameter ρ and the boundary between private ownership and nationalisation

When we solve this production and taxation model given the initial parameters we will arrive to a solution in $\{t, r\} \in [0,1] \times [0,1]$, that will lead to a production function and then to the values of the firm's profit and the government's tax capture.

In this chapter, we are interested in how all these variables depend on the parameter χ, which represents the institutional capacity of a country. We will thus arrive to the tuple $\{q^*(\chi), a^*(\chi), t^*(\chi), r^*(\chi)\}$ which will determine the government's tax capture $T^*(\chi)$.

Now, we (and the government) need to compare the tax capture with the income at autarky, that is, the income that the government would get in absence of private investment, characterised by the parameter ρ, as defined in equation (3.1) on page 145. So that there will be a threshold value ρ^*,

$$\rho^* = \rho^*(\chi) = \frac{T^*(\chi)}{\hat{\pi}_F}, \tag{3.45}$$

to the effect that if a government has a technological capacity larger than ρ^* for a given parameter χ, private investment will no longer be viable, as in that case the state will receive more funds through the establishment of a National Resources Company.

This is what we are going to do in the next sections; after finding the maximal tax capture, $T^*(\chi)$, for a given level of fiscal capacity χ, we will see how this interacts with the technology available to the host governments, represented by the parameter ρ, and what are the implications for the stability of foreign investments in any given jurisdiction.

Notation-wise, we will rely on the value of $\rho^*(\chi)$ to separate areas that are stable to private investment to those who are not, and will call this *The Investment Frontier*.

3.3 The Investment Frontier

As seen in the previous section, for a given level of technological and fiscal capacity (a point $\{\rho_0, \chi_0\} \in [0,1] \times [0,1]$) there will be an optimal level of taxation, fixed through royalties or corporate income taxes (or a combination of both). If the tax income of a mine/field is larger than the fiscal revenue from its operation by the government (determined by the alternative profitability characterised by the parameter ρ) we will say that private ownership is stable (i.e. there is no pressure for a change in the ownership regime). Otherwise, we will say that state operation is unstable, as a government would receive more income from the inefficient exploration of these resources; and therefore, would have incentives to expropriate. Another way to interpret this frontier, is to look at it as a graph where the dependant variable is on the x-axis of the function $\rho^*(\chi) = \frac{T^*(\chi)}{\hat{\pi}_F}$, with T^* being the optimal government tax take for a given level of tax capacity χ. Without loss of generality, for simplicity we can assume that the exogenous $\hat{\pi}_F$ is constant and $\hat{\pi}_F = 1$;[20] we will do this from this section onwards, and so, $T^* = \rho^*$.

3.3.1 The investment frontier with a single tax

We can first consider the behaviour of the investment frontier when only corporate income taxes, or royalties are being used.

For the pure corporate income tax, the optimisation problem would be the one described from page 157 onwards, with equation (3.29) being maximised unless the tax evasion boundary is reached: this happens when $\chi < \chi_{corp}^{min}$; so, when χ is smaller than that, the bounded problem is the one equivalent to the general case shown from page 151 onwards.

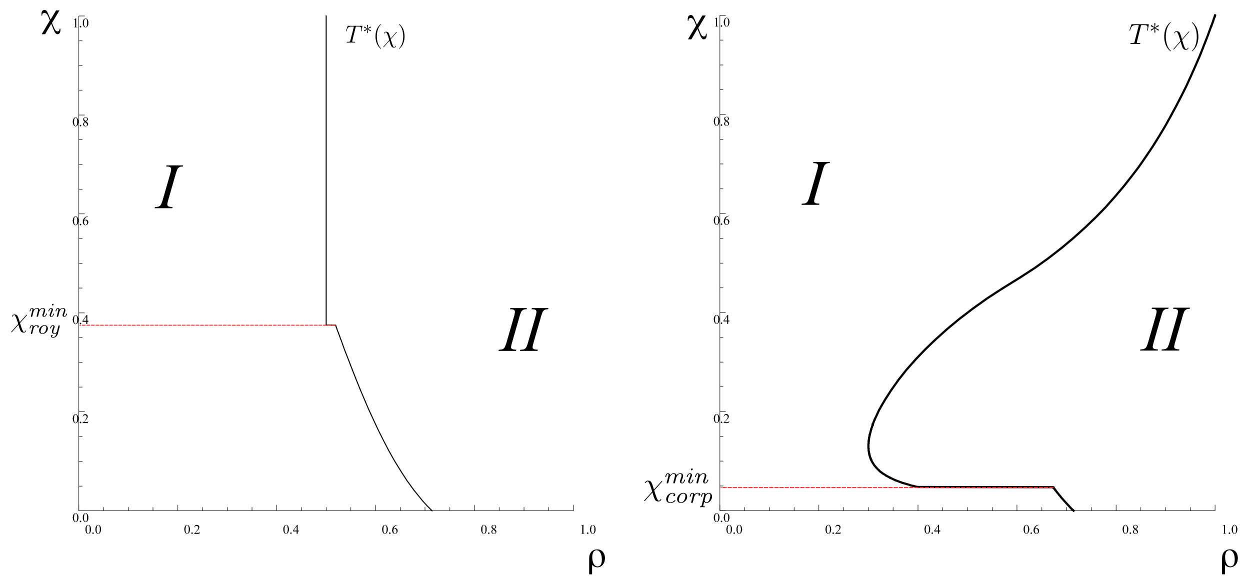
On the other hand, when pure royalties are being employed, the optimisation problem is the one described from page 159 onwards, with the optimal value being $r = 0.5$ until the tax evasion boundary hits at χ_{roy}^{min}. The conditions for the bounded problem being the same as the one above.

So we can plot $\rho^*(\chi)$, varying the institutional capacity χ which can be observed in figures 3.7a and 3.7b: the total tax take for each level of tax technology, χ, is compared against the corresponding income that the state ownership of the natural resources would yield (this, given by parameter ρ).

When a government relies only on royalties (figure 3.7a) private property of the mine/field is going to be more stable for a given level of technological capacity if the institutional capacity is low. We will have the opposite result if relying exclusively on corporate income tax (figure 3.7b), in which case a higher level of institutional capacity is going to effectively decrease tax evasion, augmenting the area of private stability. If the level of χ is sufficiently high, the transition from a royalty tax regime into a corporate income tax will shift the investment frontier rightwards for a given level of χ which would imply that private ownership becomes more feasible for technologically advanced economies (higher value of ρ).

Finally, we can observe that the increased area of stability for the royalty tax regime stems from the fact that the tax evasion boundary hits at higher level of χ: the expression $\chi_{corp}^{min} < \chi_{roy}^{min}$ from equation 3.44.

[20] This is also a consequence of having chosen the parameters $b = 0.25$, and $p = 1$, so that the optimisation without taxes of the profit $\Pi = pq^2 - bq$, (varying q) will lead to an optimal value of $\hat{\pi}_F = 1$.



(a) Royalty (b) Corporate Income Tax

Figure 3.7: Investment frontier between private ownership (area I) and state ownership (area II) according to the host government's state capacity, using *either* Royalty or Corporate Income Tax. In both graphs we can see when the tax evasion boundary starts limiting the parameter a: at χ_{roy}^{min} and χ_{corp}^{min}, with $\chi_{roy}^{min} > \chi_{corp}^{min}$.

