Finders, keepers?

Niko Jaakkola, Daniel Spiro

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Kommer prospekterare få behålla sina fynd?

Niko Jaakkola och Daniel Spiro

Kommer företag som prospekterar efter naturresurser och investerar i gruvor och oljefält få behålla det de finner i efterhand? Detta är en icke-trivial fråga då prospektering och uppbyggnad av mineral- och oljeutvinning tar många år och de flesta regeringar inte kan binda sig för framtida beskattning. Framtida regeringar har incitament att höja skatten i efterhand men vet att också nästkommande regeringar kan komma att göra det. Prospekteringsföretag förutser naturligtvis att framtida regeringar har möjlighet att ändra skatten. Denna dynamik skapar cykler av skatter och investeringar -- stora fyndigheter leder till höjd skatt vilket leder till lägre nyinvesteringar och därmed även till lägre framtida fyndigheter. Vi analyserar också effekten av utvinningsprofilen. Desto senare i processen som vinsterna kommer desto högre blir skatten och desto större blir variationerna i skatt över tid. Slutligen analyserar vilken effekt priser har. Tillfälligt höga priser leder till högre skatt medan långsiktiga prishöjningar leder till lägre skatt.

Finders, keepers?

Niko Jaakkola* Daniel Spiro†

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Abstract

Will resource exploration firms get to keep their findings ex post, or will these be heavily taxed? To analyze this question we consider resource taxation when the government cannot commit to taxes beyond the current period and when firms have to invest in developing new, long-lived resource deposits. Taxes and exploration are both affected by foreseen decisions of future governments and firms. The dynamic hold-up problem creates cycles of exploration and taxation – large findings induce a high tax which lowers exploration investment and thereby future findings. Furthermore, the more backloaded the mining profile is, the higher will be the tax level, and the more pronounced are the oscillations. Finally, temporary price spikes increase taxation while persistent price increases lower it.

JEL codes: H25, Q35, Q38

Keywords: resource taxation, mineral exploration, dynamic games, hold-up problems

1 Introduction

Taxation of resource sectors is in many countries a large, and sometimes dominant, source of government revenue. For governments in such countries, getting a large share of the profits without inhibiting investment is a problem of first order importance. In the simplest theory, the problem has an elegant solution: if the government could commit, the first best option would be to auction the exploration rights. This would induce firms to pay the total expected profits and explore efficiently thereafter. In practice it takes decades from first getting the right to explore until a valuable finding has been made, until a mine has been established, until extraction leads to any actual revenues and finally until the mine is exhausted. Since few governments can make credible promises on behalf of future governments, the issue of commitment becomes a real concern. In particular, a later government has incentives to tax an actual finding *ex post*.

*Ifo Institut

†University of Oslo, Department of Economics. Spiro is associated with and funded by CREE - Oslo Centre for Research on Environmentally friendly Energy.

This is possibly the reason for the rare occurrence of pure auction systems when it comes to exploration.

The issue of commitment is also problematic for taxation as the government today may want a low tax to induce exploration, while a later government may increase the tax in order appropriate the profits. Firms naturally expect this and choose investment based both on current and expected future taxes. Likewise, the current government expects future reneging and hence sets the current tax taking the reaction of the firms and the future government into account. In particular, a current government may recognise that (because of expected high taxes *ex post*) it has to set taxation to a low level to encourage any investment at all, but then this low level of rent taxation is in turn seen as justifying later expropriation; a cycle that has been dubbed the 'natural resources trap' (Hogan and Sturzenegger, 2010).

Such problems are very prevalent, particularly in developing countries lacking robust institutions, but also in wealthier countries. Hajzler (2012) shows empirically that expropriation is particularly common with respect to resource firms. Examples abound. For instance, after first promising beneficial conditions to gas explorers in Israel, the government increased taxes to 42%.[1] Similarly, in 2012, the Ugandan government wanted to renege on a VAT exemption for oil companies' investments.[2] The conflict between a government's desire to tax resources yet to not scare away investment, in the context of a declining resource province, has also been apparent in the British government's to-ing and fro-ing over the taxation of North Sea oil firms.[3]

We analyze this strategic interaction in a simple infinite horizon model. In any given period resource profits are made from two types of mines: old mines discovered in the previous period and new mines discovered in the current period. In order to maximize profits from the old mines, the government would want to set a high tax, but that would harm current investment and hence profits from new mines. However, since the new mines today will, tomorrow, be taxed by the next government, today's government has to take the future government's reaction into account, which itself depends on the reaction of the government the day after tomorrow, and so on. This means that, although the government may not itself directly care about the tax revenue tomorrow, it does care about how that tax affects today's firms. Hence, today's government has to consider the effect its tax has on all future taxes.

