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Abstract

The exploitation of natural resources often generates considerable economic rent. Since such so-called resource rents accrue due to innate characteristics of the resource itself thus reflecting its economic value and not due to managerial abilities of the exploiting firm, at least part of it should - as a price for the use of the resource – be collected by the owner of the resource, which is often the government.

As the owner of the resource faces a classical principal-agent problem, the incentives to exploit a resource efficiently should be taken into account when setting up a rent extraction scheme. We present a formalism that unifies different existing approaches to such schemes and address issues such as asymmetric information, risk aversion, and uncertainty. Finally, we discuss the feasibility to base a rent extraction scheme on such a formalism and point out its main problems. The most important ones are the presence of intrinsically unobservable and very uncertain values and the high complexity of the formalism.

There are mainly two possibilities to deal with these problems: either to make additional assumptions and to set boundary conditions such as to solve the problem in a simplified setting, as much of the literature does, or to refrain from solving it, and instead use it as a general guiding principle, which helps to avoid gross errors and shows the broad direction, but leaves the concrete implementation rather to a political process than to an economic analysis.

Keywords: natural resource rent, incentives, rent extraction, regulation
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1 Introduction

Natural resource extraction often generates economic rent, i.e. a surplus profit due to a difference between the price at which the resource or a product of it can be sold and the respective extraction or production costs. An example is the situation in a free electricity market where the marginal producer (e.g. gas turbines) incurs higher costs and thus producers of another technology (hydropower, coal, nuclear power) face a market price, which is above their production costs. This extra profit is not linked to the utility's ability, but to the quality or the scarcity of the natural resource exploited and can thus be understood as its value. Thus, the owner of the resource, which is often the government, has reasons to claim a "fair share" of this rent. In consequence, a main objective of the government is to implement a system to extract at least part of the rent without eroding incentives for the firms to operate efficiently and to attract investors. In particular, such a system could take the individual market situation and cost structure into account (probably including some site-related factors) and thus prevent allocative inefficiency.

In this paper, we present a generalized formalism to describe the resource rent extraction problem in a principal-agent framework.

We base our discussion on three starting points:

First, we are concerned with the concept of the natural resource rent and economic rent in general, discussing scarcity, quality and quasi-rent and their relation to "ordinary" profit.

Second, the goal of the owner of the resource to extract part of this rent calls for mechanisms to do so without spoiling incentives to produce efficiently and to (re-) invest in infrastructure. We present the basis of incentive regulation theory and show how the results can be used to define such a resource rent extraction mechanism.

Third, we unify a wide range of approaches to natural resource rent extraction given in the literature in one common formalism, including issues such as asymmetric information, risk aversion, and uncertainty. We assess the feasibility of this formalism in practical applications. In particular, we point out why this formalism fails to give complete recipes on how to ideally extract the resource rent. Moreover, normative questions and political attitudes are also important as economic criteria in determining a concrete extraction scheme. The formalism mainly serves to avoid gross mistakes and can provide some general guidelines. To tackle concrete situations of resource rent extraction it is best to analyze the respective industry paying due attention to the concrete and often intricate situation and institutional structures and rely less on some findings provided by the analysis of simplified models of mainly academic interest.

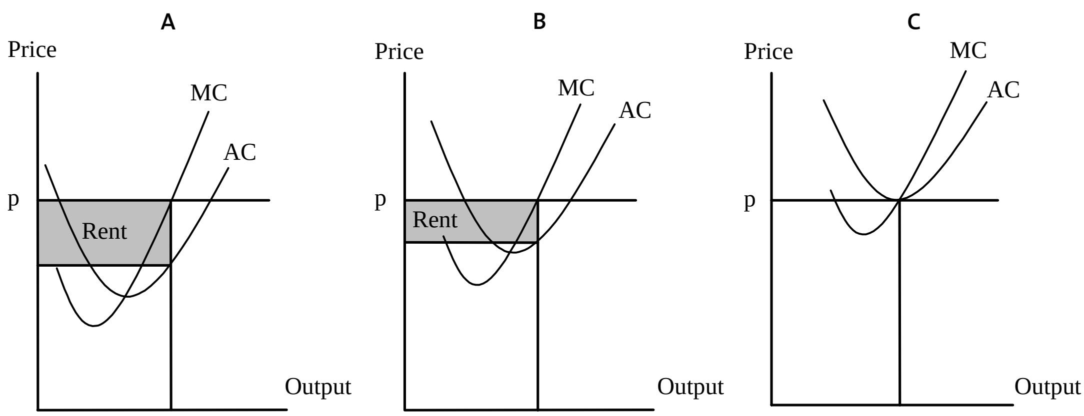
To develop such a general formalism only to state that it is of little practical use may be seen as a purely academic exercise. However, the problems approached in the literature are often down-to-earth ones and we consider it crucial to point out how big the simplifications made are in the analysis. This general formalism serves to build awareness for the discrepancy between a realistic formal treatment and the considerably lower complexity where such a formalism still allows for solutions. If this treatment achieves this goal and makes more researchers think critically on the status of extensive analytical formalisms to be applied in practical settings, we are satisfied.