3.3.2 Combining taxation regimes

When solving the broader, general solution to the model, with governments being able to choose levels of both t and r as it was presented previously in subsection 3.2.1, we have that the critical value of χ, where the tax evasion boundary starts hitting, $\chi_{general}^{min}$, is at midpoint between χ_{corp}^{min} and χ_{roy}^{min}; while $\chi_{general}^{max}$, the point where $t = 1$ is clearly seen due to the variation in $\frac{d^2T^*(\chi)}{d\chi^2}$ in figure 3.8.

The variation in the investment frontier is due to the sum of the available tax capture using just corporate income tax, plus the tax capture of using just royalties, plus the added revenue that stems from using a combination of both. This can be clearly seen in figure 3.9, where figures 3.7a, 3.7b, and 3.8 are superimposed, giving us a clearer perspective of where the different tax regimes have a competitive advantage.

So, in figure 3.9 we can see the relationship between the different taxation regimes and the areas of stability for private ownership. When the parameter χ is large, it is more convenient to use a corporate income tax,[21] whereas when the institutional capacity is low, it is much convenient to use a royalty over sales.[22] Finally,

[21]The gains from going from a pure royalty tax regime to a pure corporate income tax would be given by the addition of area III in the graph.

[22]The gains from going from a pure corporate income tax regime to royalties would be given by the addition of area IV in the graph.

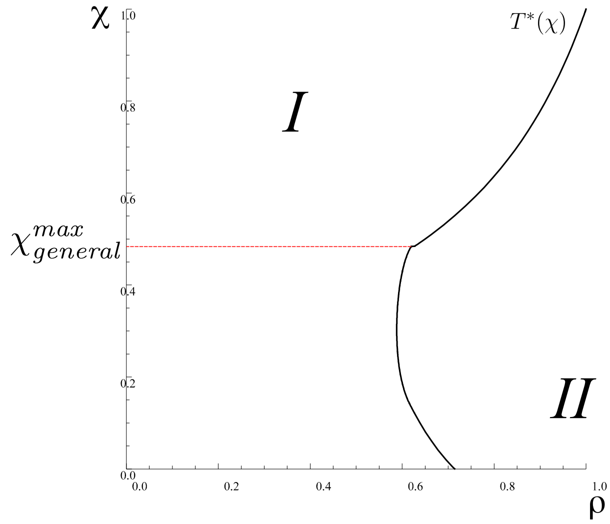


Figure 3.8: Investment frontier between private ownership (area I) and state ownership (area II) according to the host government's state capacity, using a combination of Royalties and Corporate Income Tax. $\chi^{max}_{general}$, the minimum value of χ for which $r = 0$ and $t = 1$ is shown in the graph.

when both taxes are used jointly, an additional area of stability (area V in figure 3.9) is generated.

It is reasonable to assume that the implementation of a combined tax system (royalty plus corporate income tax) will have higher costs than a single-tax regime. For this reason, it could be justifiable the use of only corporate income tax in those cases where the parameter χ is large, as well as to only rely on royalties when the same parameter χ is unusually low: the advantages of changing to a mixed tax regime only start becoming evident for intermediate values of χ.

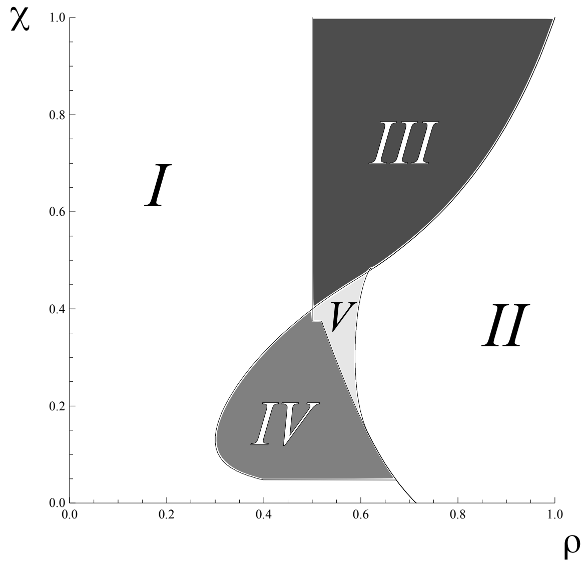


Figure 3.9: Variation in the investment frontier according to state capacity: (Areas I+III) are areas where private ownership is stable using only corporate income taxes. (Areas I+IV) are areas where private ownership is stable with just royalties. And finally, (I+III+IV+V) is the area where private ownership is stable with a combination of both tax regimes.

3.4 Incentives for the Government to Invest in Tax or General Technologies: A Royalty Trap

This investment frontier that we have just seen above shows us how the global tax take for the government is going to change as the tax parameter χ varies. We can thus see that there is going to be a local minimum, represented by a threshold χ_0 which is the point where $\frac{\partial T^*}{\partial \chi} = 0$, that is, where the optimal global tax take T_0^* is not going to vary under small variations of the tax capacity of the government.

Under the threshold χ_0, if the mine/oil field is stably privately-owned (i.e. to the left of the investment frontier and in the hatched area under χ_0^{total} of the ρ vs χ diagram in figure 3.10) there are going to be no incentives for the government to invest in improving its tax capacity, as any change in χ is going to decrease the total tax take.

The double pointing arrow in figure 3.10 shows that –when the company is privately-owned– below the threshold χ_0^{total} the government will be indifferent on whether to move alongside the ρ dimension (there will be no additional tax capture related to it); and that it will have no incentives to increase its tax capacity.

Over the threshold χ_0^{total}, $\frac{\partial T^*}{\partial \chi} > 0$, so there will be an increase in the tax capture for the privately-owned firm if χ increases.

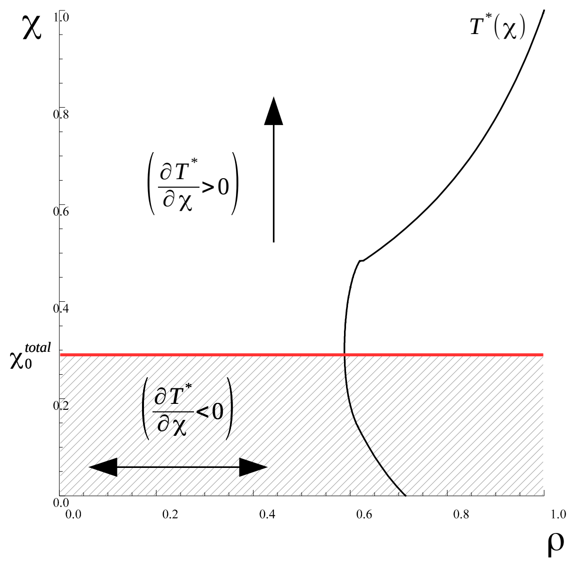


Figure 3.10: Incentives to modify the tax capacity of a country, according to the existing value of χ, considering a mixed tax system (royalties and corporate income tax)