The model predicts that taxes and exploration will be cyclical. Following an earlier large discovery, high taxes ensure the government gets a large share of the bonanza. This in turn will inhibit new investments, implying fewer mines

[1] See, e.g., The Jerusalem Post, 19th May 2014: http://www.jpost.com/Enviro-Tech/Sheshinski-2-panel-backs-42-percent-surtax-on-natural-resource-exploitation-352653.

[2] See, e.g., The Daily Monitor 17th Dec 2012: http://www.monitor.co.ug/News/National/Tullow-sues-government-in-new-tax-dispute/-/688334/1645452/-/10bijel/-/index.html.

[3] "The UK chancellor in his Autumn Statement went some way towards meeting industry calls to reverse his tax raid on North Sea oil and gas producers in 2011 by cutting the supplementary charge on profits from 32 to 30 per cent, with a hint of more to come." Financial Times, 3rd Dec 2014: http://www.ft.com/cms/s/0/632a9ace-7af8-11e4-8646-00144feabdc0.html

tomorrow, and hence a lower tax as the government refocuses to ensure new investments are high. The model predicts, however, that such cycles will dampen down, with the taxes eventually reaching a steady state.

We also study how the mining profile affects the tax. If the mining profile is backloaded, so that most of the mining profits come with a lag, then the government today knows that firms mainly care about the tax tomorrow. This makes mining investment unsensitive to today's taxes implying they are set high. This of course happens in all periods implying a high tax level throughout time which also inhibits investments. The backloaded mining profile dampens the oscillatory pattern in taxes.

Finally, we show that high spot prices increase the tax rate. This is natural as the government then focuses on getting a large share of these extraordinary profits rather than focusing on inducing new investments. This is, however, contingent on the high price being temporary. If the price increase is expected to last in the long run, then this will instead lower the tax today as the government refocuses to incentivizing new investments.

This paper is by no means the first to analyze resource taxation (for an overview see Boadway and Keen, 2010; Lund, 2009). However, to the best of our knowledge, we are the first to explictly model the interaction between successive governments. Much of the previous literature has had a normative perspective, focusing on the question of how to make resource taxes neutral (e.g., Campbell and Lindner, 1985; Fane, 1987). The papers most related to ours are the ones analysing dynamic commitment problems. Hassler et al. (2008) analyse a dynamic public finance problem in which a benevolent government, with the ability to commit, has the opportunity to tax human capital but cannot differentiate between sunk investments and investments still to be made. The depreciation structure in their model is identical to ours, but we focus on the Markovian case[4] and extend their analysis to mining profiles and price changes which are obviously important for resource. Bohn and Deacon (2000) and Wernerfelt and Zeckhauser (2010) analyze how the risk of expropriation affects the speed of extraction and optimal contracts. However, being mainly interested in the reaction of firms, the risk of expropriation in their models is exogenous. We extend their model by endogenizing the tax (including, in the extreme case, expropriation) while also considering the long term effects of prices and endogenizing the reaction of future governments.

Thomas and Worrall (1994) analyse foreign direct investment in a setting where firms and the government are, like in our model, forward looking but unable to commit. However, they consider how an incentive compatible contract in a repeated game would be structured. We dispense with contracts, considering instead a situation with minimal (one-period) commitment by the government, and with resource firms unable to credibly exit the market for good. We also want to consider natural state variables, in particular the stock of pre-existing resource deposits, as well as competition among resource firms instead of a single firm like in their model. As exploration and investment can be performed

[4]The working paper version of Hassler et al. (2008) consider a Markov equilibrium.

by more than one firm, the extension to perfect competition seems warranted.

