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Taxing the Rent of Non-Renewable Resource Sectors: A Theoretical Note

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By Julien Daubanes and Saraly Andrade de Sá

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ABSTRACT/RESUME

Taxing the Rent of Non-Renewable Resource Sectors: A Theoretical Note

This study analyses the economic rent generated by the exploitation of a non-renewable resource, and the taxation of this rent. We present a synthetic model of a non-renewable-resource sector where deposits must be costly developed before they are exploited; the analysis emphasizes the effect of resource taxation on the discouragement to the development of new reserves. We discuss the limitations of neutral profit-taxation schemes and examine the distortions caused by various resource-taxation systems on the rent and its allocation: tax evasion, royalty-induced distortions, imperfect tax commitment, agency issues... We also discuss the measurement of resource rents for taxation purposes, and issues with the management of the resource tax income.

JEL Classification codes: Q30; H20.

Keywords: non-renewable resources, resource rents, tax distortions, tax income management

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Taxer la rente d'exploitation des ressources non renouvelables : une note théorique

Cette étude analyse la rente générée par l'exploitation d'une ressource non renouvelable, ainsi que la taxation de cette rente. Dans un modèle simple, nous représentons une industrie minière dont les gisements de ressource non renouvelable, pour être exploités, requièrent des efforts de développement ; l'analyse porte principalement sur les effets néfastes de la taxation sur la production de nouvelles ressources. Nous évoquons les limites à la possibilité théorique de ponctionner les profits de manière neutre, puis examinons les distorsions impliquées par les systèmes de taxation existants : évasion fiscale, capacité d'engagement limitée, redevances distorsives, problèmes d'agence... Nous discutons également les manières d'évaluer les rentes à taxer, et les problèmes relatifs à la gestion des revenus fiscaux issus des secteurs miniers

Classification JEL : Q30; H20

Mots clés : ressources non renouvelables, rentes minières, distorsions fiscales, gestion des revenus fiscaux

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TAXING THE RENT OF NON-RENEWABLE RESOURCE SECTORS: A THEORETICAL NOTE

by Julien Daubanes and Saraly Andrade de Sá[1]

1. Introduction

The exploitation of non-renewable resources generates economic rents. For some countries, rents from non-renewable resource sectors represent a substantial part of the gross national product. Also, pure rents, unlike other economic surpluses have the particularity that they may be taxed without causing any economic loss. Thus for any country endowed with exhaustible resources, the taxation of their exploitation is an issue, all the more important as governments are committed to cover their public revenue needs.

Methodology

In this paper, we develop a synthetic formal framework for the analysis of the economic rent generated by a non-renewable resource sector. This framework aims at explaining the origin and the nature of the total resource rent, at describing how this rent is allocated among involved agents, and at understanding how the rent and its allocation are affected by taxation. We also review arguments on whether the income taxed away from a resource sector must be treated in a way that differ from other government revenues.

Following the very influential analyses of Gray (1914) and Hotelling (1931), most of the resource economics literature has treated non-renewable resources as fixed, limited endowments. In this vein, the literature has paid a considerable attention to the issue of the allocation of global reserves across dates of a very long horizon. Most results from the resource taxation literature emphasise that taxation affects the speed at which finite reserves are depleted.

Yet current taxation systems that aim at collecting the rent of resource sectors seem to be mainly concerned by how taxation discourages the development of new deposits to be exploited. This concern can be put as follows. When exploitable reserves pre-exist at some fixed level as in the Hotellian model, part of the resource rent is the pure rent generated by the scarcity of those reserves: it is impossible, or prohibitively costly, to develop more reserves than those already existing. Taxing the scarcity rent has no effect on how much is to be exploited and can be done in a neutral fashion.

However, as a matter of fact, currently exploited reserves arose from prior investments in exploration and development of resource deposits. In this context, the scarcity rents of the Hotellian model become quasi-rents, that are rents that exist because investments have been realised. Taxing such rents is not neutral: when producers anticipate that the exploitation value of their reserves is reduced by taxation, they adjust their investment in the development of new deposits.

We thus follow Gaudet and Lasserre (1988) and consider that deposits are discovered and developed in the first place, and subsequently exploited. Costly exploration and development activities are major investments for resource sectors, that are made in anticipation of the future tax treatment that resource exploitation will receive. This approach has been recently used by Fisher and Laxminarayan (2005),

1. Daubanes: Center for Economic Research at ETH Zurich; Andrade de Sá: Institute for Environmental Decisions at ETH Zurich. The authors thank Patrick Lenain and Douglas Sutherland for inspiring discussions and helpful comments on an earlier version of this paper. Suggestions by an OECD internal reviewer are also gratefully acknowledged.

Daubanes and Lasserre (2012a, 2012b), van der Ploeg (2012), and Gaudet and Lasserre (2013). It fits well with the analysis of resource rent taxation systems in the spirit of Garnaut and Clunies Ross (1983) and Garnaut (2010) and with the recent IMF review of Daniel *et al.* (2010).

On the one hand, our emphasis on the development of reserves to be exploited connects resource taxation with the taxation of regular, producible commodities. Profits accruing to producers can be expressed as ordinary profits, arising from the difference between revenues and costs. Unlike many standard treatments, our approach does not explain the dynamic effect of taxation on the speed of extraction, but rather on efforts to develop new reserves. Indeed, for taxation purposes, it is sensible to consider that the speed at which one deposit will be extracted matters less than how much will be exploited from this deposit. On the other hand, the sequential representation takes into account an important peculiarity of resource exploitation activities: costs of producing reserves are incurred before revenues are derived from the exploitation of those reserves.

Outline

We first study a simple sector that consists of a single deposit of homogeneous resource and that faces no uncertainty on its future environment. Section 2 sets up our synthetic resource sector representation and examines how it generates its total economic rent. The total economic rent differs from the resource scarcity rent for two reasons: with given reserves, a resource sector generates a scarcity rent as well as an ordinary surplus; their sum amounts to the gross exploitation profit; part of this gross profit covers exploration and development losses.

Profits derived from resource exploitation activities can be taxed away, in principle, without imposing any distortion to the economy. Section 3 exposes the principles of neutral profit taxation in the context of a resource sector.

Yet there exist limitations to neutral tax collection. Too high a profit tax rate may discourage investments in the resource sector. Moreover, imperfect observability results in imperfect tax enforcement because of the possibility of tax evasion. Section 4 examines the case of distortionary tax instruments that are commonly used: royalties, unlike profit taxation, discourage the development of exploitable reserves and thus reduce the value generated by the sector. The analysis therefore also examines to which extent a higher tax raises a greater tax income. Other distortions may be unavoidable. One is due to the perception that the tax system may change in the future. The administrative costs and potential agency costs entailed by the fiscal apparatus are also discussed.

The tax system may not only modify the total rent generated by the resource sector; it affects how this value is allocated to various agents. Section 5 examines how the rent is allocated across economic agents like workers, resource holders, other capitalists and the government, and discusses how taxation affects their shares.

While the model exposed in Section 2 is parsimonious in various respects, it can easily by extended to more realistic settings. Section 6 extends the analysis in two directions. As a matter of fact, resources are produced from many deposits that differ by their geological properties. These deposits may be developed and exploited at different dates. In this context, a new source of distortion arises: taxation may affect the date at which a deposit is opened. Also, the introduction of global uncertainty is discussed; the analysis of the previous sections carries over.

Existing resource tax systems combine a variety of tax instruments. In the light of the analysis of the previous sections, Section 7 summarises the properties of the main tax instruments used or advocated by the literature: fixed fee, royalties, cash flow taxation and resource rent taxes.

How to measure the value generated by a resource sector? In some contexts, the resource economics literature studied the measurement of scarcity rents with the view to assessing whether a resource was becoming more scarce over time. Section 8 reviews such contributions. Yet for taxation purposes, the value of interest is not the scarcity value, but the total rent generated. The data required to implement the taxation of resource rents is also discussed.

In some countries, public revenues taxed away from resource sectors represent a large fraction of the total public income. Empirical evidence shows the failure of governments to make use of their share of resource rents, which raises the question of the optimal management of such rents. Many recent contributions shed light on this issue. In principle, the origin of public revenues must not justify earmarking. From the perspective of very large agents on the resource market, however, strategic objectives may be pursued by investing in related sectors.