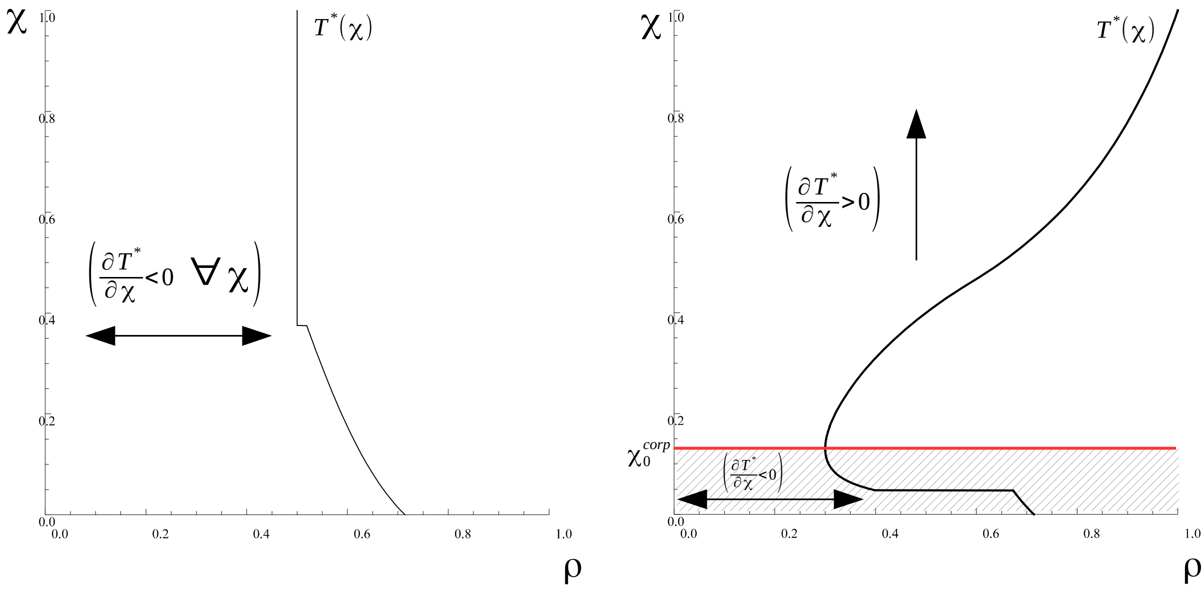
For this reason, the incentives that a government has to change its tax capacity are not static; they will vary depending on the tax regime that is being implemented. As can be seen in figure 3.11a the parameter $\frac{\partial T^*}{\partial \chi}$ will have a value equal or inferior to zero when the only tax regime available is one based on royalties, this is, when the natural resources are privately-owned and in a stable condition (a low value of ρ) a government would have no incentives to invest in improving its tax capacity if it only relies on royalties, and, even worse, governments will solely rely on royalties if they are already in a weakened institutional condition (thus, compounding the problem).

A pure corporate income tax regime (see figure 3.11b), on the contrary, will have a double effect. On one hand the threshold parameter χ_0^{corp} is going to have a much lower value, implying that a government will have more incentives to invest in raising its tax capacity in a broader range of initial conditions. However, the slope $\frac{\partial T^*}{\partial \chi}$ is going to be much more negative under the threshold value, implying that the incentive to improve the tax capacity is going to be less appealing if the initial conditions have a very low χ value.[23]

We need to bear in mind that these results will only be applicable if the initial conditions of the state –$\{\rho_0, \chi_0\}$– are to the left of the investment frontier, and the resources are privately-owned.

Moreover, when the government, aside from having a very low value for χ_0 (lower than χ_{corp}^{min}), has an initial

[23]To this we must add what we already saw in the previous section; that if χ is low on a pure corporate income tax situation there will be more –costly– incentives to expropriate.



(a) Only Royalty

(b) Only Corporate Income Tax

Figure 3.11: Incentives to modify the tax capacity of a country, according to the existing value of χ, considering either pure royalties or a pure corporate income tax

value of ρ_0 that is sufficiently low (very much to the left of the investment frontier); what is going to happen is that the government is going to be agnostic with respect to the taxation regime.[24,25] And again, in those cases only a massive jump of χ would improve the conditions of the government; so that it will be other, exogenous factors, the ones that will contribute to a greater extent in the build-up of state capacity under such circumstances, as we will see in subsection 3.4.1 on page 168.

What does this all mean? Considerations for policy making

The lack of monotonicity of $\frac{\partial T^*}{\partial \chi}$ –i.e. that the shape of the investment frontier implied the existence of *Royalty Traps* or thresholds– has consequences for the prescriptions that can be made in order to improve the institutions in less developed nations.

On the one hand, the importance that a country has a bad **starting point** cannot be understated: it puts a focus on the orderly processes of decolonisation and transfer of property to new sovereign entities; as well

[24] And this might further explain why there is a lack of investment in the build-up of fiscal capacity in some oil-rich countries, for example.

[25] This agnosticism comes from the fact that the tax evasion boundary is binding in any sort of tax regime, and so the tax capture, and the dynamics of it, are identical.

as to nationalisation processes from foreign-owned companies.[26]

Additionally, governments should become aware of their own limitations and realise that if the starting point is deficient, a more sequential approach to privatisations or block offerings (in the case of finding new oil fields) would be advisable.

Moreover, how **deep** a country is into the private-stable zone (i.e. how large is the distance between its ρ value to the investment frontier at their current level of tax capacity χ) will affect how technology transfers work for a country. When the level of ρ is too low, development in the form of pure technology in the Natural Resources extraction is going to be irrelevant to the welfare of the population as it is not going to affect the tax capture of the state. This would give an alternative explanation to the phenomenon of governments being paid in infrastructure (as features in the case of Chinese investment in Africa by Song and Wagner, 2013), where both the possibility of slacking (à la Hart and Moore, 2008) and of retribution play a larger role than the improvement of native technology and tax capacity.

3.4.1 A proposed evolution of state capacity for less developed economies

The existence of *Royalty Traps* might allow for the presence of repeated privatisation and nationalisation cycles as the state capacity evolves. In figure 3.12 we can see a proposed evolution of the state capacity[27] (both in technology and in tax collection: of which an applied interpretation can be seen in section 3.7).

This figure takes into account the government's incentives as shown in the previous pages.

To illustrate this, we can assume that a country starts with a fairly low state capacity, **point 1** of figure 3.12. Under these conditions, as $[\rho_1, \chi_1]$ is below the critical threshold χ_0^{total}, the state will have no incentives to *learn* how to improve its tax capacity, and so its state capacity will move –more or less randomly– through the ρ axis.

If, for endogenous or exogenous factors the parameter ρ reaches the investment frontier at point $N^{(1)}$, pressure for nationalisation will mount, until it is finally achieved.

If that happens, the state will suddenly start having an interest in improving its revenue by increasing in extractive technology (augmenting ρ): that is why the arrow that goes from $N^{(1)}$ to **point 2** in figure 3.12 is unidirectional.

[26]This *decolonisation* idea can also apply to the transfer of sovereignty rights to subnational entities, which can be less technologically and fiscally capable than central governments, O'Callaghan (2010) mentions Indonesia as one of those examples where decentralisation is counterproductive.

[27]In this figure we combine the general case of the investment frontier shown in figure 3.8 on page 164 with the incentives to modify the tax capacity that are illustrated in figure 3.10 on page 166.