A number of papers analyze resource contracts under the risk of expropriation when the expropriation entails costs such as lower efficiency in extraction (Trolle and Schwartz, 2010) or higher volatility in income (Rigobon, 2010). In a recent paper, Stroebel and Van Benthem (2013) analyze similar trade-offs from a positive perspective. Finally, Engel and Fischer (2010), in their initial discussion about resource contracts note that reneging of the current government, and the anticipation that future governments will face similar incentives, should lead taxes to cycle with prices. However, being interested in the optimal contract, they do not pursue this line of modeling but instead let the risk of expropriation be exogenous. This is the main dimension along which we depart from the earlier literature on resource taxation and contracts – that governments not only face a choice of reneging but also that they take into account that future governments will face the same problem, and that the endogenous sequence of decisions made by all governments is what determines the investments of firms.

2 Basic model

In this section we outline a simple model of resource exploration and solve for the equilibrium policies. The overall purpose with our setup is to capture three main aspects: firstly, that old mines and new mines exist in parallel; secondly, that mines exist beyond the time a government can commit to; thirdly, that mine development takes time, so that there is a delay between the investment decision and the first revenues.

There are two types of agents in the economy: a government wanting to maximise revenue and a large pool of candidate resource prospecting firms. The sequence of decisions is depicted in Figure 1. The government commits to a tax for a certain time interval with the objective of maximising its own revenues from the resource during this time (we think of this time interval being in the order of magnitude of five years). After the interval has elapsed it can freely change the tax. Hence, there is in essence a sequence of governments maximising their own profits. Each such time interval, which we call a period, is denoted by t. The timing of decisions within each period is as follows. The government observes the existing stock of mines and then announces a tax rate. After this announcement, new firms determine their exploration effort and their mines are opened with a lag. This means that within each period t there are two subperiods $s \in \{1, 2\}$. In the first sub-period only the old mines are being extracted from and in the second sub-period extraction is taking place both from the old and the new mines. Finally, when the current period t ends, the old mines close down while the new stay open for the entire next period $t + 1$ (i.e., the new mines in period t become the old mines in $t + 1$).

There is an infinite quantity of land available. A small plot of land can be explored for natural resources by using appropriate factors (e.g. hired petroleum geologists and drilling rigs, or dynamite and diggers). There is a linear supply curve for these factors, so that factor cost w as a function of aggregate

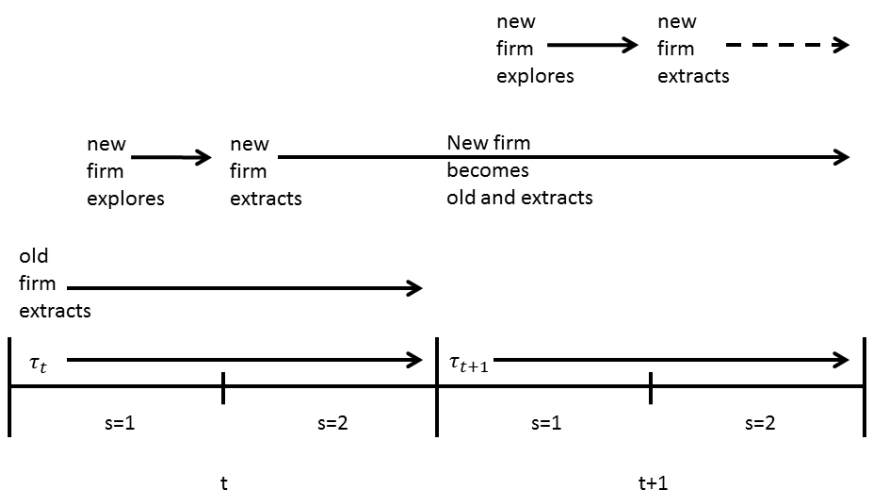

Figure 1: The sequence of events.

exploration $\overline{e}$ is, after a normalisation of the price level,

$$w_t = \overline{e}_t$$

implying that aggregate costs are quadratic.[5] We work with the linear-quadratic case to obtain analytical solutions.

Aggregate exploration effort in period t, measured in geographical area, is denoted by e_t. Exploration takes place in the first subperiod and every unit of exploration yields a known quantity of resources α_t. This parameter could be time-varying, reflecting e.g. exogenously changing land quality or advancements in mining technologies.

Any discoveries made in period t can be exploited in period t and $t+1$, after which the firm in question closes down. Denote the resource price in period t, subperiod s by $\mu_{t,s}$. Assume that the exploration costs are inclusive of the costs of developing the deposit, so that extraction itself is costless. Extraction is performed during the two periods – in the first period a share $\delta < 1$ of the mine's content is extracted and in the second period $1-\delta$ is extracted. This way, a small δ captures a backloaded mining profile and vice versa. For example, if $\delta < 1/2$ then most of the extraction takes place beyond the commitment period of the government.