2. Resource Rents in a Single-Deposit Model

Resource sectors usually consist of many heterogeneous deposits. For simplicity, this section deals with the very abstract case of a single deposit. In the rest of this study, the analysis of this section will be extended in various directions. A single producer exploits a single deposit of homogeneous reserves.[2] At each date t of the countable set $t = 0,1,2...$ the producer extracts a flow of resource $y_t \geq 0$ from exploitable reserves $R > 0$. Since the resource is non-renewable, it must be that the cumulative extraction flows fall short of the initial amount of reserves, that is $\sum_{t\geq 0} y_t \leq R$. Call it the exhaustibility constraint. As will turn out to be true later on when reserves will be endogenously developed, this constraint will always be satisfied with equality at the producer's optimum, meaning that exploitable reserves are completely exhausted. Thus

$$\sum_{t\geq 0} y_t = R. \qquad (1)$$

Besides the resource underground, extraction processes use other inputs, such as labor andmachinery. Assume that extracting a quantity y_t of resource requires the use of a quantity x_t of a single input for simplicity.[3] Specifically, extraction is determined by the production function

$$y_t = f_t(x_t), \qquad (2)$$

that is strictly concave to reflect that the productivity of the input is decreasing with its use.[4] The function f_t may also be varying with time because the extraction technology encompassed into it can be subject to technical progress.

It is assumed that the producer has no influence on market prices, so that he treats them as given.[5] Assume that the producer expects given streams of resource prices $p \equiv (p_t)_{t\geq 0}$ and of input prices

2. Section 6 extends the analysis to the case of multiple heterogeneous deposits, each with its own opening date.
3. Section 5 will assume that x_t is a vector of inputs like labour and physical capital; we will then analyse how the allocation of the rent to the payment to these inputs is determined, and how taxation affects this allocation.
4. For simplicity, in this paper, we assume that all functions are differentiable to the relevant order.
5 When the production sector is sufficiently large so that taxation policies applied to that sector may affect the international prices, "optimum-tariff arguments" arise, i.e. international prices may be strategically manipulated to pursue national objectives (see e.g. Daubanes and Leinert, 2013). At the international level, such strategies clearly result in a non-desirable outcome. Optimum-tariff arguments are out of the scope of the

$\omega \equiv (\omega_t)_{t\geq 0}$. Throughout the analysis, values will be expressed in present-value terms, that is in units of any arbitrary numeraire, that are discounted to be expressed in terms of their value at date 0 – for instance in constant dollars. This relies on the existence of an objective rate at which monetary values, like profits, must be discounted, as when there is a well-functioning financial market that establishes a common rate of interest.[6] Thus, the present-value extraction cost is $\omega_t x_t$ where $x_t = f_t^{-1}(y_t)$ is the quantity of input needed to produce y_t; we denote it by the cost function

$$c_t(y_t) \equiv \omega_t f_t^{-1}(y_t),$$

which is convex as a result of the concavity of f_t: more and more additional input is needed to produce additional extraction. Thus, the instantaneous profit from extraction accruing to the producer at any date $t \geq 0$ is $p_t y_t - c_t(y_t)$. His total intertemporal discounted extraction profit is

$$\sum_{t\geq 0} p_t y_t - c_t(y_t). \qquad (3)$$

2.A The Case of Fixed Reserves

Assume, in this section, that the amount of exploitable reserves is given. Following the very influential work by Hotelling (1931), this has been a very standard way to represent the non-renewability of resources. This case is particularly relevant for deposits that have been already developed and are currently being exploited. It is also useful to represent the situation of resource producers in the short run, over which capital variables such as exploitable reserves can hardly be adjusted (Daubanes and Lasserre, 2012a and 2012b).

With fixed reserves, the problem of the producer is that of maximizing exploitation profits (3) subject to the exhaustibility constraint (1) by choice of extraction flows $y_t \geq 0$ for all dates $t \geq 0$. In the following, we will denote by λ the Lagrange multiplier associated with the exhaustibility constraint. This abstract variable has always played a fundamental role in the economics of non-renewable resources, because of its interpretation. The λ multiplier, as we shall often refer to, indeed reflects the scarcity of the resource. Precisely, it corresponds to the value added by one additional unit of initial exploitable reserves R. It is thus the unit value of the resource underground from the producer's perspective, and so the opportunity cost of extracting one unit from these reserves. Accordingly, it must be interpreted as the scarcity value of the resource, of which it is the standard indicator.

In principle, it is possible that prices would not warrant the full depletion of the deposit; in that case, $\lambda = 0$ and the resource is not scarce. We assume away such uninteresting situations where the non-renewability of the resource is irrelevant. Therefore, $\lambda > 0$. The first-order conditions characterizing the optimum extraction schemes for the producer formally write as follows and will be interpreted shortly below:

$$p_t - c_t'(y_t^*) = \lambda^*, \text{ if } y_t^* > 0 \qquad (4)$$

$$p_t - c_t'(0) \leq \lambda^*, \text{ if } y_t^* = 0 \qquad (5)$$

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present study; that is, we assume that the sector under study is small compared with the world market in which it is participating.

6. In practice, depending on the access of individual producers to financial markets, and on the risk on their future profits, their profits are not discounted at the same rates.

where a star superscript indicates that a variable is evaluated at the producer's optimum extraction. The first condition is traditionally referred to as the famous Hotelling rule. It tells us that across dates of active exploitation, production is chosen so as to equalise the marginal exploitation profit accruing from the extraction of an additional unit of resource $d\left(p_t y_t - c_t(y_t)\right)/dy_t = p_t - c'_{t'}(y_t^*)$ to the unit opportunity cost of extracting it λ^*.[7] The second condition tells us that extraction may be interrupted ($y_t^* = 0$ for some dates t during the extraction period) if prices are so low that the marginal profit always falls short of the scarcity rent, even when extraction is very low: the resource has more value under the ground than above.[8]

In those interpretations, unlike the explicit price p_t for the extracted resource, the scarcity rent λ^* is an implicit price of the resource underground: it is endogenous to the extraction problem. As already mentioned, it indicates the scarcity of the resource for the producer; in absence of taxation and with a well-functioning market that establishes the extraction price p_t, λ^* is also the adequate measure of resource scarcity for society. How is it determined? All extraction flows y_t^* are implicitly defined by the above conditions as functions

$$y_t^* = y_t(p_t, \lambda^*), \qquad (6)$$

increasing in the contemporaneous price p_t and decreasing in the value of reserves underground λ^*. As explained by Sweeney (1993), resource supply as expressed by the above y_t function can be interpreted as jointly responding to two prices: it is increasing in the output that is the extracted resource, and decreasing in the input that are reserves units underground. Summing these flows across periods and keeping in mind the exhaustibility of the resource as per (1), yields $\sum_{t\geq 0} y_t(p_t, \lambda^*) = R$. Therefore, λ^* is determined as a function that is increasing in the entire set of prices p and decreasing in the exploitable reserves R:

$$\lambda^* = \lambda(p, R). \qquad (7)$$

That is, the greater the reserves, the lower their unit scarcity value.

Consequently, extraction quantities that are solution to the producer's problem turn out to be functions of the price and reserve parameters of that problem: $y_t^* = \tilde{y}_t(p, R) \equiv y_t\left(p_t, \lambda^*(p, R)\right)$. At the producer's optimum, the total extraction profit accruing to a producer with fixed reserves R can be written as

$$V^*(p, R) \equiv \sum_{t\geq 0} p_t \tilde{y}_t(p, R) - c_t\left(\tilde{y}_t(p, R)\right), \qquad (8)$$

and it can be verified that V^* is increasing in all prices in p and in reserves R and such that[9]

7. This can be put as follows, that stresses the fundamental peculiarity of non-renewable resources. The supply of an ordinary good that is producible without limit is characterised by the conventional equality between price and marginal production cost. Unlike such goods, resource supply results from the equalization of the price p_t with an "augmented marginal cost": $p_t = c'_{t'}(y_t^*) + \lambda^*$, where the value of reserves units underground is an additional opportunity cost of resource production.
8. The same condition applies for all dates following the exhaustion of the resource as it is more profitable not to extract any units at those dates so as to extract them earlier.
9. Formally, this results from the Envelope theorem for constrained problems.