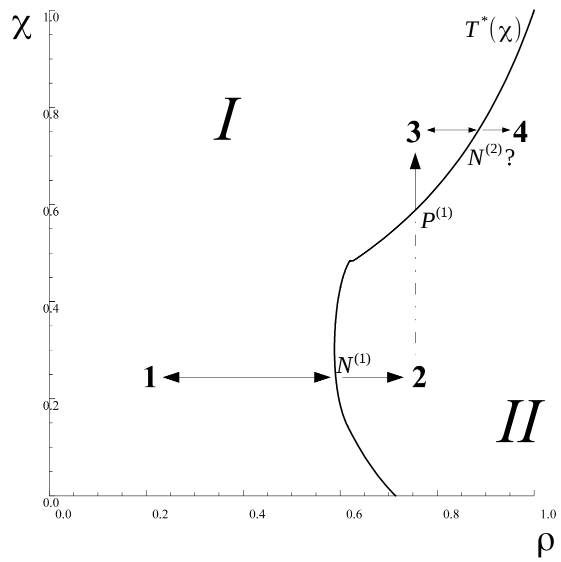


Figure 3.12: Schematic view of the evolution of state technological prowess (ρ) and fiscal capacity (χ) in a country that starts with a fiscal capacity as un point 1, where **I** represents the area where private ownership of assets is stable, and **II**, the area where state ownership of the assets is preferred.

After some time in **point 2**, spillover effects of native technology might increase the institutional capacity. A government would be agnostic initially to variations in the parameter χ, but if this changes up to the point where it is sufficiently close to the area of privatisation it might result in an opportunity to attract investment.

Therefore, when point $P^{(1)}$ is reached, institutions are sufficiently robust to privatise *again*; at this point, as χ is over the threshold χ_0^{total} the government finally *has* incentives to increase its tax capacity in order to improve its tax take; going then from point $P^{(1)}$ to **point 3** (again, a unidirectional arrow).

From **point 3** changes in ρ can happen again, albeit with more difficulty (these are technological improvements at the very margin), and a new cycle of nationalisation, at point $N^{(2)}$ might begin anew.

3.5 How do Tax Rates Evolve?

Up until now we have analysed the total tax take for any given set $\{\rho_0, \chi_0\}$. Now we will explore what happens to the tax rates themselves: the results from solving the model in Section 3.2, and the ones that end up generating the investment frontier seen previously. When royalties and corporate income tax are used jointly then we will have a tax regime that will vary according the parameter χ, as shown in figure 3.13.

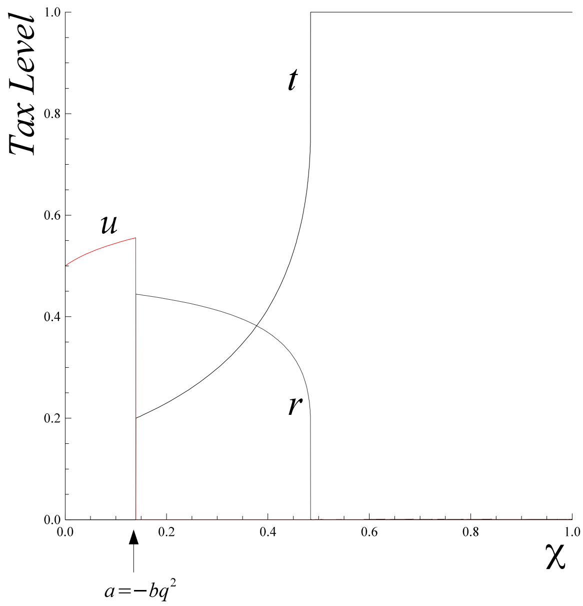


Figure 3.13: Change in different taxes $-r$, t and the composite $u-$ as the parameter χ varies, note the discontinuity when the transferred amount a equals $-bq^2$, the tax evasion boundary.

There, we can observe three different taxation regimes for different values of χ, which will follow, basically, the different equilibria shown in subsection 3.2.1 on page 148. When the institutional capacity is high we see the corner solution already shown in figure 3.6 on page 156, where $t = 1$ and $r = 0$;[28] then there is a middle range where t decreases as χ decreases and royalties increase as a response of higher evasion capacity by the companies.[29] Finally, when the capacity of the state is too low the limit to what a company can evade is reached (the tax evasion boundary) and then, as we saw before, from the tax authority perspective, the tax can be expressed as the composite in equation (3.46):[30]

$$u = t - rt + r \ , \tag{3.46}$$

Meaning that there is a family of taxes r and t that will yield the same amount for the government and elicit the same response from the producer.

Therefore, this composite tax needs to be then reconstituted into t and r so that it is applied to the investing firm. Of the possible combinations of t and r we are interested in those that show a smooth transition

[28] In this case production continues because it is still feasible for the producer to evade taxes: The government sets $t = 1$ with the knowledge that some tax from the profits will be evaded.

[29] See equation (3.25) on page 155.

[30] Taken from equation (3.17) on page 153.

between the two sides of the transfer limit. For this reason, two possible combinations of this reconstitution can be seen in figures 3.14 and 3.15.

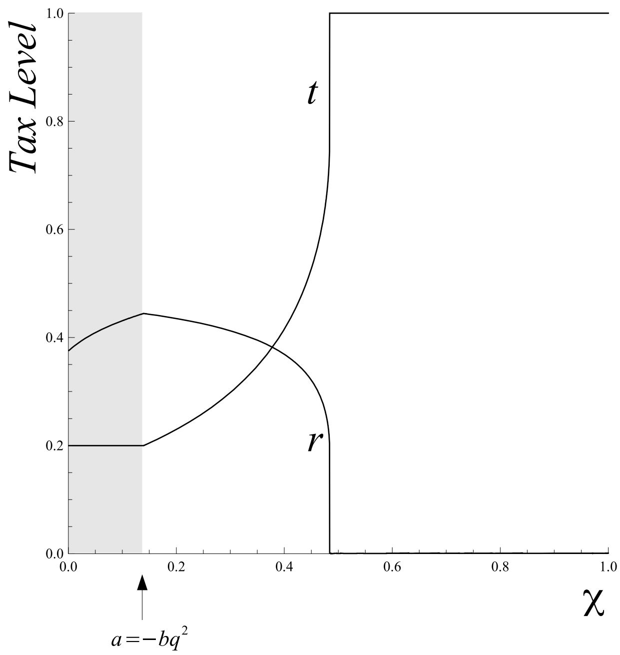


Figure 3.14: Change in taxes r and t as the parameter χ varies and corporate income tax, t, is kept constant for the corner solution.

In figure 3.14 we can see a shaded area where the composite tax u is applicable. In this first case t is left constant for those values where the income being shifted is constant (to the left of the $a = bq^2$ threshold). Figure 3.15 makes t decrease as if there was no limit to income shifting.[31]

If we assume, as in subsection 3.4.1 on page 168, that parameters ρ and χ evolve with time, it would be then more efficient to use the version shown in figure 3.14, for the sole reason that it is more cumbersome to change the corporate income tax than the royalty for each individual project.[32,33]

It is interesting to note that in both cases (figures 3.14 and 3.15) a further decrease in the parameter χ to the left of the tax evasion boundary will make r decrease, as it is the sole tax instrument remaining. However, variation here will be low compared with the gradient of $\frac{\partial r}{\partial \chi}$ when χ increases.