2 The Natural Resource Rent

An economic rent is a surplus value, that is, the difference between the price and the production costs of a good. In Ricardo's (1817) classical example, economic rent accrues due to different productivity of different agricultural production sites. A site with less favorable characteristics will – ceteris paribus - face higher production costs, and thus earn less (in the case of a free market with exogenously given prices). The marginal firm will be able to cover exactly its production costs and not receive any economic rent. In many realistic examples, it could be argued that one producer might face ideal conditions to construct and operate a plant, whereas another firm will build its plant in a location with more difficult base characteristics, and thus will have higher investment and operation costs for a given output. Thus, in a free market situation with exogenously given prices, the rent can be seen as reflecting the "true economic value" of the natural resource exploited and is, per unit of output, given by the difference between the price and the average production cost.

Illustration 1 shows the situation of three different production sites. Firms A, B and C do not differ in any other characteristic but the production environments they face.

Illustration 1: Different production sites and the resource rent (MC/AC = marginal/average costs)



At market price p, firms A and B decide on their output (where MC=p) and are earning an economic rent, which is represented by the shaded area. Producer B faces less favorable site characteristics and thus produces at higher costs than producer A, but still exhibits lower costs than the marginal competitor, C, who just covers his average/marginal costs at market price p.

Economic rent can be divided into **three different kinds**: differential, scarcity, and quasi-rent. Differential rent arises because of innate differences of production sites, as described before, whereas scarcity rent emanates from excess demand for the good, which is only available in restricted supply, due to natural or political circumstances[1]. Both kinds of rent arise from the characteristics of the natural resource and their sum is therefore called 'resource rent'. These two kinds of rent can also be described by scarcity rent alone, taking the viewpoint that the differential rent accrues due to the relative scarcity of high-quality sites and thus making lower quality sites just profitable to exploit. Due to their nature, differential and scarcity rent are not competed away even in a free market. In contrast, quasi-rent is defined as an economic value, which can be attributed to a firm's extraordinary wise investments in its facilities. Such investments could be: advertising, specific training of the employees, and so forth. These expenses can result in a higher price (brand) or lower costs (better technology)[2]. Quasi-rents are thus rents, which accrue due to managerial investments in the products and should be left with the company in order to have it make these investments. Further on, quasi-rents tend to be competed away as the competitors will adopt such profitable strategies as well. On the other side, the resource rent is not attributable to managerial effort, but only to the resource itself. It belongs, therefore, to the owner of the resource and should be at least partly extracted. Full extraction could only take place if one faced a situation of full information and perfectly enforceable contracts. A reasonable sharing mechanism has to be found, which redistributes part of the rent to the owner of the resource without destroying the incentives for the firm to operate efficiently, which would result in a lower rent to be shared.

Given the definition of the rent as the difference between prices and average costs, it is clear that these two quantities have to be defined precisely. In the case of a liberalized market, the prices are exogenously given and can be observed. In this situation, the concept of natural resource rent is sensible for assessing the price for the use of the resource. Otherwise, if the market prices are regulated by the government or set by a monopolist, it is less useful, since it does not reflect anymore the true economic value of the resource. However, regardless of how the prices are set, as long as they are not affected by the resource extraction scheme, the discussion of these schemes remains the same for all prices.