$$\frac{\partial V^*(p,R)}{\partial R} = \lambda^*, \qquad (9)$$

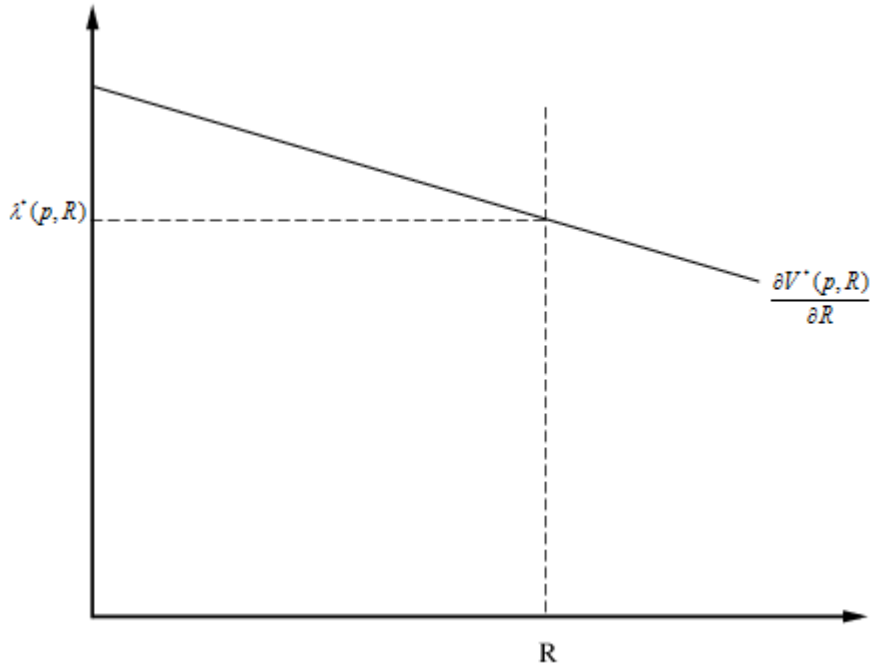
meaning that, as anticipated, the total value of the deposit for the producer increases with additional reserves by the unit value λ^*.

Furthermore, this total value function $V^*(p,R)$ is concave in R. Indeed, as we have earlier established, $\lambda^*(p,R)$ is decreasing in R because the unit value of reserves diminishes as there are more reserves. One major implication of the concavity of $V^*(p,R)$ or of the decreasing value of additional reserves is that total extraction profits are greater than the total scarcity value of reserves:

$$V^*(p,R) > \lambda^*(p,R)R. \qquad (10)$$

That means that the total scarcity rent $\lambda^* R$ is lower than the overall profit accruing to the extraction sector. Both values appear in Figure 1: for given prices p, and given reserves R, $V^*(p,R)$ is the integral below the marginal value curve $\partial V^*(p,R)/\partial R$ and $\lambda^*(p,R)R$ is the area of the rectangle. For taxation purposes, this is fundamental as it implies that *the scarcity rent understates the income that a government can tax away from that sector*. More on this further below.

Figure 1: Total profit and scarcity rent.



2.B Exploration and Development

As a matter of fact, reserves to be extracted do not arise without some prior exploration and development efforts. This is a major consideration that all advanced resource taxation systems aim at taking into account. Indeed, as will be clear shortly below, any taxation policy that has some bite on the scarcity rent λ reduces the incentives to develop new exploitable reserves, and thus deteriorates future tax prospects.

At the level of a single deposit, a simple and meaningful way to represent the development of exploitable reserves consists in assuming that reserves are developed instantaneously at date 0 of the deposit's opening.[10] The producer incurs exploration and development expenditures $E \geq 0$. Unlike the previous section, assume now that reserves are endogenously determined, instead of being exogenously fixed. This is the relevant approach to adopt when a resource sector responds to a taxation system over the long run. Exploitable reserves are determined by expenditures E via the increasing production function $R = F(E)$. Additional reserves may always be produced with higher expenditures.[11] Yet, an important aspect of non-renewable resources is that the exploration prospects are finite. Thus it is more and more difficult to produce new reserves. Assume accordingly that the F function is strictly concave and that marginal expenditures are extremely productive when no reserves have ever been developed: $F'(0) = +\infty$. Thus the cost of producing exploitable reserves R is $C(R) \equiv F^{-1}(R)$ is convex – that is that the marginal cost of reserve development is strictly increasing – which reflects that more and more expenditures are needed to find additional reserves to be exploited. The property that $F'(0) = +\infty$, implies $C'(0) = 0$. Hence, the first units of reserves require extremely low development expenditures, which excludes uninteresting cases where no reserves are ever produced. This representation follows Gaudet and Lasserre (1988) and has been recently used for instance by Fischer and Laxminarayan (2005), Daubanes and Lasserre (2012a) and van der Ploeg (2012).

Once reserves are developed at any level $R > 0$, the analysis of the previous section applies and the value earned by the producer is $V^*(p, R)$; it is never optimal to develop costly reserves that will not be extracted, which justifies the earlier assumption that the exhaustibility constraint is binding at the exploitation stage. It turns out that the ex ante problem of the producer can simply be expressed as the maximization of the value of exploiting reserves R, net of cost of developing such reserves,:

$$V^*(p, R) - C(R), \tag{11}$$

by the choice of exploitable reserves level R.

Keeping in mind that the exploitation value of additional reserves is λ^* as per (9), it turns out that exploitable reserves are determined by the supply relationship

$$C'(R^*) = \lambda^*, \tag{12}$$

that is that the marginal cost of reserves is equalised to the unit scarcity value of reserves underground.

It follows that the optimum level of reserves is an increasing function of the rent λ^* which has been shown to be a decreasing function of R^*, and to positively depend on all prices in the vector p. Thus, when reserves are endogenous: $\lambda^* = \lambda^*(p)$, $R^* = R^*(p)$. Also $y_t^* = y_t^*(p) \equiv \tilde{y}_t\left(p, R^*(p)\right)$ and $V^*(p) = V^*\left(p, R^*(p)\right)$.

The convexity of development costs $C(R^*)$ implies that the cost of developing units of reserves in R^* is lower than λ^*, the cost of developing the last unit of it. Thus the scarcity rent $\lambda^* R^*$ more than covers the loss from exploration and development:

10. In Section 6, we will consider that the opening date is endogenous.
11. In reality, the outcome of these expenditures is often uncertain. Therefore, they must comprise unavoidable expenditures in unsuccessful exploration projects.

$$\lambda^*(p)R^*(p) > C\left(R^*(p)\right). \qquad (13)$$

That means that the cost of reserves development understates the total scarcity rents.

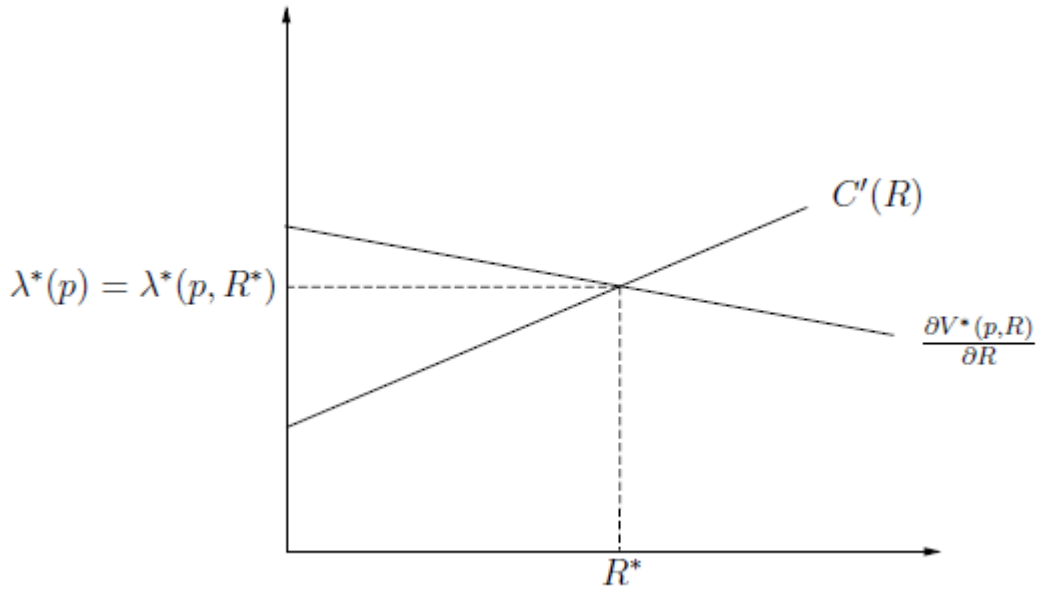
2.C The Net Total Rent of a Resource Sector

When reserves are exogenously given at some level R, the scarcity rent $\lambda^* R$ understates the total profit of the extraction sector $V^*(p,R)$. Taking into account that reserves' development efforts endogenously determine the level of reserves R^*, the total profit of the sector is $V^*(p) - C(R^*)$, which is strictly positive.

The resource economics literature has spent considerable efforts to understand the determinants of scarcity rents because it provides an economic indication of the scarcity of the resource. Yet, the total scarcity rent $\lambda^* R^*$ does not provide a good indication of the profit of the sector that taxation policies can target; this for two reasons. On the one hand, resource exploitation revenues V^* are greater than this rent; on the other hand, part of it is used to cover development expenditures $C(R^*)$.