Define the average resource price in period t as $\tilde{\mu}_t \equiv (\mu_{t,1} + \mu_{t,2})/2$. The representative firm's problem is given by

$$\max_{e_t} \left((1-\tau_t)\delta\mu_{t,2} + \beta(1-\tau^e_{t+1})(1-\delta)\tilde{\mu}^e_{t+1}\right)\alpha_t e_t - \overline{e}e_t$$

in which the firm takes the current and expected taxes and resource prices (τ_t, τ^e_{t+1}, $\mu_{t,2}$, $\mu^e_{t+1,1}$, $\mu^e_{t+1,2}$) as given. The discount factor used for future revenues is $\beta \in [0,1]$.

As the objective function is linear in the choice variable, an equilibrium requires that the objective function equals zero and with a representative firm $\overline{e}_t = e^*_t$, hence

$$e^*_t = \left((1-\tau_t)\delta\mu_{t,2} + \beta(1-\tau^e_{t+1})(1-\delta)\tilde{\mu}^e_{t+1}\right)\alpha_t.$$

Prices are assumed to be strictly positive and $\delta \in (0,1)$, so that exploration effort can be zero only if $1-\tau_t = \beta(1-\tau^e_{t+1}) = 0$, i.e., only if there would be full expropriation (100% taxes) both this period and the next, as long as the resource prospectivity is not fully exhausted (i.e. $\alpha_t > 0$). Suppose now that the government next period will use a linear tax policy

$$\tau_{t+1} = A_{t+1}e_t + B_{t+1} \tag{1}$$

(so that taxes tomorrow are a linear function of the discoveries made today). To emphasise, the coefficients A_{t+1}, B_{t+1} may depend on time. Note that the supposition of a linear policy function also requires the coefficients A_{t+1} and

[5] Alternatively we could consider atomistic firms with internal diseconomies of scale, e.g. an increasing cost of time spent on exploration.

B_{t+1} being such that $\tau_{t+1} \leq 1$, $\forall t$. We will impose conditions to ensure this indeed holds. With the supposed policy function, the firm's FOC can be turned into a fixed-point problem:

$$e_t^* = \left((1-\tau_t)\delta\mu_{t,2} + \beta(1-(A_{t+1}e_t^* + B_{t+1}))(1-\delta)\tilde{\mu}_{t+1}^e\right)\alpha_t$$

with the equilibrium resource exploration effort given by

$$e_t^* = \frac{\left(\delta\mu_{t,2} + \beta\tilde{\mu}_{t+1}^e(1-\delta)(1-B_{t+1})\right)\alpha_t}{1+\beta\tilde{\mu}_{t+1}^e(1-\delta)\alpha_t A_{t+1}} - \frac{\alpha_t\mu_{t,2}\delta}{1+\beta\tilde{\mu}_{t+1}^e(1-\delta)\alpha_t A_{t+1}}\tau_t. \quad (2)$$

This is a linear function of the current period tax τ_t, and also a function of current prices $\mu_{t,2}$ and the expected average future prices $\tilde{\mu}_{t+1}^e$.

We assume the government is unconcerned with the revenues obtained in the future, and only wants to maximise the revenues obtained today.[6] The government recognises the firms' reaction function and solves

$$\max_{\tau_t} \tau_t\left(\alpha_{t-1}(1-\delta)\tilde{\mu}_t\alpha_{t-1}e_{t-1} + \alpha_t\delta\mu_{t,2}e_t^*(\tau_t)\right)$$

with the corresponding FOC

$$\tilde{\mu}_t\alpha_{t-1}(1-\delta)e_{t-1} + \mu_{t,2}\alpha_t\delta e_t^*(\tau_t^*) + \tau_t\mu_{t,2}\alpha_t\delta e'(\tau_t^*) = 0.$$

In a very standard manner, the government trades off the extra revenue on the existing tax base versus the new tax base getting smaller. If the pre-existing revenue were zero ($e_{t-1} = 0$), then the government would simply choose to sit at the top of its one-period Laffer curve. With a positive pre-existing stock of developed mines, the government prefers to set a somewhat higher tax rate.