Regarding production costs, it has to be decided which cost components to include and how to define them. One question to be answered is if the costs include taxes or not. From the definition of the resource rent it is clear that profit-related taxes should not be included. But it has to be paid due attention to this fact, especially when it comes to combine the rent extraction and the tax scheme to be applied. Taxes and fees are often interconnected, resp. one cannot be assessed without considering the other. Another crucial point is the capital costs: For the resource rent, the costs should include some "reasonable" rate of return for outside and company capital. Thus, the only difference between the natural resource rent and

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[1] Some general references on the concept of the economic rent and the resource rent in particular are Tietenberg (2000) and van Kooten and Bulte (2000)

[2] Further information on the quasi-rent may be taken from Johansson (1991) and van Kooten and Bulte (2000).

the company profit[3], and in consequence the only difference between rent and profit sharing mechanism to extract the rent (see below) is the assessment of several cost components.

Besides review articles, most of the literature on natural resource rent and its extraction deals with the comparison of different extracting schemes in a more or less restricted setting (Amundsen et al., 1992; Osmundsen, 1995; Quentin-Grafton, 1995; Sappington and Weisman, 1996; Fraser and Kingwell, 1997; Amacher et al., 2001; Lund, 2002; Osmundsen, 2002) - some of them explicitly focusing on issues of risk-sharing and uncertainty (Campbell and Linder, 1983; Chavas 1993; Sansing, 1993; Bousquet et al., 1998; Fraser, 2000; Low, 2000). A general overview on the various sharing-mechanisms under operation can be found in the following contributions:

Garnaut and Ross (1975) address the problem of rent extraction under risk aversion, uncertainty (long investment periods) and private information, and propose a realistic rent extraction scheme, namely the resource rent tax. They show the drawbacks and complications of this scheme, but conclude that it reduces the risk of loss to the investor that is associated with a given expected tax.

Copithorne et al. (1985) name the different instruments at hand to share the values of natural resources and point out their advantages and limitations. They illumine the rent collection by royalties and taxes used in Alberta, and dwell on the cash flow tax.

Heaps and Helliwell (1985) do not only present the wide range of possible extraction schemes including discussions of applications in more specific settings, but also mention the main problems and potential drawbacks faced by extraction schemes in general.

3 Description of the general rent extraction scheme

3.1 Incentive regulation

To describe rent extraction systems, we employ the methods of (new) regulatory economics (Laffont and Tirole, 1993). We motivate this by the following observation: Regulation comes into action in the presence of market failures, e.g. in monopolistic/oligopolistic structures or natural monopolies, where the firm, by maximizing its profits, causes welfare losses by equating marginal costs with marginal revenue and earning a monopoly profit, or by setting the price higher (at average costs) than marginal costs in the case of a natural monopoly. The objective of the regulator is to maximize total welfare and thus to set the prices subject to the constraint that the monopolist breaks even. Thus, the regulator may set the prices the monopolist can charge, e.g. by cost-of-service regulation (i.e. the prices are set to cover the costs) or by a price cap (i.e. the maximum price that can be charged is fixed by the regulator). Depending on the concrete implementation, such price-setting rules bear the danger of eroding the incentives for the mo-

[3] Besides the conceptual ones, like understanding the rent as the value of the resource, etc.

nopolist to produce efficiently (especially with a cost-of-service rule) or to leave ‘too much’ monopoly rent with the producer (with price-cap regulation), which may also result in welfare losses. Moreover, some regulation mechanisms might lead to a situation where an otherwise marginal project becomes unprofitable (fixed fees). The regulator wants the monopolist to produce at an efficient cost level, which would, in a world of complete information, not be a major problem. But due to the presence of asymmetric information (moral hazard and adverse selection) regarding the type of the firm and the effort supplied to lower costs, i.e. with regard to the true costs, the regulator faces an inherent trade-off between reducing the monopoly rent and providing incentives to produce (and sell) efficiently. This is a main result from the ‘new theory of regulation’ as presented in Laffont and Tirole (1993): in order not to erode the incentives of the firm to produce efficiently and to make further investments, the government has to cede part of the (monopolistic) rent to the firm.

From this example we can deduce three main ingredients to regulation: a price–setting rule, a scheme to redistribute the remaining rent that is given by the difference between prices and costs without eroding the incentives to produce efficiently and reinvest, and, contemporaneously, an approach to minimize the asymmetric information problem. Assuming that both the firm and the government try to maximize their utility[4], and specifying these utility functions, this allows at least in principle to identify a set of optimal schemes.