Figure 2 illustrates the total profit from resource exploitation as the hatched area, that is the area between the marginal value curve $\partial V^*(p,R)/\partial R$ and the marginal development cost curve $C'(R)$.

Figure 2. Optimal level of reserves to be exploited.



3. Neutral Taxation Schemes

In general, taxation may impose economic distortion to the targeted sector, that is that it may reduce the total economic value generated by the sector's activity. When this is the case, raising one dollar of public tax income implies the destruction of more than one dollar of private income. Such distortionary taxation schemes are only desirable when governments need to apply them in order to raise required revenues.

When possible, indeed, governments must prioritise using non-distortionary or neutral ways of collecting tax revenue. When they exist, such neutral schemes allow the raising of one dollar of public tax income without destroying more than one dollar of private income.

Resource sectors generate rents that have always been very attractive targets for governments. One reason for this particular attractiveness is that resource rents may be so-called "pure rents" and that pure rents can notoriously be taxed away without imposing distortions. In the following sections, however, we argue that resource rents are not always pure rents and thus are not always so easily taxable.

3.A Taxation of Fixed Reserves

When exploitable reserves pre-exist at a given level as in the traditional Hotelling model of resource extraction, the rent $\lambda^* R$ is a pure rent because it arises without any prior investment. In that standard representation, the producer earns this rent without incurring the costs of developing the reserves.

In this context, it is well-known that some fiscal instruments can tax the rent away in a neutral fashion. For instance, any constant royalty (constant in present-value) is neutral. Consider in the analysis of Section 2 that a unit tax is imposed at the constant rate θ on the flow of resource. Introducing this tax amounts to replacing the price p_t in absence of tax by the net-of-tax producer price $p_t - \theta$. Further assume that the tax is not too high, so that $p_t - \theta \geq 0$. Then, one can easily show that the producer's supply at all dates, $y_t^*(R)$, is unchanged. Simply, the rent λ^* in (4) is reduced by θ, so that no quantity readjustment is needed.[12]

Thus a constant royalty allows to tax part of the rent away without implying any distortion to the resource sector. When the present-value price p_t is constant, the royalty can even collect the entire rent $\lambda^* R$ in absence of tax.

Other taxation schemes would have a similar effect. For instance, a tax on the extraction cash-flow that is constant, or equivalently a tax on intertemporal extraction profits (see further below), would capture the scarcity rent, without any quantity change. Unlike a royalty, those profit or cash-flow taxes, if set at 100%, are able to capture more than the scarcity rent $\lambda^* R$ in absence of taxation, but the entirety of the economic value $V^* > \lambda^* R$.

3.B. Pure Rents versus Quasi Rents

When account is taken that reserves result from exploration and development efforts, things are more complex. In this context, the pure rent λ^* of the previous section becomes a quasi-rent in the sense that it only arises from sunk investments. Any of the above attempts of taxing extraction revenues reduces the rent, and thus also discourages exploration investment. Indeed, reducing λ^* also reduces established reserves by (12).

12. The proof goes as follows. The producer's solution y_t^* is given by the function $y_t(p_t - \theta, \lambda)$, implicitly defined by (4). Thus by definition $y_t(p_t - \theta, \lambda^*) = y_t(p_t, \lambda^* + \theta)$. Summing those functions over time while taking into account (1) still determines the rent λ^*: it appears that $\lambda^* + \theta$ has the same value as λ^* in absence of taxation. In other words, the unit scarcity rent λ^* is exactly reduced by θ.

Thus when reserves are endogenous as in Section 6, a royalty, an extraction cash-flow tax, or an equivalent tax on extraction profit are all distortionary because they result in less developed reserves to be exploited.

3.C Intertemporal Profit Taxation

Even when reserves are endogenously determined, it is possible to tax away the benefit of the resource sector without imposing any distortion. One possibility consists in taxing the total profit, that is the intertemporal extraction profit, $V(p,R)$, net of the development cost $C(R)$. This is the most basic way to tax profits and rents and thus the archetypical taxation instrument of corporate income, not only for resource sectors, but in general in the realm of public economics. The neutrality of such a scheme relies on the observation that the problem (11) of maximizing the net intertemporal profit $V(p,R)-C(R)$ is equivalent to that of maximizing the net-of-tax profit $(1-\mu)\big(V(p,R)-C(R)\big)$, $0\le\mu\le 1$, which is proportional to the former.

A tax on total profit of rate $0\le\mu\le 1$ amounts to the combination of a tax on the extraction profit V of rate μ and of a subsidy to the development cost C of rate μ: $(1-\mu)\big(V(p,R)-C(R)\big)=V(p,R)-C(R)-\mu V(p,R)+\mu C(R)$. When the tax liability is positive, the cost subsidy amounts to a tax deduction. Since the cost C is incurred before the extraction profit is realised, such tax systems ensures that development cost C gives right either to an immediate compensation, or to a future tax credit: costs may be fully supported by the producer in the first place and then compensated by a tax deduction μC; in that case taxes on extraction revenues are not claimed as long as total tax liabilities fall short of the tax credit; when the tax credit is exhausted, taxes on extraction profits are fully paid.

Such taxation of total profit, when set at a maximum level very close to $\mu=1$, can theoretically raise the entire value generated by the resource sector V^*-C^*. That is indeed the maximum amount of revenues that can be taxed away from this sector. Further below in this section, reasons why the profit tax rate may be limited to the maximum rate $\overline{\mu}<1$ will be discussed.

3.D Fixed Fees for Exploration and Exploitation Rights

Another way of taxing the profit of the producer of Section 2 consists in requiring the producer to pay a fixed fee in exchange of the rights to explore and exploit the resource. As long as the fixed payment is covered by the total profits derived from the extraction activity $V^*(p)-C\big(R^*(p)\big)$, the problem of the producer of maximizing (11) is unchanged: at the exploration and exploitation stages, the fee is sunk.

Absent any uncertainty, issuing such a right allows taxing away the profit entirely $V^*(p)-C\big(R^*(p)\big)$ If part of the profit must be left with the firm to ensure its participation, the right may be fixed to any amount lower than $(1-\overline{\mu})V^*(p)-C\big(R^*(p)\big)$, where $\overline{\mu}<1$ is justified in Subsection 3.E. The fact that rights have been acquired at some cost by the firm should not distort its behavior.

When the profits to be derived from the rights are uncertain, competitive bidding makes candidates reveal information about the maximum amount they would be ready to pay for it $(1-\overline{\mu})V^*(p)-C\big(R^*(p)\big)$, and thus about the expected value of exploring and exploiting the resource. In these situations, we refer to the literature on the design of auctions. See Cramton (2010) for a recent review of issues about auctioning resource exploitation rights.

In many resource sectors, there is a limited number of exploitation companies, which is susceptible to collusion developing. In that case, competition for the exploitation rights may result in too low a price. As in the case of a state-owned sector, pricing rights requires the delegation of some tasks to experts. Delegation may be accompanied with the distortions already mentioned; it also raises the issue of the capture by the industry (Stigler, 1971) of the pricing agency.

3.E Limitations of Neutral Taxation Levies

There are two basic limitations to the attractiveness of conventional profit taxation. The first one concerns the amount that a government can tax away from a resource sector with the aforementioned neutral tax schemes. This will be the subject of this subsection.Another one concerns the ability of a government to enforce such systems. When this ability is imperfect, unavoidable distortions arise. It will be addressed in Section 4 as a source of distortions.

Even absent pure scarcity rents, ordinary profits can be strictly positive. For instance, this is the case in the above analysis with fixed reserves because total profits exceeds the scarcity rent. When profits arise under perfect competition, they can be thought of as a payment to an input that the standard measurement does not capture. For instance, say this input is the willingness of the entrepreneur.

When a government is in need of raising significant revenues that would imply imposing distortions on the economy, it is usually assumed that neutral profit taxation opportunities must be fully used up first, before turning to other, maybe distortionary, ways of collecting tax revenue. Yet the taxation of profits at 100% leaves nothing to the entrepreneur. If the entrepreneur's willingness can be paid a positive profit in another sector, the entrepreneur would decide not to participate in the zero-net-profit sector.[13] The argument implies that too high a rate of profit taxation is not neutral.

Another similar argument is related with the risk associated with resource exploitation. Exploration activities are uncertain, as are future market conditions for the extracted resource. If the objective of resource exploitation companies reflects some aversion for these risks, their participation requires compensation. Also in this case, too high profit taxation is not neutral as it threatens producers' participation. See for instance Land (2010, pages 252-253) on rates of returns thresholds and resource rent tax rates.