Lemma 1. *The policy rules $\tau_t^*(e_{t-1})$ and $e_t^*(\tau_t)$ are given by* (1) *and* (2)*, with*

$$A_t = \frac{1}{2\delta\alpha_{t-1}\tilde{\mu}_t}\frac{1-\delta}{\delta}\sum_{i=0}^{\infty}\left(\frac{\beta}{2}\left(\frac{1-\delta}{\delta}\right)^2\right)^i\left(\frac{\alpha_{t-1}}{\alpha_{t+i}}\right)^2\prod_{j=0}^{i}\left(\frac{\tilde{\mu}_{t+j}}{\mu_{t+j,2}}\right)^2$$

$$B_t = \frac{1}{2} - \frac{1}{2}\sum_{i=1}^{\infty}\left(-\frac{\beta}{2}\frac{1-\delta}{\delta}\right)^i\prod_{j=1}^{i}\frac{\tilde{\mu}_{t+j}^e}{\mu_{t+j-1,2}}$$

as long as the sums are bounded and always yield taxes $\tau^* \in [0,1]$.

Proof. Using the optimal response function $e^*(\cdot)$, we obtain

$$\tau_t^* = \frac{1+\beta^F\tilde{\mu}_{t+1}^e\alpha_t(1-\delta)A_{t+1}}{2\alpha_t\delta\mu_{t,2}}\frac{\alpha_{t-1}}{\alpha_t}\frac{\tilde{\mu}_t}{\mu_{t,2}}\frac{1-\delta}{\delta}e_{t-1} + \frac{1+\beta^F\frac{\tilde{\mu}_{t+1}^e}{\mu_{t,2}}\frac{1-\delta}{\delta}(1-B_{t+1})}{2}$$

Now using the conjectured policy rule we get

$$A_t = X_t + \Psi_t A_{t+1}$$

[6] Relaxing this assumption is work in progress and will form an extension of the current model.

where $X_t \equiv \frac{1}{2\alpha_t \delta \mu_{t,2}} \frac{\tilde{\mu}_t}{\mu_{t,2}} \frac{\alpha_{t-1}}{\alpha_t} \frac{1-\delta}{\delta}$, $\Psi_t \equiv \frac{\beta^F}{2} \frac{\alpha_{t-1}}{\alpha_t} \frac{\tilde{\mu}^e_{t+1}\tilde{\mu}_t}{\mu^2_{t,2}} \left(\frac{1-\delta}{\delta}\right)^2$. Note that $X_{t+1} = \frac{\alpha_t^3}{\alpha_{t+1}^2 \alpha_{t-1}} \left(\frac{\mu_{t,2}}{\mu^e_{t+1,2}}\right)^2 \frac{\tilde{\mu}^e_{t+1}}{\tilde{\mu}_t} X_t$ and $\prod_{i=0}^n \Psi_{t+i} = \left(\frac{\beta^F}{2}\left(\frac{1-\delta}{\delta}\right)^2\right)^{n+1} \frac{\alpha_{t-1}}{\alpha_{t+n}} \frac{\tilde{\mu}^e_{t+n+1}}{\tilde{\mu}_t} \prod_{i=0}^n \left(\frac{\tilde{\mu}^e_{t+i}}{\mu_{t+i,2}}\right)^2$. Then

$$
\begin{aligned}
A_t &= X_t + \Psi_t \left(X_{t+1} + \Psi_{t+1} A_{t+2}\right) \\
&= X_t + \Psi_t X_{t+1} + \Psi_t \Psi_{t+1} \left(X_{t+2} + \Psi_{t+2} A_{t+3}\right) \\
&= \dots \\
&= X_t + \sum_{i=0}^{\infty} \left(\prod_{j=0}^{i} \Psi_{t+j}\right) X_{t+i+1} \\
&= X_t \left(1 + \frac{\beta^F}{2}\left(\frac{1-\delta}{\delta}\right)^2 \left(\frac{\alpha_t}{\alpha_{t+1}}\right)^2 \left(\frac{\tilde{\mu}^e_{t+1}}{\mu^e_{t+1,2}}\right)^2 \right. \\
&\qquad \left. + \left(\frac{\beta}{2}\left(\frac{1-\delta}{\delta}\right)^2\right)^2 \left(\frac{\alpha_t}{\alpha_{t+2}}\right)^2 \left(\frac{\tilde{\mu}^e_{t+1}}{\mu^e_{t+1,2}} \frac{\tilde{\mu}^e_{t+2}}{\mu^e_{t+2,2}}\right)^2 + \dots \right) \\
&= X_t \sum_{i=0}^{\infty} \left(\frac{\beta}{2}\left(\frac{1-\delta}{\delta}\right)^2\right)^i \left(\frac{\alpha_t}{\alpha_{t+i}}\right)^2 \prod_{j=1}^{i} \left(\frac{\tilde{\mu}^e_{t+j}}{\mu^e_{t+j,2}}\right)^2
\end{aligned}
$$