[31]We must remember that the initial model did not require that there was any limit to the transfer of costs. But we introduced it to acknowledge both that there is institutional capacity at the home jurisdiction and that we could not be able to engage in cost transferring that is verifiable, that is, that would exceed the verifiable production revenues.

[32]We should remember that the tax evasion boundary is driven by the expression $a = -bq^2$, which means that is going to vary with each project, as their unique characteristics are given by the parameter b.

[33]Sunnevåg (2000), for example, discusses the reasons behind keeping corporate income tax constant throughout the industry.

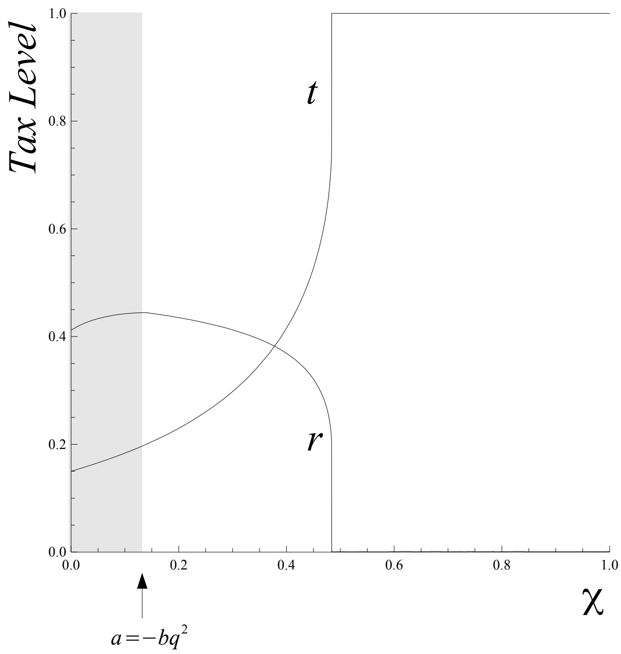


Figure 3.15: Change in taxes r and t as the parameter χ varies and corporate income tax, t, decreases as in the case shown by Lund (2002).

3.6 Extensions to Productivity and Costs

Up until this point, the production function and its associated parameters have been completely deterministic, we will now focus on the effects of introducing some variation in the characteristics of production (i.e. the heterogeneity of mines or oil fields) and on the consequences of introducing exploration costs that precede the operations.

Heterogenous cost of production b

The cost of production parameter, b, as expressed in equation (3.2), can be considered as a proxy for the productivity of a specific mine or oil field. A low value for b implies lower costs or a larger potential for extraction, and thus, a larger optimal production quantity q; as a matter of fact, the parameter $b \in [0, \infty)$ can represent any possible level of production.

In figure 3.16 we can see what happens to the investment frontier when the value of this parameter decreases. The figure shows that when χ is large the total tax capture $\frac{dT}{db} \leq 0$. However, when the value of χ is lower, $\frac{dT}{db} \geq 0$.

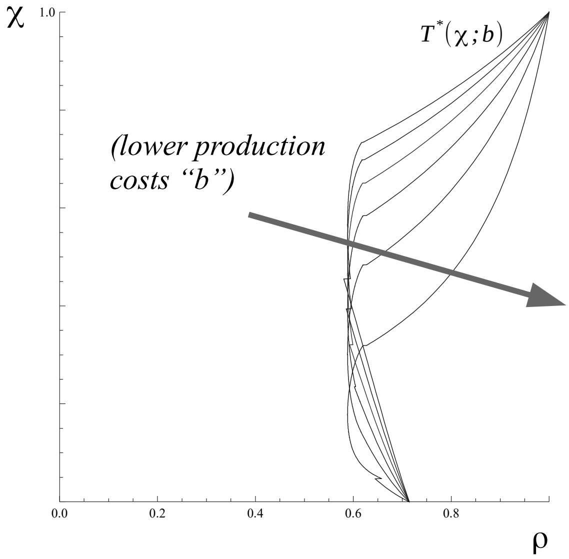


Figure 3.16: Shift of the investment frontier when the production cost, b, decreases.

The intuitive explanation provided by Lund (2002) is that lower costs of production (or a larger size of the operations) imply a higher level of rents, and therefore that there is more to lose from distorting production decisions. Therefore, the less distortive taxes should fare better in this scenario. We must remember that when χ is lower, royalties (which are distortive) become more relevant, and so we should expect larger tax gains from lowering costs of production in this case. However, when the parameter χ is extremely low, the equation,[34]

$$a \geq -bq^2 \ , \tag{3.47}$$

becomes binding, meaning that the constraint on production is not going to be given by the cost parameter b, as the corporate income shifting strategy will render production costs irrelevant. In that case, a lower cost of production will decrease the amount, a, of profits that can be transferred, and as such production will suffer and the overall taxes collected from royalties are going to decrease.

Throughout this chapter, the model considers the situation of a single mine or oil field, however, parameter b will vary when there are several mines or oil fields with different cost structure or size, in this situation we might see an overlap of different areas of taxation/ownership for a given level $\{\chi_0, \rho_0\}$. So that one of two

[34]Taken from equation (3.5) on page 147.

possible different equilibria might emerge: either there is a sequential expropriation of the mines as ρ and χ evolve, or a single unified structure arises that linearly combines both incomes.[35] In the first case, when χ is low, expropriation will start with the largest operations whereas if χ is high it will start with the smallest, less profitable, operations, from which less rent can be obtained.

Fixed exploration costs before time t_0

Let us consider now the case when there are non-retrievable exploration costs $-w_0-$ incurred at the same time as the host government sets the tax regime. Additionally, as we have assumed previously in this chapter, we consider that only corporate income taxes and royalties are available, and so we will have a tax capture equivalent to

$$T = t(pq - bq^2 - a - w_0) + r(1-t)pq \ . \tag{3.48}$$

That is, assuming that the cost w_0 can be fully tax deductible. If this were the case the profits for the firm will satisfy

$$\Pi = (pq - bq^2 - w_0)(1-t) - r(1-t)pq - \frac{\chi}{(1-\chi)}a^2 + a(t-s), \tag{3.49}$$

together with the condition that these profits need to be greater than zero for the firm to make the decision to sink the investment in the first place. The solution would be equivalent to what has been presented before but with this additional restriction.

In figure 3.17 we can see how profits of the investing firm vary with parameter χ in the baseline case (where $w_0 = 0$): these profits decrease as the government improves its tax capacity.

All else being equal, this implies that a fixed cost w_0 will distort less the previous taxes t and r in those cases where χ is low. Thus, when w_0 is lower than the profit generated at a given level of χ then there will be no change in the production function or in the tax regime, as there will be enough rents to pay for the investment and to assure that the firm does not incur in losses.[36]

However, when χ is high, then the *post-tax* profit of the private company cannot compensate for the invest-

[35] This is coincident with the lack of diversity between operation contracts mentioned by Johnston (2008) and by the empirical evidence in oil contracts shown by Stroebel and van Benthem (2013).

[36] We must remember that the government is interested in setting t and r taxes both to maximise income and to also to render the operations profitable to a prospective firm. So if there are an excess of rents available no changes in t or r would be required.