This general setting of new regulatory economics also applies to the case of natural resources: The resource rent, given by the difference between prices and costs, is not reduced to zero even in a competitive market. This leaves the proprietor (often the government) with the problem to extract and redistribute at least part of this rent. In a competitive market, the prices are exogenously given and thus the price-setting rule does not need to be discussed. The scheme how to redistribute the rent without eroding the incentives to produce efficiently - and also to sell in a profit-maximizing way - and the need to reduce the problem of asymmetric information, however, are of primary importance. Thus we can make use of the formalism and results from regulatory economics.

In the following, we concentrate on the first point, i.e. to describe incentive-compatible rent extraction systems. We will not discuss additional measures to reduce the problem of asymmetric information, such as a benchmarking based on econometric estimations of the cost-function of several firms or a scheme that offers the firm a set of contracts, designed in such a way that each firm chooses the one that suits it best, corresponding to its efficiency level (cf, e.g. Laffont and Tirole (1993)).

[4] More specifically, the structure of the relation between firm and state can be described by a two-stage sequential game, where the state plays first and the firm subsequently chooses the strategy maximizing its utility.

3.2 The general formalism

General Assumptions

In this section, we present a unified formulation of the natural resource rent extraction problem. The general setting is as follows, based on the concepts defining the formalism used by Laffont and Tirole (1993)[5]: we consider a firm *F* exploiting a natural resource, which is the property of the government over some years $t = 1,...N^F$, be it nonrenewable (i.e. the exploitation comes to an end: $N^F < \infty$) or renewable (i.e., if managed in a sustainable way, exploitation may take place forever: $N^F = \infty$). Income, extracted quantities, boundary conditions, etc. are assessed on an annual basis. We assume the situation of a free and competitive market for the end products, thus they are sold at exogenously given prices and the utilities do not have the market power to influence them. We may have product differentiation (e.g., in the power sector, peak- or base load power, regulating power, reserve capacity, green power, etc.), i.e. the utility sells K_t^F different "qualities" of the resource (with quantity $q_{i,t}^F(p_{i,t}) \in \mathbf{R}, i = 1,..., K_t^F$) at the respective market prices $p_{i,t}$, and, due to the situation of a free market, the utility can sell as much as it chooses to produce. Some exogenously given parameters (as interest rates, inflation, etc.) that are of influence for all the utilities are summarized in the vector $\vec{\theta}_t \in \mathbf{R}^k$. It is assumed that they are common knowledge. Firm-specific qualities (i.e. the technology employed, the quality of the site, etc.) are not or only partly observable and summarized by $\vec{\theta}_t^F \in \mathbf{R}^l$ which, in combination with $\beta_t^F : \mathbf{R}^l \to \mathbf{R}, \vec{\theta}_t^F \mapsto \beta_t^F(\vec{\theta}_t^F)$, the efficiency level of the firm of type $\vec{\theta}_t^F$, formalizes the adverse selection part of the asymmetric information problem. In addition, we assume that the natural resource production is the only source of income for the firm. Within this setting, the total annual natural resource rent produced by a firm, described by the function $R_t^F : \mathbf{R}^{K_t^F} \times \mathbf{R}^k \times \mathbf{R}^l \to \mathbf{R}$, which takes the values $R_t^F(q_{1,t}^F,..., q_{K_t^F,t}^F, p_{1,t},..., p_{K_t^F,t}, \vec{\theta}_t, \vec{\theta}_t^F, \beta_t^F)$, is given by the difference between its total revenue, $\sum_{i=1}^{K_t^F} p_{i,t} q_{i,t}^F(p_{i,t})$, and its total production costs $C_t^F(q_{1,t}^F,..., q_{K_t^F,t}^F, \vec{\theta}_t, \vec{\theta}_t^F, \beta_t^F)$[6]. Profit-related taxes and other fees to be paid are described by $T_t^F(q_{1,t}^F,..., q_{K_t^F,t}^F, \vec{\theta}_t, \vec{\theta}_t^F, \beta_t^F)$ and are not included in the total production costs. Let $\tilde{R}_t^F$ be the amount of resource rent, which is to be partly extracted by the owner of the resource.

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[5] However, we make fewer assumptions than they do in their book. In particular, we do not assume risk-neutrality of the firm and the government.

[6] Including labour, material, energy and other rather "variable" costs plus capital costs etc., i.e. more "fixed" costs. In particular, these costs *shall not include* any profit-related taxes but *must include* the return on company (e.g. dividends, reserves) *and* outside capital.