which yields A_t. We obtain B_t similarly; defining $\tilde{\Psi}_t \equiv \beta \frac{1-\delta}{\delta} \frac{\tilde{\mu}^e_{t+1}}{\mu_{t,2}}$,

$$
\begin{aligned}
B_t &= \frac{1}{2}(1+\tilde{\Psi}_t) - \frac{1}{2}\tilde{\Psi}_t B_{t+1} \\
&= \frac{1}{2}(1+\tilde{\Psi}_t) - \frac{1}{4}\tilde{\Psi}_t(1+\tilde{\Psi}_{t+1}) + \frac{1}{8}\tilde{\Psi}_t\tilde{\Psi}_{t+1}(1+\tilde{\Psi}_{t+2}) - \dots \\
&= \frac{1}{2} - \frac{1}{4}\tilde{\Psi}_t + \frac{1}{8}\tilde{\Psi}_t\tilde{\Psi}_{t+1} - \dots \\
&\qquad + \frac{1}{2}\tilde{\Psi}_t - \frac{1}{4}\tilde{\Psi}_t\tilde{\Psi}_{t+1} + \dots
\end{aligned}
$$

which yields the result. □

We will next make particular assumptions to simplify the general policy rules of Lemma 1, in order to conduct comparative statics on the equilibrium outcome and to so derive empirical predictions.

2.1 Base case

As our base case, we take the specification with constant resource price and prospectivity ($\mu_t = \mu$, $\alpha_t = \alpha$, $\forall t$) and a flat extraction profile ($\delta = \frac{1}{2}$). The geometric sums in Lemma 1 are then bounded and we obtain

$$
A_t = \frac{2}{\alpha\mu(2-\beta)}, \qquad B_t = \frac{1+\beta}{2+\beta}
$$

so that the equilibrium policy rule for the government is

$$\tau_t^*(e_{t-1}) = \begin{cases} \frac{2}{\alpha\mu(2-\beta)} e_{t-1} + \frac{1+\beta}{2+\beta} & \text{if } e_{t-1} \leq \frac{\alpha\mu}{2}\frac{2-\beta}{2+\beta} \\ 1 & \text{otherwise.} \end{cases}$$

The exploration investment for the firm is

$$e^*(\tau_t) = \frac{\alpha\mu}{2}\left(1 - \frac{\beta}{2}\right)\left(\frac{2+2\beta}{2+\beta} - \tau_t\right).$$

Combining these, for an interior solution we have $\tau_{t+1} = \frac{2+2\beta}{2+\beta} - \frac{1}{2}\tau_t$. It is straightforward to show that there is a unique steady state at

$$\tau_{\text{SS}} = \frac{2}{3}\frac{2+2\beta}{2+\beta} \in \left(\frac{2}{3}, \frac{8}{9}\right)$$

as $\beta \in (0, 1)$. The government's value function is given by

$$V(e_{t-1}) = \begin{cases} \frac{1}{2(2-\beta)}\left(e_{t-1} + \frac{\alpha\mu}{2}\frac{1+\beta}{2+\beta}(2-\beta)\right)^2 & \text{if } e_{t-1} \leq \frac{\alpha\mu}{2}\frac{2-\beta}{2+\beta} \\ \frac{\alpha\mu}{2}\left(e_{t-1} + \frac{\mu\alpha}{2}\frac{\beta(2-\beta)}{2(2+\beta)}\right) & \text{otherwise.} \end{cases}$$

Note that the tax transition rule has a slope of $-\frac{1}{2}$. In other words, low taxes today, by inducing higher exploration, lead to high taxes in the next period; but the resulting cycle diminishes in magnitude, converging to the steady state.