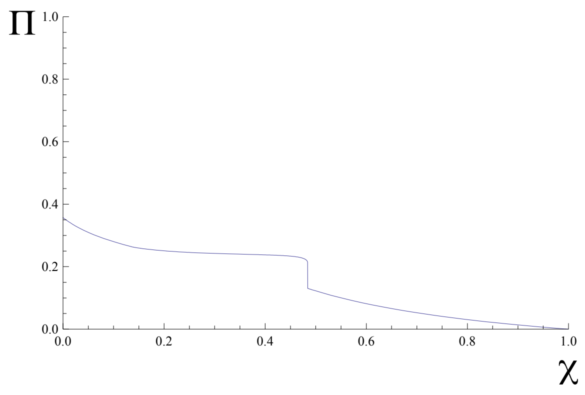
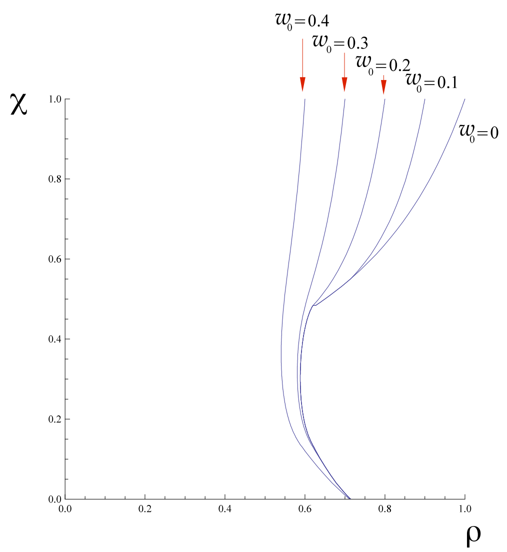


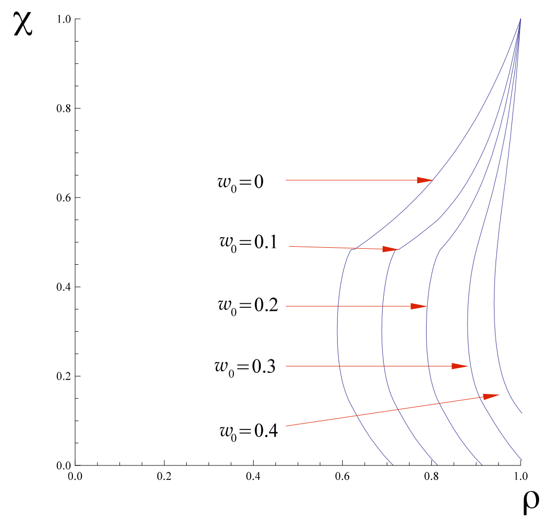
Figure 3.17: Company profits with varying levels of parameter χ, and no investment cost w_0.

ment w_0 if tax conditions are kept as usual. For that reason, a government will find necessary to adjust the values of r and t in order to promote investment.

In figures 3.18a and 3.18b the effect of the introduction of a fixed cost on the investment frontier is shown. On the first case, the state can appropriate the initial investment without compensation, and as a consequence: the higher the required investment, the smaller the area of private property.



(a) Non-recoupable investment



(b) Recoupable Investment

Figure 3.18: Variation in the investment frontier according to state capacity, considering varying levels of initial investment w_0 considering both recoupable and non-recoupable investment in case of expropriation.

But when the cost of the investment is returned by the state if it takes control of it (the panel on the right), the equivalent to the outside option becomes $\hat{\pi}_F + w_0$ and the *effective* value of ρ is lower: if the investment increases in magnitude the areas of "safe" private property becomes larger. Thus, the cost of the investment acts as a deterrent for the takeover of the mine/field by the state, as the necessity to promote investment crowds out the introduction of distortionary taxes.

It is interesting to note that the difference between figures 3.18a and 3.18b implies that there will be some cases where it would be convenient for the host government to have private investment, but it has to go for an inefficient, state-owned alternative if it cannot commit to pay back the investment in case of expropriation: this is a classic hold-up problem. In practice, we often see governments taking a middle road, choosing a more inefficient investor that forces the host government to abide by its promises, this is what Song and Wagner (2013) argue that has happened with Chinese investment in Africa: countries let China invest not because it is particularly efficient but because it has sufficient retaliatory power to discipline them. Earlier literature, such as Moran (1974) or Dunn (1983) stressed the fact that there had been few retaliatory measures against the *predatory states*[37] such as the application of the Hickenlooper Amendment to protect foreign U.S. investments. However, once a more exhaustive follow up has been made –as the one done by Maurer (2013)– we can see that cost-free expropriation (figure 3.18a) is rather the exception than the rule over the long-term during the post World War II years.

Figure 3.19 shows us how the tax rates evolve when there is an upfront investment, a figure that can be compared to figure 3.14 on page 171. We can clearly see that the taxes decrease as w_0 becomes more significant, this happens to the unlabelled royalties as well.

As we mentioned before, this behaviour can be expected as the level of taxes should decrease more when the tax burden is higher to make investment feasible. Corporate income taxes are the ones that vary by the greater extent when investment requirements are introduced, as they are especially relevant in those cases where the parameter χ is large, it is in those cases where the total profit –Π in figure 3.17 on page 175– from the companies is lower. To sum it up: taxes need to decrease by a larger magnitude when χ is large and profits for the firm are low to allow that investment remains attractive for private investors.

[37]A term coined by Dixit (2004).

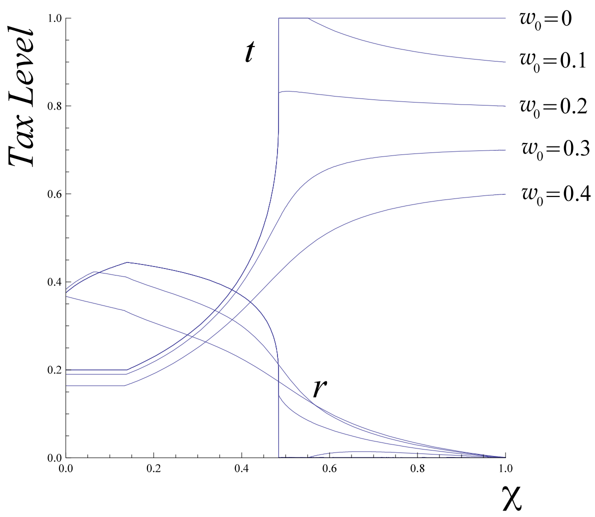


Figure 3.19: Change in taxes r and t as the parameter χ varies for different investment costs w_0.

3.7 Taxes and Stability: The Case of Chile

We will now retake the view shown on page 168 of section 3.4 where we consider how governments have different incentives to invest in changing the parameters χ and ρ. Both the technological gap and the institutional capacity of the state change with time, and when that happens the incentives to keep a given tax regime are also modified.

To exemplify this, in figure 3.20 we can see a simple diagram of the evolution of state capacity in Chile during the last century, which can be contrasted with figure 3.12 in page 169. From a starting point where there was a very low level of institutional and technological capacity (point 1); evolving then into a lower technological gap with the government, and with that, increasing the pressure towards nationalisation (point 2), to go then towards a new increment in the tax capacity of the state by the end of the 70s (point 3).