The case of interest is $R_t^F > 0$, which is the case where some rent, at least some scarcity rent, is present. Due to that, the allocation of productive factors does not need to be efficient, since the firm can make some profit without being on the "proper" production possibility frontier.

Problems with an extraction mechanism

We now come back to the problem to be solved in the context of rent extraction: to propose a concrete extraction scheme that does not erode incentives to operate efficiently and to (re-) invest.

The problems with the goal of setting incentives for efficient production are twofold.

1. The presence of asymmetric information, i.e. missing information on the cost structure or on the true (capital) costs of the firm, prevents the government from knowing the true amount of the rent and thus from extracting just this amount. In addition, it is not clear if any reported or otherwise observed cost level coincides with the cost of an efficient firm – i.e. it is not clear where to set the benchmark of efficient costs to be used as a point of reference to assess the single firm. Thus, in general, this calls for some mechanism (e.g. a benchmarking using yardstick competition) to assess the efficiency parameter $\beta_t^F(\vec{\theta}_t^F)$ of the firm, i.e. to know how efficient production could be in the best case, or which part of inefficiency is related to the (unobservable) type $\vec{\theta}_t^F$.

2. More efficient production is tied to some costs of effort for the firms. This effort $e_t^F \in \mathbf{R}$ can be coded directly as the cost reduction achieved: a function $\Psi_t^F : \mathbf{R} \times \mathbf{R}^l \times \mathbf{R}^k \to \mathbf{R}$ taking the values $\Psi_t^F(e_t^F, \vec{\theta}_t^F, \vec{\theta}_t, \beta_t^F)$ shall denote the disutility/expenses for the firm to reduce its costs by e_t^F. This function depends on the type of the firm, $\vec{\theta}_t^F$, its efficiency level β_t^F and the general boundary conditions $\vec{\theta}_t$. Due to these definitions, Ψ_t^F also measures the incentives provided to the firm to become more efficient. The incentives to do so are high enough if the firm is willing to incur the disutility to reduce production costs or to increase the revenue, e.g. by optimizing the relative amount of the different qualities of output produced[7]. Thus, the effort level and the cost of the effort enter the cost function of the firm as well and add to the problem of asymmetric information due to them being unobservable (moral hazard). Parallel to the corresponding quantity for the firm we add a quantity $\Psi_t^G(e_t^F, \vec{\theta}_t^F, \vec{\theta}_t, \beta_t^F)$ to the theory to reflect the costs the government incurs by setting the incentives for the firm to provide effort e_t^F to increase efficiency.

[7] As can be seen from equation (2), these two possibilities can be captured by the same utility function, as reducing the costs by e_t^F or increasing revenues by the same amount have the same effect on it.

Given all this input we can now formalize the utility function of the firm and the government and their respective maximization problem with regard to the quantities at discretion to the firm and the government, respectively (i.e. the output produced, rent extracted, effort level provided and investments planned and undertaken). This, in principle, provides the conditions for the optimal solution for a rent extraction system.

Establishing a general formalism

On this level, the preference relations of the government and the firm on the set of alternative situations X (i.e. different choices of the parameters and variables introduced above) shall be given by the prescription that higher monetary returns are preferred to lower ones and alternatives yielding the same return are indifferent to each other. Thus, we have a rational preference relation on X which, in consequence, can be represented by a (Bernoulli-) utility function. One choice of these functions for the government and the firm, respectively, is given by the monetary value of the respective returns. r_t shall denote the discount rate and λ_t the shadow costs of public funds in period t.

$$u_t^G = \tilde{R}_t^F \cdot (1+\lambda_t) + T_t^F - \Psi_t^G, \qquad u^G = \sum_{t=1}^{N} (u_t^G \cdot \prod_{i=1}^{t-1} \frac{1}{(1+r_i)}) \qquad (1)$$

$$u_t^F = \sum_{i=1}^{K_t^F} p_{i,t} q_{i,t}^F(p_{i,t}) - (C_t^F - e_t^F) - T_t^F - \tilde{R}_t^F - \Psi_t^F, \quad u^F = \sum_{t=1}^{N} (u_t^F \cdot \prod_{i=1}^{t-1} \frac{1}{(1+r_i)}) \qquad (2)$$