From the decision rule, it is apparent that $\tau_t^* \in \left[\frac{1+\beta}{2+\beta}, 1\right] \forall t$. Note that $\tau_t(\tau_{t-1} = 1) = \frac{2+3\beta}{2(2+\beta)} > \frac{1+\beta}{2+\beta} = \tau^*(0)$. A full expropriation this period will of course yield some positive exploration, as firms expect next-period taxes to be low: recall that zero exploration could only occur if taxes were set to 100% in two consecutive periods. More interestingly, the tax rate τ' that would induce a full expropriation next period is $\tau' < \tau^*(0)$. Thus full expropriation can only occur in the initial period, if the economy starts with a very large existing stock of active mines; following this, taxes will always be strictly interior.

We summarise the dynamic properties of the benchmark case here:

Proposition 1. *With a constant resource price μ and prospectivity α_t, and a flat resource extraction profile, the taxes will cycle in diminishing cycles around the steady state τ_{SS}. Expropriation can happen only in the initial period t_0, if the initial stock of developed mines e_{-1} is sufficiently high.*

Proof. In the preceding text. □

The empirically testable predictions following this proposition are as follows:

- **Prediction 1**: Within a time period there is a positive relationship between the tax rate and the value of the current mines.

- **Prediction 2**: Within a time period there is a negative relationship between the tax rate and mining investments (i.e., exploration and setting up of mines)
- **Prediction 3**: The tax in period t is negatively related to the tax in period $t+1$.
- **Prediction 4**: The number of existing mines in period t is negatively related to the number of existing mines in period $t+1$.

As a rough empirical check, consider the case of Norway. Set the period length to 4 years, which is the interval between successive elections. Impose an annual discount factor of .8 (a value indicated by oil company sources as realistic for their internal project evaluation). Then the steady state tax is approximately .77999, essentially identical to the actual tax rate of .78.

2.2 Mining profile

Consider again the expressions for A_t and B_t in Lemma 1. We here abstract from all complications apart from the possibility that the mining profile is not flat, i.e. we allow δ to take any value between 0 and 1. We then get

$$A = \frac{1}{\alpha\mu\delta\left(2\frac{\delta}{1-\delta} - \beta\frac{1-\delta}{\delta}\right)}$$

$$B = \frac{1+\beta\frac{1-\delta}{\delta}}{2+\beta\frac{1-\delta}{\delta}}$$

implying the policy rules

$$\tau_{t+1} = \begin{cases} \frac{1}{\alpha\mu\delta\left(2\frac{\delta}{1-\delta}-\beta\frac{1-\delta}{\delta}\right)}e_t + \frac{1+\beta\frac{1-\delta}{\delta}}{2+\beta\frac{1-\delta}{\delta}} & \text{if } e_t < \alpha\mu\delta\frac{2\frac{\delta}{1-\delta}-\beta\frac{1-\delta}{\delta}}{2+\beta\frac{1-\delta}{\delta}} \\ 1 & \text{otherwise} \end{cases},$$

$$e_t^* = \alpha\mu\delta\left(2-\beta\left(\frac{1-\delta}{\delta}\right)^2\right)\left(\frac{1+\beta\frac{1-\delta}{\delta}}{2+\beta\frac{1-\delta}{\delta}} - \frac{1}{2}\tau_t\right),$$

tax transition

$$\tau_{t+1} = \frac{1}{\delta}\frac{1+\beta\frac{1-\delta}{\delta}}{2+\beta\frac{1-\delta}{\delta}} - \frac{1}{2}\frac{1-\delta}{\delta}\tau_t$$

and a steady state tax given by

$$\tau_{ss} = \frac{1}{1+\delta}\frac{2+2\beta\frac{1-\delta}{\delta}}{2+\beta\frac{1-\delta}{\delta}}.$$

We must have $\frac{\beta}{2}\left(\frac{1-\delta}{\delta}\right)^2 < 1$ for the policy rules to converge, and $\delta > \frac{1}{3}$ to ensure the tax transition is stable; i.e.

$$\delta > \max\left\{\frac{1}{3}, \frac{\sqrt{\frac{\beta}{2}}}{1+\sqrt{\frac{\beta}{2}}}\right\}$$

i.e. that resource revenues are not too backloaded.[7] Note, from the tax transition rule, that the tax oscillations become more pronounced as δ grows. The steady state tax τ_{ss} is below unity and decreases in δ. Furthermore, as A, B are both decreasing in δ we get the following prediction.