4. Distortions from the Taxation Systems: Total Income and Allocation

4.A Limited Tax Enforcement

Another issue is that of the limited enforcement of profit taxation schemes. The attractiveness of profit taxation relies on the assumption that there is no evasion at zero administrative cost. The assumption is contradicted by the situation of developing countries, where the formal economy coexists with a large informal system. Casual observation also suggests that there are considerable administrative efforts to fight evasion in developed countries. As stressed by Gordon and Li (2009), limited tax enforcement may account for many puzzling tax policies in developing countries. Recommendations to governments must take this aspect into account whenever it is relevant as the welfare effect of tax reforms may be of opposite directions depending on the capacity of governments to collect taxes (Emran and Stiglitz, 2005).

A recent study suggests that imperfect tax enforcement accounts for the fact that some countries prefer the distortionary taxation of observable output, to the theoretically neutral taxation of profits; the output tax base is indeed harder to evade. Specifically, in the case of Pakistani corporate taxation, Best,

13. The issue of fiscal competition between several jurisdictions is beyond the scope of this paper.

Brockmeyer, Kleven, Spinnewijn and Waseem (2013) estimated that a switch from profit taxation to output taxation reduces evasion by up to $60-70\%$ of corporate income.

Therefore, it can be argued that when tax enforcement is limited, profit taxation may be subject to evasion and may thus be dominated by other instruments. Those other instruments, even if they impose distortions to the economy, may be subject to less evasion, because, for instance, their tax base is harder to evade andthus they may allow for a better collection of tax revenues. As suggested by the above Pakistani example, this is the case of a tax on output (a "royalty" in the case of resource taxation). In all such examples, a government concerned with social welfare but in the need of collecting revenues from the resource sector, faces a trade-off between reducing the economic value generated by the sector (greater distortions) and collecting a greater amount of that value (greater tax collection).

The explicit consideration of evasion possibilities is out of the scope of the present document. With limited tax enforcement, distortionary tax instruments like royalties can be attractive ways to collect the tax income. Section 4 will examine the distortions that arise when the system departs from neutral taxation schemes. For instance, Boadway and Keen (2010, page 56) suggested that when profits are less observable than resource outputs, combining a royalty with profit taxation can improve the resource sector's efficiency because it alleviates the asymmetric information issue.

4.B Ordinary Tax Distortions: The Example of Royalties

Empirical evidence suggests that tax levies that are linear in the resource production like royalties are the most common form of resource taxation (Boadway and Flatters, 1993; Boadway and Keen, 2010). The Albertan case (Alberta Royalty Review, 2007) provides the example of an advanced system for the taxation of oil production that relies on royalties (also cost tax credits).

In this section, we will analyze how the production discussed in Section 2 is distorted by the introduction of a royalty. In the context of Section 2, consider that a royalty of present-value rate $\theta > 0$ is imposed at all dates. Further assume that the royalty is not too high so that net-of-royalty producer prices still warrant the exploitation of the deposit.[14]

From the producer's perspective, the only difference with the situation of Section 2 is that the price accruing to him at date $t \geq 0$ is no longer p_t, but $p_t - \theta$. Therefore, the same analysis applies, with the new price $p_t - \theta$. From condition (4) for the choice of producer's supply, it is clear that a lower price $p_t - \theta$ for the extracted resource is equivalent to a decrease in the scarcity value λ. Thus the function y_t defined in (6) and giving the supply at date t, must be such that $y_t(p_t - \theta, \lambda) = y_t(p_t, \lambda + \theta)$. Let us now turn to the determination of the scarcity rent λ in that context. For given reserves R, λ is determined by the binding constraint that cumulative supplies exhaust exploitable reserves $\sum_{t \geq 0} y_t(p_t - \theta, \lambda) = R$. In light of the property of the y_t function established above, once can also write $\sum_{t \geq 0} y_t(p_t, \lambda + \theta) = R$. Thus compared with the no-royalty situation where the price is p_t and reserves are established at level R, the rent is exactly reduced by the royalty: $\lambda = \lambda^* - \theta$. Denoting by $\Theta \equiv (\theta)_{t \geq 0}$ the vector of taxes applied to the vector of prices p, once obtain the property of function (7) that $\lambda(p - \Theta, R) = \lambda(p, R) - \theta$, which

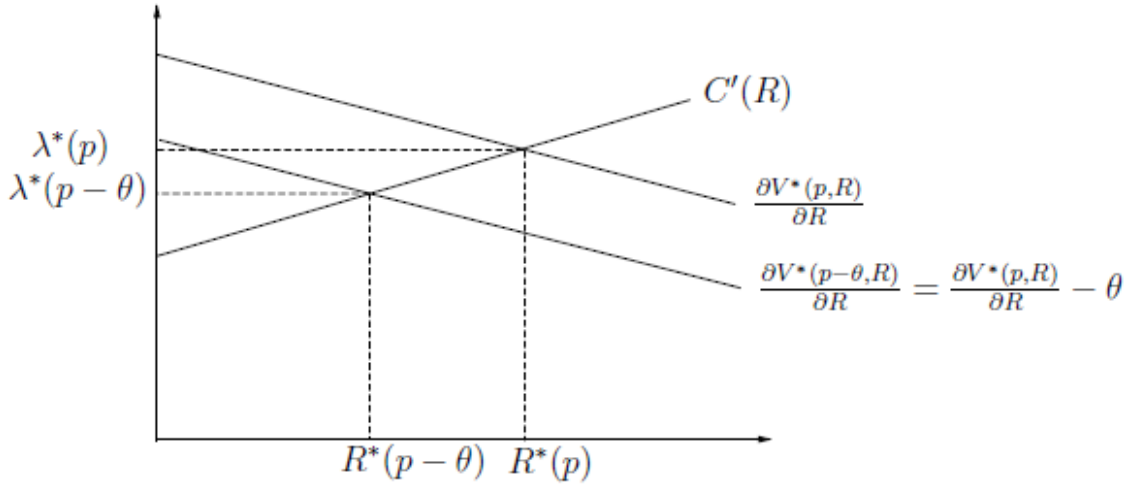
14. The royalty is assumed constant so as to ignore its dynamic effect on the extraction of given reserves, and to focus on the distortion to the overall production. See the Introduction.

means that for unchanged reserves, a constant royalty of rate θ reduces the rent by exactly θ. This is in line with the fixed-reserves case examined in Subsection 3.A.

When reserves are fixed as in Subsection 3.A, say at level R, either because they have been developed already, or because the producer's cannot adjust them in the short-term, the introduction of the royalty does not affect reserves at all; p_t is replaced by $p_t - \theta$ and λ is reduced by exactly θ. By the property of the y_t function shown above, the optimum supply of the producer is not affected at all by those changes: $y_t^*(p-\Theta) = y_t\left(p_t - \theta, \lambda^*(p-\Theta)\right) = y_t\left(p_t - \theta, \lambda^*(p) - \theta\right) = y_t\left(p_t, \lambda^*(p)\right)$. Thus, $y_t^*(p-\Theta) = y_t^*(p)$, that is the royalty is neutral. This result has been first shown by Burness (1976), and later extended by Dasgupta, Heal and Stiglitz (1981). It suggests that the simple taxation of the output of a resource sector, unlike for ordinary sectors, is not distortionary, which greatly contributes to the attractiveness of resource sectors for what concerns the collection of tax requirements.

When reserves are endogenous, as they are in the long-run, things are not so; a result stressed by Daubanes and Lasserre (2012b) and Gaudet and Lasserre (2013). The optimal amount of reserves produced is determined by the equality of the marginal cost of developing reserves $C'(R)$ and the marginal extraction profit $\partial V^*(p-\Theta, R)/\partial R = \lambda^*(p,R) - \theta$. Figure 3 illustrates that the shift in λ^* induced by the royalty causes a reduction in $\lambda^*(p) - \lambda^*(p-\Theta)$, not by θ as if reserves were fixed, but by less than θ, because the rent reduction is partly compensated by the reduction in developed reserves R^*. These effects depend on the slope of the marginal development cost curve: the decrease in the rent is all the stronger, and the reduction in reserves all the weaker, as it is marginally more difficult to develop new reserves. In the extreme case where the marginal cost curve is vertical, things go as if the level of reserves was fixed: the rent decreases and no reserves compensatory adjustment occurs. Finally, because the reduction in the rent λ is lower than that of the price $p_t - \theta$, it can be shown that the supply y_t is reduced at all dates as a consequence of the royalty.