In these formulae, the rent extracted, $\tilde{R}_t^F$, depends in principle on all the quantities involved: $\tilde{R}_t^F = \tilde{R}_t^F(R_t^F, C_t^F, T_t^F, \Psi_t^F, \Psi_t^G, e_t^F, q_{1,t}^F, ..., q_{K_t^F,t}^F, p_{1,t}, ..., p_{K_t^F,t}, \vec{\theta}_t, \vec{\theta}_t^F, \beta_t^F, r_t, \lambda_t)$. The basic boundary conditions for the firm and the government are their respective participation constraints:

$$u^G \geq 0 \text{ and } u^F \geq 0. \qquad (3)$$

The objective of the government resp. the firm is to maximize its utility. Taking the tax scheme as given exogenously and not being subject to changes, the government (resource owner) designs a rent extraction scheme for the firm: The objective of the firm is then to maximize its utility given this rent extraction scheme (thus, the two actors play a two-stage, sequential game with the government playing first).

These utility functions assume complete knowledge of the exogenous parameters like the prices. In general, this complete knowledge is –especially in the long run- not given and the external parameters have to be replaced by probability distributions, which, on their own, may not be perfectly known. We have to deal with this uncertainty by means of expected values of the utility functions, or, put differently, by the introduction of the von-Neumann-Morgenstern (vNM) expected utility function. Thus, we introduce the following probability distributions: $f_{i,t}^{p_{i,t}}(p_{i,t})$ for the distribution of $p_{i,t}$, the price of product i

at period t, and $f_{i,t}^{q_{i,t}}$, $f_t^{\lambda_t}$, $f_t^{\theta_t^F}$, $f_t^{\theta_t}$, $f_t^{\beta_t^F}$, $f_t^{e_t^F}$, $f_t^{\lambda_t}$ and $f_t^{r_t}$ for the probability distributions of the respective quantities indicated in the superscript. Usually, most of these distributions will be more or less well known. The vNM utility function is given by the expected value of the utility functions in each period, i.e. by inserting these distributions of the variables instead of the variables in (1) and (2) and subsequent integration over the original variables. The total vNM utility functions are then given by the sum of the expected values calculated after multiplication with $\prod_{i=1}^{t-1} \frac{1}{(1+r_i)}$ over $t=1$ to N.

We can generalize even further by considering not only one but P different firms. If these firms are not interlinked by inter-firm externalities, the problem is separable into P one-firm problems (Laffont and Tirole 1987). If, however, the firms are linked by inter-firm externalities, e.g. in a setting where a common access problem is present (e.g. in fisheries), these externalities have to be included into the utility functions of the firms. This is formalized by inclusion of the output produced by each of the firms as parameters in the cost function for each of the other firms.

Summing up, we have thus the expected utility functions of the government and the P firms over the whole extraction period (where, to avoid problems, $N=\infty$ for renewable resources may be replaced by some finite number, e.g. motivated by the (expected) lifetime of the physical capital built, and an additional condition on the size of the stock at the end of this period):

$$U^G := E\left[u^G\right] = \sum_{t=1}^{N} E\left[u_t^G \cdot \prod_{i=1}^{t-1} \frac{1}{(1+r_i)})\right] = \sum_{t=1}^{N}\left[\sum_{F=1}^{P} E\left[u_t^G(\tilde{R}_t^F, T_t^F, \Psi_t^G, \lambda_t) \cdot \prod_{i=1}^{t-1} \frac{1}{(1+r_i)})\right]\right] \tag{4}$$

with

$$E\left[u_t^G(\tilde{R}_t^F, T_t^F, \Psi_t^G, \lambda_t) \cdot \prod_{i=1}^{t-1} \frac{1}{(1+r_i)})\right] = \int \ldots \int (\tilde{R}_t^F \cdot (1+\lambda_t) + T_t^F - \Psi_t^G) \prod_{i=1}^{t-1} \frac{1}{(1+r_i)} \omega_t^F \, d\omega_t^F \,, \tag{5}$$

where the integration is over all variables. We have introduced the probability distributions, represented by the probability measure

$$\begin{aligned} \omega_t^F d\omega_t^F &:= f_t^{\theta_t^F}(\theta_t^F) f_t^{\theta_t}(\theta_t) f_t^{\beta_t^F}(\beta_t^F) f_t^{e_t^F}(e_t^F) f_t^{\lambda_t^F}(\lambda_t^F) \prod_{i=1}^{t-1} f_t^{r_t^F}(r_t^F) \prod_{j=1}^{K_t^F} f_{j,t}^{p_{j,t}}(p_{j,t}) \cdot \\ &\cdot d\theta_t^F d\theta_t d\beta_t^F de_t^F d\lambda_t^F \prod_{i=1}^{t-1} dr_t^F \prod_{j=1}^{K_t^F} dp_{j,t}. \end{aligned} \tag{6}$$

Congeneric equations give the expected utilities of the firms. These are subject to the expected utility version of the participation constraints (3) and the solution is characterized by the requirement of the maximization with respect to the quantities at discretion of the government and, subsequently, of the firm.