- **Prediction 5**: Given the stock of existing mines, the more backloaded the mining profile is, the higher is the tax.

It can also be shown that:

- **Prediction 6**: Given the stock of existing mines, the more backloaded the mining profile is, the lower is the exploration effort.

These predictions are intuitive. When the mining profile is very backloaded, then the firm, when deciding exploration investment, mainly cares about future taxes as that is when the mine will produce most of its value. The government today knows this and therefore is free to set a high tax to ensure getting a large share of the profits from the old mines. This of course happens in all periods implying that in general the tax rate will be higher. When the mining profile is sufficiently backloaded then the tax regime becomes so directed at getting at the current mines' profits that this altogether strangles the industry (i.e. if $\frac{\beta}{2}\left(\frac{1-\delta}{\delta}\right)^2 \geq 1$).

Likewise, given the existing stock of mines, more backloaded revenues will reduce their total value (because of discounting) while making the government's tax schedule today more onerous. As a result, exploration falls with backloadedness.

2.3 Price changes

We will now consider the effect of price changes on the tax policy. To highlight the mechanism we will consider the effect of a price change for two periods ($\mu_{t,s}$ and $\mu_{t+1,s}$) and assume that the price afterwards is constant at some level ($\mu_{t+i,s} = \mu \ \forall i \geq 2,\ s \in \{1,2\}$). Using the expressions for A and B from Lemma 1, for constant prospectivity ($\alpha_t = \alpha$), we get

$$A_t = \frac{1}{2\delta\alpha_{t-1}} \frac{1-\delta}{\delta} \frac{\tilde{\mu}_t}{\mu_{t,2}^2} \sum_{i=0}^{\infty} \left(\frac{\beta}{2} \left(\frac{1-\delta}{\delta} \right)^2 \right)^i \prod_{j=1}^{i} \left(\frac{\tilde{\mu}_{t+j}}{\mu_{t+j,2}} \right)^2$$

$$B_t = \frac{1}{2} - \frac{1}{2} \frac{\tilde{\mu}_{t+1}^e}{\mu_{t,2}} \sum_{i=1}^{\infty} \left(-\frac{\beta}{2} \frac{1-\delta}{\delta} \right)^i \prod_{j=2}^{i} \frac{\tilde{\mu}_{t+j}^e}{\mu_{t+j-1,2}}$$

From these expressions we get the following prediction:

[7] If the discount rate is very high, i.e. $\beta < \frac{1}{2}$, then the lower bound for δ is given by the stability of the tax transition. A high discount rate may force the sums in A_t, B_t to converge, but if also $\delta \leq \frac{1}{3}$, the assumption that taxes are always strictly interior will fail.

- **Prediction 7**: The higher is the spot price $\mu_{t,1}$, the higher is the current tax.

Prediction 7 is intuitive. An unexpected, temporary, positive price shock will tend to increase the tax rate: the government becomes more concerned about milking the existing stock of mines.

Persistent price shocks are more difficult to analyse for an arbitrary price path. However, if we only consider a path of constant prices, as in the previous section, we get the following prediction:

- **Prediction 8**: An unexpected and persistent positive price shock will tend to lower taxes and increase exploration.

Prediction 8 says that if this price shock is expected to persist, taxes will fall. This occurs as the price increase makes new firms more sensitive, on the margin, to the tax rate. The indirect effect—taxes lowering exploration effort—outweighs the direct effect of higher tax revenues, even taking into account the pre-existing stock of mines.

3 Conclusions

We have considered a dynamic hold-up model of resource taxation, in which resources are developed by costly exploration investments, but when the government cannot commit to not taxing the resulting resource rents beyond a single period. This is a highly policy-relevant problem, not only in developing countries lacking strong institutions, but also in developed countries.

We have shown how resource taxes typically vary non-monotonically. Large discoveries will tempt the government into pushing up taxes, as it cares relatively little about the harmful impact on the discovery and development of new fields. We have also analyzed how the mining profile and price changes affect the tax.

Thus, our parsimonius model produces a number of potentially testable empirical predictions. The model can also be extended along a number of dimensions, as it accommodates e.g. price trends, stochastic discoveries and falling land prospectivity as the most attractive areas are explored first. These extensions are work in progress.

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