Figure 3. Royalty distortion.



4.C Total Rent and Tax Income with Tax Distortions

What is the effect of the royalty on the total tax income? When reserves are fixed at the level R, we have seen that the royalty was not affecting production in any manner. Thus the total income taxed away by the royalty is $T = \sum_{t\geq 0} \theta y_t^*(p) = \theta R$, expressed in present-value terms. Since R is independent of θ in that case, an increase in the royalty increases the tax income. The reasoning is valid under our assumption that the royalty is relatively low. In fact, the royalty is neutral up to the point where it causes the marginal profit in (4) to be negative, that is where the tax is eating the entire rent in absence of taxation: $\theta \geq \lambda^*(p)$. Therefore the royalty is capable of raising the entire scarcity rent in absence of taxation $\lambda^*(p)R$. For higher values, for instance when the royalty makes the maximum marginal profit $p_t - c_{t'}(0)$ negative, extraction ceases as per condition (5) and no tax income is collected at all.

When reserves are endogenous, the taxation of the resource output is less attractive. The generated tax income is $\sum_{t\geq 0} \theta y_t\left(p-\Theta, \lambda^*(p-\Theta, R^*(p-\Theta))\right) = \theta R^*(p-\Theta)$. The effect of a greater royalty rate decomposes as follows:

$$\frac{d\theta R^*(p-\Theta)}{d\theta} = R^*(p-\Theta) + \theta \frac{dR^*(p-\Theta)}{d\theta},$$

where the first term is positive, as it corresponds to the increase in the income levied per unit of resource, and the second term is negative as it reflects the reduction of the exploited reserves tax base. It is sensible to assume that when the tax is low and reserves are high, an increases in the tax increases the tax income: reserves are reduced, but relatively little because the marginal cost of developing reserves is rising a lot when reserves are high. Vice versa, when the tax is high, reserves development should be very sensitive to a tax increase because the marginal cost of developing new reserves is not rising much when reserves are low. Thus it is to be expected that the relation between a royalty and the income it levies, unlike the standard case of fixed reserves, has the famous inverted-U shape of Laffer curves.

4.D Risk Perceptions on the Tax Systems

In most analyses of the effects of resource taxation, the tax schemes is assumed given, in a way that all involved agents perfectly foresee the evolution of the system. For instance, a path of royalties or profit tax rates is set from date 0 on and is left unchanged all along the horizon. In practice, there is always some uncertainty about how taxation will change in the future. Indeed, fiscal institutions are usually not independent, implying that the tax systems is subject to changes associated with the political cycle.

Those changes can be considered endogenous (e.g. Hoel, 2012). A very simple and meaningful representation assumes that producers perceive a given risk that the system will change.

One extreme example is the risk of nationalisation of the sector by which private producers would be completely expropriated of their future profits. This is the situation studied by Long (1975), which is particularly relevant for unstable developing countries where the government is unable to commit to a future system. When reserves to be exploited are set as given and there is a positive probability that the sector will be nationalised from one future date on, producers tend to exhaust the resource more rapidly, so as to mitigate this risk. See also Sinn's (2008) case of "green paradox" for an insightful exposition of such matters.

When reserves are endogenous as in Daubanes and Lasserre (2012b) and van der Ploeg (2012), similar risks may be referred to as a hold-up issue: the tax is low at the stage when a producer decides his exploration and development investments and high when such investments are sunk during the exploitation phase. This causes an important source of distortion.

In the following, we modify the problem of Section 2 in a very simple way that introduces the risk that exploitation profits may be completely taxed away by the system. Once exploration and development investments are sunk, and reserves are established, assume that the stream of exploitation profits (3) accrues to the producer with a given probability $0 \leq \pi < 1$. With probability $1-\pi$, the producer is completely expropriated of the value of the reserves he developed, so that profits are zero. Thus, exploitation profits (3) must be replaced by the expected profits $\pi\left(\sum_{t\geq 0} p_t y_t - c_t(y_t)\right)$. The first-order condition (4) for the choice of extraction becomes $\pi\left(p_t - c'_{t'}(y_t^*)\right) = \lambda^*$, that is

$$p_t - c_t'(y_t^*) = \frac{\lambda^*}{\pi}, \text{ when } y_t^* > 0. \qquad (14)$$

Therefore, the analysis of Section 2 applies as before, but with λ^* replaced by λ^*/π. In the producer's optimum, it follows that the marginal value of reserves can be directly compared with its level in absence of hold-up risk. For given reserves R, it will be established at the level $\lambda^\pi(p,R)$ such that $\lambda^\pi(p,R)/\pi = \lambda(p,R)$; that is $\lambda^\pi(p,R) \leq \lambda(p,R)$. It follows from (’12) that, in anticipation of the hold-up risk, the level of reserves will be established ex ante at a lower level $R^\pi \leq R^*$. Thus, supply y_t^π is lower at all dates than in absence of hold-up risk.

The above distortion may arise in various tax environments. In the context described by Long (1975), producers perceive a risk of future nationalisation. In general, the government is not able to commit perfectly to a future tax treatment of extraction revenues. This lack of perfect commitment results in the perception that the system may penalise future revenues. This is the case in the situation described by Sinn (2008) where producers anticipate that extraction will be penalised in the future by more stringent environmental policies at the aggregate level. Such policies, by reducing the demand, would indeed lower the producer price established on world markets. The analysis could easily be modified to the case of an uncertain price or tax level, and would deliver the same message. Unstable systems that generate a risk that future extraction revenues be penalised cause reserves development and thus instantaneous supply to decrease.

4.E Administration and Agency Costs

Administrative Costs

Administrative costs are inherent to any tax system. Since they reduce the collected tax income, they must be considered when assessing whether the system raises positive net levies and thus if it justifies introducing economic distortions.

Administrative costs can be expected to be all the higher as the taxation scheme is sophisticated, and all the lower as the fiscal apparatus is already developed. It may be a crucial consideration for new taxes in developing countries that do not rely on a well-developed apparatus and experience.

Levying taxes requires implementing an administration, which is endowed with resources and expertise for that. Delegation often entails agency costs because governments lack resources and time to

monitor perfectly their administrations. Hence, part of the cost of administering a tax may correspond to agency costs.

The agency costs implied by the delegation of tax levies can be increased when it is possible for the industry to capture the fiscal administration. For a recent model where delegation is more costly because of the industry's influence, see Daubanes and Rochet (2013). An example is the setting of fixed fees under low transparency. The institution in charge of pricing or allocating exploitation rights may display favoritism.

State-Owned Resource Sectors

Empirical evidence shows that state-owned extraction companies or sectors are common. A nationalised sector means that no profits are left to private producers: one the one hand, output revenues are completely appropriated by the state; on the other hand, all costs are fully financed by the state.

If a state-owned sector was performing as a private sector under competition, then it would allow the government to collect directly 100% of the total value generated by the sector $V^*(p)-C\big(R*(p)\big)$. Thus a nationalised sector should be viewed as an extreme form of profit taxation (Daubanes and Lasserre, 2012b).

In practice though, a state-owned sector implies that the government delegates the task of exploring and exploiting the resource to an agent. The delegation problem should be viewed through the lens of principal-agent relationships (Laffont and Tirole, 1993). First, there must exist an agent with resources and expertise to which the task can be delegated. If no domestic agent is endowed with the required expertise to execute the task, the government can still delegate it, maybe not through the structure of a state-owned company, to foreign companies or professionals. Second, governments often lack the expertise and resources to monitor public companies effectively. The resulting asymmetry of information causes distortionary agency issues having to do with the difficulty to provide the agency with strong incentives (to reveal cost information, to make desirable efforts...). In particular, part of the income must be abandoned to the agent.

5. Rent Allocation to Various Inputs

The total gross revenue generated by the deposit is $\sum_{t\geq 0} p_t y_t^*$. This gross revenue is allocated to various actors, implicit to the above analysis.

First of all, part of the revenue is used to cover costs. Costs incurred by a resource sector can be considered to be of two main sorts. There is a cost of discovering and developing the exploitable reserves, that we have denoted by $C(R)$. Moreover, the exploitation of the developed reserves also implies cost of extracting and processing (maybe also transporting) the resource to deliver the final product; this cost is incurred all along the exploitation period. We have denoted it by $c_t(y_t)$ and it amounts overall to $\sum_{t\geq 0} c_t(y_t)$. Section 2 assumed that the exploitation cost $c_t(y_t)$ was the payment to the single input needed to produced y_t. In general, those costs correspond to payments for various inputs that are combined to develop and exploit the resource. They are usually considered as two categories: labor inputs provided by workers, and capital inputs provided by capitalists. The next subsection will explicitly characterise the payment to workers and capitalists.