The reappearance of the tax debate on mining in Chile around the year 2000 –ending in the application of a modest royalty law in 2005 (cf. Congreso Nacional de Chile, 2005)– may have been related to the natural obsolescence of productive processes in the mining industry, something that narrowed the technological gap again. After analysing the parliamentary discussion,[38] it is not clear that there was not also a weakening of the institutional capacity of the state, given that tax avoidance mechanisms naturally evolve with time and use.

[38] Cf. Senado de la República de Chile (2004).

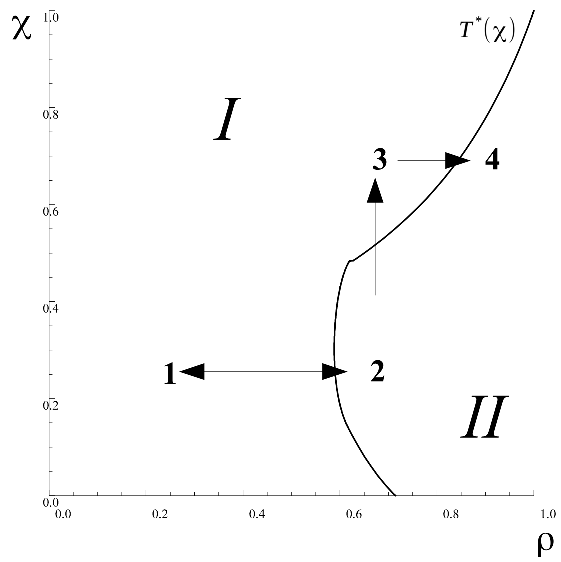


Figure 3.20: Schematic view of the evolution of state capacity in Chile during the 20^{th} century

We will now review how the evolution of the tax capacity has influenced tax decisions in the case of Chile and see how it fits the model shown above.

3.7.1 Historical evolution of the tax regime in Chile

Throughout Chile's history there has been a constant tension between how to manage natural resources more effectively for the state, either by tax reform or nationalisation in the mining industry: an industry that has been of great importance to the country in the past as can be seen in figure 3.21, and whose importance in tax revenue terms has been weakly but positively correlated with the size of the mining sector in the economy, as can be seen in figure 3.22.

One can observe the high volatility of the contribution of mining taxes to the state, which has been a factor in the development of friction between government and mining companies, a friction that has changed as the capacity of the state has evolved. In the case of Chile, it is easy to identify the following stages[39] between privatisation and state capture according to state capacity:

- The nitrate cycle: from royalty to a higher institutional capacity of the state, 1880-1930.

[39] A similar separation of stages can be found in Mamalakis (1967) and also in Bergsten, Horst and Moran (1978); for the last two periods, Lavandero Illanes (2004) and Congreso Nacional de Chile (2005) provide a good historical context.

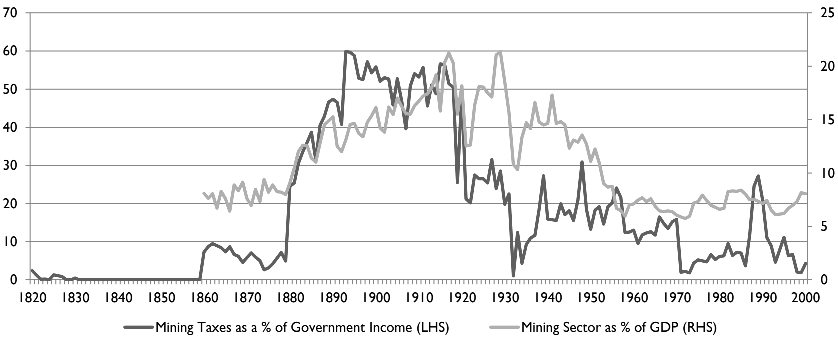


Figure 3.21: Tax capture from natural resources as a percentage of GDP and of total fiscal income.*(From Díaz et al., 2010).*

- The path towards nationalisation of mining assets: narrowing the technological gap without additional institutional capacity.
- The modernisation of the state and its institutions: a return to private investment.
- The erosion of institutional advantage: the new drive towards a more active role of the state in mining.

The nitrate cycle: 1880-1939

Characterised by the gradual loss of importance of nitrates as the main mineral resource and the emergence of copper as Chile's main export, it was named by Mamalakis (1967) as the *laissez-faire period*: with almost no taxes being levied[40] and the change from locally owned mines (90% of copper mines in 1880) to foreign owned large scale mining (only 4.47% of mines remaining in local hands by 1918).[41]

In this period, all the pressure for more control over exploitation was effectively blocked by the need to sell the commodities in the open market and to motivate further investment. The response to the resulting low tax capture was then to promote increasing the exported volume to augment the absolute collection of taxes; as most of the existing taxes were not *ad valorem*, when prices decreased producers had all the incentives to associate between them in order to lower production and raise prices: these attempts towards cartelisation were successfully fought by the government.

From a tax perspective, this period relied solely on royalties, which might have affected overall production

[40]Mamalakis and Reynolds (1965) show that a representative (copper) mining company paid a tax of 0.8% over gross sales during the 1913-1924 period.

[41]This change in the ownership structure of the mines could have effectively changed the objective function of the government to one focused purely on tax collection (as the one presented in this chapter).

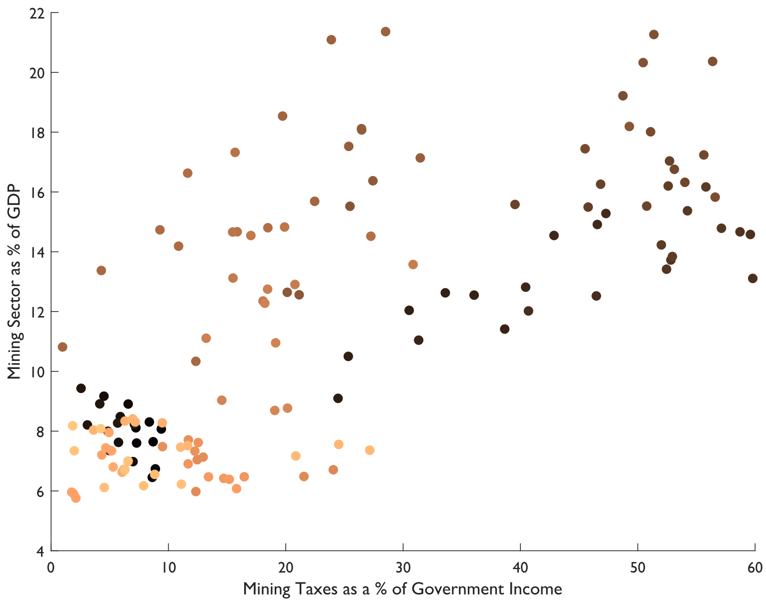


Figure 3.22: Figure 3.21 viewed in a scatter plot, where the lighter dots are the more recent ones. Showing the correlation between the two dimensions of tax capture.

levels. As this easy form of taxation became more relevant, the state had no incentives to increase its institutional capacity somewhere else, which prevented χ from raising even further; and coinciding with our early scenario in section 3.4 were $\frac{\partial T}{\partial \chi} < 0$.