In absence of taxation, the total revenue net of the above costs is the total profit, which accrues to the owner of the deposit.

Tax levies clearly reduce the profit of deposit holder and/or the payment to workers and capitalists. Taxation may affect profits only, as when it is a neutral profit taxation scheme such as described in Section 3. When taxation is distorting, it also affects costs of development and exploitation (see for instance Section 4), and thus also affects workers and capitalists related to the resource sector.

5.A. Costs as Input Payments to Labor and Capital

Production, like reserves development and extraction, are using various labour and capital inputs: in the first categories will be engineers, analysts, various skilled workers , researchers aimed at improving techniques... In the second one, will be various sorts of machinery, but also intangible capital like new techniques; maybe directly available against payments for intellectual property rights, or indirectly available because they are embodied in innovation-improved machinery.

Any cost function such as the functions $c_t(y_t)$ and $C(R)$ used in the above formal representation, is a simple and useful manner of representing that when the production increases, more inputs are needed, and thus higher is the cost associated with the payment to the increased inputs.

This subsection aims at making explicit that the cost of production is allocated to inputs so as to assess how the inputs' revenue is affected by taxation.

Assume for simplicity that two inputs only are used in the extraction y_t at any date t: labor l_t and capital k_t, whose respective prices w_t and r_t are given. Specifically, the two inputs combine as per the production function $y_t = f_t(l_t, k_t)$ to determine the production y_t. Thus the cost of producing y_t is defined as the minimum expenditures necessary to produce y_t by choice of the combination (l_t, k_t), as follows:

$$\min_{l_t, k_t} w_t l_t + r_t k_t$$

$$\text{subject to } f_t(l_t, k_t) = y_t.$$

The minimised value function is $c_t(y_t)$.

5.B Distortions to the Rent Allocation

When taxation is neutral, it does not affect the production y_t, and thus not the revenue made by workers and capitalists providing services to the resource sector. Whenever taxation implies a distortion that reduces the production, the cost $c_t(y_t)$ must also be reduced. One may wonder if all inputs are affected in the same direction or if inputs' revenues vary in different direction as a result of the production reduction, i.e. if workers are more, less, or identically affected than capitalists.

In fact, one can show under very reasonable conditions on the $f_t(l_t, k_t)$ function introduced in the previous subsection, the two categories of inputs are affected negatively by an output reduction. It is sufficient for instance that the productivity of each input be decreasing with the use of this input, and be complements to the use of the other input.

6. Other Aspects: Multiple Deposits, Total Profits Uncertainty

6.A Multiple Heterogeneous Deposits and the Mine-Opening Decision

For simplicity, the analysis of Section 2 has considered a resource sector that consists of a single homogeneous deposit. As a matter of fact, resources are heterogeneous because they are extracted from various deposits that differ by their location, their geological property, their quality, etc... In the words of our single-deposit setting, deposits have different costs of exploration and development, as well as different costs of extraction.

Assume now that the resource sector under study produces a homogeneous resource, that is extracted from many heterogeneous deposits indexed by $j = 1,...,M$. At each date t, the total flow produced at the sectoral level is

$$y_t = \sum_{j=1,...,M} y_t^j, \qquad (15)$$

where y_t^j is the production extracted and processed from deposit j .

Deposits may not be developed at date $t = 0$ as the deposits in Section 2. Assume that deposit j is developed at date $\tau^j \geq 0$, $j = 1,...,M$, considered exogenously fixed for now.

There is an exhaustibility constraint like (1) for each deposit:

$$\sum_{t \geq \tau^j} y_t^j = R^j, \qquad (16)$$

where R^j is the level of exploitable reserves in deposit j .

Deposits differ by their costs of development $C_t^j(R_j)$ and by their costs of extraction $c_t^j(y_t^j)$. The cost of development may depend on time, to reflect that exploration and development technology may improve over time.

The problem facing the producer or the sector with the deposits is to maximise the sum of intertemporal profits derived from all the deposits, subject to constraints (16). The problem of developing reserves R^j, and of choosing extraction rates $(y_t^j)_{t \geq 0}$ for these reserves, is independent from one deposit to the other.

Assume that the dates τ^j are given. Then, the problem for each deposit is the same as for the single deposit discussed in Section 2. The only difference between such a deposit and the deposit in Section 2 is that the former is developed at a date that may differ from zero, which amounts to a redefinition of the time scale without loss of generality. The analysis of Section 2 carries over for each deposit and thus at the sectoral level.

When dates of development τ^j , $j = 1,...,M$, are free, they enter the problem as extra control variables for the producer. Daubanes and Lasserre (2012a) examine this situation. Under reasonable assumptions, a deposit will never be developed before its extraction begins. Unlike neutral taxation, distortionary taxation instruments may lead to a change in the opening choice of the producer. This is another source of distortion. As Daubanes and Lasserre (2012a) show, policies that penalise future extraction (e.g. a royalty) cause deposits to be opened earlier, and developed reserves to decrease.

6.B Total Profits Uncertainty

It has been assumed in the above formal analysis that producers are able to foresee perfectly future market conditions. The outcome of exploration activities and market conditions are in fact often very uncertain. A simple way to introduce uncertainty is to assume that the intertemporal profit of the producer is affected by a noise, which is zero on average; in other words, producers's expectations are right on average, or it is not possible to have better expectations than the average producer forecast.

In such context, the expected profit objective of the producer corresponds to its deterministic objective in the above treatment, so that the analysis is unchanged. The deterministic analysis of the above sections can thus be interpreted as an analysis in which all values are expectations or averages.

7. Performance of the Various Forms of Resource Rent Tax Schemes

This section summarises the performance of the main tax instruments used for resource sectors, in the light of the above analysis. Most of our conclusions are in line with Garnaut and Clunies Ross (1983) and Garnaut (2010).

7.A Fixed Fee

A fixed fee is in principle a once-for-all payment made in exchange of the rights to explore, develop and extract a resource on a specified area.

Its level is in general set by competitive bidding. When there are enough candidates to warrant competition, the auction system can make the private sector reveal its valuation of the rights, that is of the value of the resource. In that case, it is comparable with a maximum neutral profit tax. When there are not many such candidates, setting the level of the fee by individual negotiation is also an option. In either case, lack of competition makes the process subject to collusion. Also lack of transparency in the process may allow favoritism.

When uncertainty about the prospects of exploration is an issue, Garnaut (2010) suggested to combine competitive bidding with some tax conditional on the output (extraction revenues, or rent). See Garnaut (2010) for examples where those instruments have been imposed.

7.B Royalties

Royalties are similar to ordinary commodity taxes. They may be applied to extracted volumes (specific) or to extraction revenues (ad valorem). They have the distortionary effect characterised earlier in Section 4, which shows that royalties discourages the development of reserves to be exploited.

7.C Regular Profit Taxes

Extra profit taxes have sometimes been imposed to resource sectors under the rationale that part of their income are resource rents. Those taxes may take the same form as conventional taxes on corporate income that levy a constant fraction of positive instantaneous profits.

They may also be progressive, applying higher rates of taxation when profits exceed some specified amount.

As shown by the analyses of royalty-induced distortions and of distortions due to the risk of ex post exploitation penalties (Section 4), taxing profits only when they are positive, regardless of the prior investments made to develop profitable reserves, discourages reserves development and exploitation.

7.D Resource Rent Tax

What has been termed a resource rent tax aims at taxing the intertemporal profit. Unlike a tax on positive instantaneous profits, it allows the deduction from the taxable income of prior expenditures. In years when expenditures exceed revenues, no taxes are paid and the negative net cash flow is carried forward as a future tax credit. In years when expenditures fall short of revenues, tax credits may be used to reduce the taxable net cash flow, so that the tax is applied on the net cash flow, net of prior tax credits.[15]

Transferring expenditures across periods requires the use of an interest rate. For the resource rent tax to be equivalent to a neutral tax on the intertemporal profit, the rate of discount must be that of the producer's problem, i.e. the rate at which the producer can borrow to cover his expenditures. An objective rate may not exist at the sectoral level where companies may have different positions vis-à-vis financial markets.

Various versions of resource rent taxes exist, that should in principle be equivalent to each other. The Brown tax and some of its modifications provide for a payment to the company in years when expenditures exceed revenues. Such systems are closer to a theoretical intertemporal profit tax, that taxes net revenues and subsidises net expenditures at the same rate. The various existing versions differ in the treatment given to payments for negative cash flows. It has been argued (Garnaut and Clunies Ross, 1983) that such systems may be perceived as less credible to producers; when it is anticipated that costs will not be subsidised, the situation is not unlike the hold-up risk case described in Section 4.

Finally, resource rent taxation has the two limitations discussed in Section 3. First, it must give up a fraction of total profits to the resource sector so as to guarantee a minimum return to entrepreneurs. Second, it is subject to evasion. Evasion may be mitigated by combining the resource rent tax with royalties, because the tax base of royalties is harder to evade.

7.E Nationalisation

A nationalised resource sector can be interpreted as an extreme form of intertemporal profit taxation: all costs are directly incurred by the government; all benefits are directly collected. No rent is left to the private sector at all.

Such system requires that expertise exists at the state level so that delegation to the state-owned company and its regulation can be done efficiently.

The costs of a nationalised sector are agency costs due to the difficulty of monitoring the structure. Also, when financial stakes are very high, there is a risk of regulatory capture: a regulator that is swayed by the company's interest would be unable to impose adequate standards and practices, which would entail further social costs.

8. Empirical Rent Measurement

8.A Scarcity Measurement Literature

The literature on the measurement of non-renewable resources' rents was mainly initiated in the 1970s when concerns with oil scarcity became acute. The rents, or more precisely their increase, were indeed

15. Not all expenditures should be considered for tax deductions; financial expenses like interest on debts are usually not allowed as they are not part of the returns to investment. In the formulation of Section 2, those potential interests are implicit. Adding them would be redundant with the fact that flows of different dates are discounted.

considered to be a fairly good measure of resources depletion; following the well-known Hotelling rule, the higher the rents the closer the stock depletion. Another important argument for devoting attention to the measurement of oil rents is, of course, governments' need to raise public funds via taxation (See Sections 2 and 3).

A main estimation strategy advocated by the literature has been to look at exploration costs (see, e.g. Devarajan and Fisher, 1982 and Lasserre, 1985), which were expected to provide a lower bound of the total rent value. Below, we shall argue that, following our analysis of Section 2, rents can be much more easily estimated.

8.B Relevant Data for Taxation Purposes

According to Section 2, the most relevant notion of rent for taxation purposes is not the scarcity rent but the total profits produced by the sector. Hence, the empirical estimation of the total rents generated by resource sectors can be obtained using the data companies are obliged to declare to fiscal authorities (Garnaut, 2010). Indeed, the data used to estimate the resource sector's profits should not be any different from the data used to tax it.

Obtaining the necessary data can nevertheless be a challenge in resource-rich low-income countries, mainly due to more severe asymmetric information issues (Collier, 2010). In such countries, governments suffer from a higher informational disadvantage compared to OECD-member countries; the lack of specialist information among public servants, in particular, is an important issue.

8.C Other Issues: Discounting, Evasion...

Our analysis assumed that all values can be expressed in present-value terms. This requires that an objective rate exists at which values earned at different dates can be discounted and compared. The relevant rate of discount for the estimation of rents to be collected by governments must depend on the interest rate at which the government under study can cover its current needs.

Because of evasion possibilities, a distinction must be made between existing or future rents and the part of those rents that can be collected by the government. When estimates of the evasion of corporate incomes exist in other sectors, their should be taken into account to calculate taxable resource rents.

9. Resource Taxation Income and its Management

The income generated by non-renewable resource sectors is an essential component of the GDP of about 50 countries (van der Ploeg and Venables, 2012). Among these, some have been able to grow on the basis of these revenues (e.g. Norway, Chile), while others have not. The latter are generally recognised to suffer from the "resource curse" (e.g. Nigeria).[16] Hence, along with the measurement and taxation of resource rents, the adequate use of the public revenues these rents generate is a crucial issue for resource-rich countries. In this section, we thus focus mostly on the macroeconomics of revenue management.

9.A The Permanent Income Hypothesis

The standard analysis of resource-revenue management has long relied on the "Permanent Income Hypothesis" (PIH for short) which provides a theory of how consumption should vary with income. According to the hypothesis, short-term or temporary variations in income should not affect current consumption levels. Consumption should indeed be smoothed rather in consideration of the long-run level

16. There exists a vast literature on the determinants and consequences of the resource curse. Readers interested in this specific topic may refer to van der Ploeg (2011) for recent a review.

of income. Hence, applying the PIH rule to resource windfalls tells that resource revenues should be saved so as to hold constant the level of wealth, with consumption set equal to the interest earned on this stock of wealth. In the meanwhile, the depletion of the natural resource should be offset by the implied accumulation of other assets.[17]

A simple way for governments to comply with this rule is to hold revenues in a standard investment fund. This raises at least two questions. The first question concerns whether public revenues derived from non-renewable resource sectors should be accumulated in a specific fund or pooled with other revenues. The stylised theory would suggest pooling so as to allocate them to public expenditures in a way that equalises the marginal benefit of public spending across all expenditures. In some cases, pooling revenues offers greater flexibility to countries in case they face unexpected changes (e.g. natural catastrophes) implying priority expenditures (Collier, 2010).

The second question assesses whether the fact that a large fraction of public revenues is derived from non-renewable resource sectors affects the optimal constitution of the public's asset portfolio. The answer depends on the situation of the country. The case of developing countries will be discussed in the next subsection. In absence of market power on the resource market, the portfolio theory suggests that the portfolio composition should follow the standard rules of financial assets management: choose investments that maximise the expected return for a given portfolio risk or equivalently minimise the total risk for a given expected return, regardless of the origins of funds. Domestic investment should be completely independent of resources revenues and there is a complete separation between the production side of the economy and resource wealth. Van der Ploeg and Venables (2012) recommend investing all savings into foreign assets.

In the presence of market power on the resource sector, things may not be so simple. According to the multi-product monopoly literature, market power exerted on several related markets can be complementary. Thus for a large resource producer, it can make sense to invest strategically in sectors so as to magnify the demand for the resource.

The PIH hypothesis is only a good guide for policy advice when countries are not subject to liquidity constraints and capital absorption constraints. As we shall see below, this is manifestly not the case for low-income countries. The case of these economies call for different uses of resource revenues (Venables, 2010).

9.B Revenues Allocation in Developing Economies

Developing economies tend to face a number of constraints that turn long-term growth and development into more challenging objectives to achieve. In order to be effective, the management of resource revenues must acknowledge these specific constraints. In particular, credit constraints imply that the PIH does not serve as the most effective policy guide. A direct consequence is that, rather than saving these revenues in sovereign funds, it is optimal to allocate at least part of them to reducing these constraints. In the following, we evoke the main constraints that resource revenues can potentially decrease.

First, developing countries tend to face fiscal constraints – with an associated shortage of public funds – and capital scarcity. The low levels of capital concern both public capital (e.g. roads, electricity network) as well as publicly funded services (e.g. education and health). A resource windfall can then be used to increase the stock of public and human capital and thus raise the productivity of private capital. Concurrently, resource wealth can also effectively be allocated to reducing the cost of capital for the

17. The IMF in particular has often advocated this rule as the optimal strategy for resource-rich countries. See for instance Venables (2010), and the references therein.

private sector, by improving credit worthiness and lowering borrowing rates in international markets. Combined with public capital investments, this can effectively boost private investment and enable capital deepening of developing economies.

On top of capital constraints, developing countries also face high levels of poverty. This specific concern calls for using a least part of the resource revenues for reducing poverty in the current generation. This results in a trade-off on revenues allocation between capital accumulation and increased consumption. The optimal balance of these two objectives will be determined by the needs and characteristics of each specific economy.

As a result, when compared to the PIH benchmark, developing countries' optimal composition of savings should incorporate higher levels of domestic, rather than foreign, investment. Also, the level of savings should be lower than under the PIH, since it is optimal to raise the consumption of the present generation. Nevertheless, investing in foreign funds may still be useful for cushioning volatility in prices and revenue streams. Of course, should the economy not be able to absorb capital investments then reserving funds and implementing the PIH rule becomes optimal (see van der Ploeg and Venables, 2010).

Finally, the relationship between private and public sectors is also an important issue for determining optimal resource-revenue management. Private sector investment is the main mechanism through which resource wealth can sustain growth and employment; It is not, however, a control variable for the government. Hence, the constraints faced by the private sector are important to understand. These will ultimately determine the optimal use of resource revenues.

While we have focused here on three main instruments (purchase of foreign assets, investment in public capital and services and transfers to the private sector), many other instruments are available to resource-rich countries' governments. Among these, one can cite direct support to productive sectors, reduction of tax distortions and domestic debt management. The effectiveness of these instruments will of course depend on the institutional capacity of each government to implement them.

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