Towards nationalisation: 1960-1970s

The fall in nitrate prices forced the takeover of the ailing producers by the state. Thus, by an exogenous chance, the state started slowly acquiring the capacity to manage mining corporations.

As a consequence, ρ increased due to the forced hands-on expertise recently acquired, so that the two main multinational mining companies, Kennecott and Anaconda, designed strategies to minimise the risk of expropriation.[42] While Anaconda tried to manage its influence directly –through its contacts at the top levels of government– and relied on the fact that more investment would bring a larger tax capture for the host government, Kennecott, on the other hand, co-opted the government by establishing a joint venture for future expansion of its main asset: the El Teniente copper mine.

The consequence of this disparity of strategies was that the Chilean government rapidly acquired the tech-

[42] Cf. Moran (1973).

nological capacity to operate these mines. The joint-venture accelerated the acquisition of technological knowledge, ρ, by the state, and the prospect of larger private operators (a lower parameter b in the model) lowered the value of the threshold χ_0^* and gave incentives to invest in the increase of tax capacity. In fact, by the time of the nationalisation of the industry, in 1971, there were only ten non-Chilean employees on Kennecott's payroll, from a total of ten thousand employees.[43]

The modernisation of the state: 1980-1990s

The complete overhaul of the Chilean state under the dictatorship period resulted in a modernisation agenda that required capital influxes to be implemented. For this reason, there was a strong pressure to modernise the taxation system (a further increase in χ) in order to allow private investment in mining without compromising public spending (as would have happened if the focus had been on the capitalisation of state-owned companies); and noting that the past investments had lowered the critical value χ^* so that $\frac{\partial T}{\partial \chi} > 0$.
Relying solely on corporate income tax, and tackling the creation of evasion loopholes, the state effectively raised the value of χ, thereby allowing private investment to happen again.

The erosion of institutional advantage: from 2000 onwards

The tax stability that has prevailed since the beginning of the 1980s allowed investing companies to have expert knowledge on the workings of the taxation code. At the same time, the reinvestment of profits allowed the state-owned company to develop new projects, further narrowing the technological gap.[44]
This mixture of higher ρ and a stable χ was not always welcomed, in fact, in 2002 a mine, Disputada de las Condes, was sold from one foreign owner to another using the tax code to attempt a complete exemption of taxes upon the sale. The uproar was generalised and from that moment onwards, public perception started agreeing that the tax law, as it was, had become obsolete against novel ways of evading taxes,[45] and therefore prompted legislation on the setting of royalties.[46]
We can infer that this transition from point 3 to point 4 in the figure 3.20 from page 178 will continue building pressure for further nationalisation.[47]

[43] Cf. Bergsten et al. (1978).
[44] Cf. Titelman Goren (2007).
[45] For a full discussion of the sale of Disputada, see González Castillo (2004).
[46] See Senado de la República de Chile (2004) for the discussion of the law.
[47] Which is very much in line to the recent wave of emerging *state capitalism* mentioned by Kurlantzick (2016).

3.7.2 Similar paths in other countries

The evolution of the tension between the state and investors in Chile during the past hundred years is by no means extraordinary. In Hogan and Goldsworthy (2010) we find a similar timeline in a stylised historical evolution of mineral taxation worldwide: before World War II, governments granted generous concessions to corporations, receiving payments mainly through initial bonuses, land rental fees and royalties. Royalties were generally low, implying that much of the rent flowed out of the country to corporations and investors in their home jurisdiction.

After World War II, decolonisation increased the pressure for economic rents to remain inside the host country (i.e. a change in the objective function of the government), therefore we saw the increase in state ownership, together with the introduction of other taxes.

In Bergsten et al. (1978) we can find evidence of the conscious attempt by governments, like Saudi Arabia to increase their technological capabilities, and how this preceded the expropriation the oil fields to form a state-owned company. And Kurlantzick (2016) provides a more up-to-date review of how countries have engaged in aggressive capacity building during the past decade in response to heightened volatility of related income.

Finally, Çakir-Melek (see both Çakir-Melek, 2011; Çakir-Melek, 2013) provides evidence of what happens when a country with low ρ attempts nationalisation, and how the change in ownership towards the state affects the efficiency of the resource company, even reducing the tax capture for the state. This gives us a cautionary lesson, that ρ may not always be truthfully assessed.

3.8 Conclusions

In this chapter we have shown the implementation of a simple, deterministic model to explain the absence of full rent taxation in the natural resources sector, and how this lack of efficient outcome can affect the stability of ownership when the state capacity changes.

As usually happens in models where the welfare depends on two factors, in this model the improvement of a single dimension can prove detrimental for the stability of the ownership structure and general welfare.

However, this model leaves many questions unanswered: for instance, why we do not see more host states offering to finance the initial investment to make their promises more credible or take measures to avoid excessively changing the property regime.

Another disturbing fact is that some of the interesting results we obtain are due to the fact that in this model, when $t < s$ there is an *inflow* of resources. Reasons that might explain the apparent lack of these inflows in the real world are that in general, as part of their tax engineering, multinationals choose their headquarters in locations that have particularly low tax rates, s. The other, complementary reason is that when t is too low, it is more probable that there are other significant risks (political, external), that might leave taxation as a secondary issue.

Moreover, we are tackling only one of the purely economic motives behind expropriation, which is the perception that investors are obtaining excessive rents, this is the line argued by Summers (2010), when he says the hold-up problem is inevitable if results have a high volatility: as rents, when they materialise are going to look excessive even if the expected profitability *ex ante* is modest. The alternative explanation is the complete opposite: a perception that benefits from exploitation have decreased to such an extent that as a consequence the "discomfort" of allowing low taxes for foreign companies cannot be justified any longer. Again, this is argued by Kurlantzick (2016) as one of the reasons for consolidation in the oil industry, and of the growing importance of state-backed players which he denominates *state capitalists*.

Furthermore, this model does not take into account that the perception that a country does not have enough control over its own destiny can give additional impulse to the tendency to expropriate; as it is mentioned in the *dependentista* development literature.[48] So that not only the absolute level of taxation is relevant, but also the history of taxation for a given commodity, and the perception of having been treated unfairly in the past.

Nevertheless, expropriation is better understood not as an irrational measure but as a course of action that can be encouraged by certain factors; in this sense, Kobrin (1980) mentions how the level of technology affects both perceived benefits and bargaining power: at its maturity, the investment may seem like a good candidate for expropriation, as the technology gap will surely have eroded.

Finally, the existence of Royalty Traps provides an additional reason to the ample arsenal of motives for which less developed resource rich nations might fail to develop institutions: it might not be in their short-term interest if it implies a lowering of their tax capture. And it provides a cautionary tale about the unintended consequences of raising the taxes at the home jurisdiction of multinationals (s in this model): in many cases it will help to reduce the gap $(t - s)$ that promotes the diversion of costs in middle income countries; however it can also promote more transfer cost issues if the initial situation of the host country is

[48] Cf. Moran (1974) for a review on the consequences of this hypothesis.

sufficiently dire.

Thus, this model, while leaving many questions unresolved, gives some insight on why the improvement of national technology or of institutions can prove to be detrimental under very low institutional starting points. Here we should remember the indications by Dixit (2004), on what a model should attain, namely: explain more than the simple facts that motivated the building of the model on a first place; and obtain evidence that validates the story in a different context.

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