Further considerations

Up to now, the discussion has been focused on matters of economic efficiency alone (due to the goal of profit maximization implied by our definition of the utility functions). Further on, only monetary terms and probability functions have entered the utility function to assess the incomplete information. But besides the issues and quantities represented in the terms of the maximization problems stated above, the formalism should include means to assess potentially different preferences for the certainty with which a certain amount of revenue or profit is realised in a determined period and for different values of the spread of such an expected value. More formally, it should allow for means to assess the degree of risk-aversion of the firm and the government. This is not the case in our formulation as can be seen using the classical notion of risk-aversion[8]. According to this, the utility function as defined above represents a risk-neutral agent. To include risk-aversion or its opposite, we have to somehow redefine the formalism.

In addition, the utility function should also reflect 'soft' issues such as the fact that it does matter whether a certain amount to be paid represents total rent/profit or only a small percentage of it. This is an example employing some notion of 'justice', which might influence the effort level of a firm[9]. It has to be paid due attention as well to the presence of such and other values of importance for the players.

From a theoretical point of view, we have the following possibilities to include these additional topics into the formalism:

a) We can define other utility functions, not setting monetary quantities equal utility, as do the functions defined in equations (1) and (2), being basically the identity map between profit and revenue and the corresponding utility. Thus we could represent preferences that are, for example, more sensible to changes at a lower than a higher level of total income.
Formally, such new utility functions can be defined by composition with a strictly increasing function $f:\mathbf{R}\rightarrow\mathbf{R}$: $v(x) := f(u(x))$. However, it might be necessary to use more general functions as well.

b) We can introduce additional terms into the utility functions. However, due to their design, this essentially boils down to a monetarization of these additional issues, a complex and far from straightforward task that cannot be undertaken in a truly objective manner. Moreover, it is not the topic of this paper to discuss such normative issues, which would have to be addressed in a political process anyway. An example would be the monetarized value of a potential production site not being exploited for society but left in its original state for recreational activities. This option may be only feasible in combination with a).

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[8] I.e. $E[u(L)] < u(E[L])$ for all lotteries L and, in consequence, concave utility functions (for the definition and discussion of lotteries we refer to Mas-Collel et al. (1995)).

[9] It might even refuse to exert part of the cost-reducing efforts even if this attitude diminishes its own rent. For a discussion of this behaviour called 'strong reciprocity' see Fehr et al. (2002).

c) We can impose more conditions on the utility functions and their derivatives. A key role may be played by conditions for the utility function for one period t or for the change of it between two subsequent periods. As an example, we present the situation where the government decides its utility (i.e. revenue) to be larger than some minimum amount. This could be implemented by altering the value in the participation constraint of the government. A preference on the side of the firm to have relatively constant expenditures could be taken into account by means of a fixed fee. We could also impose some conditions on single terms in the utility functions only and on their derivatives, for example by imposing some cap on the profit of the firm to avoid it making exorbitantly high profits.

These possible generalizations finally lead to the most general extraction scheme, where the rent extracted by the government (the owner of the resource) is given by the total rent generated times an extraction factor depending on all the parameters, quantities and probability functions and its value has to be identified by solving the constrained maximization problem:

$$\tilde{R}_t^F = \alpha_t^F (R_t^F, C_t^F, T_t^F, \Psi_t^F, \Psi_t^G, e_t^F, q_{1,t}^1, ..., q_{K_t^P,t}^P, p_{1,t}, ..., p_{K_t^F,t}, \vec{\theta}_t, \vec{\theta}_t^F, \beta_t^F, r_t, \lambda_t, f_t^{...}) \cdot R_t^F, \quad (7)$$

where $\alpha_t^F \in [0,1]$ and it is also understood to depend on all the probability distributions involved In the formalism, symbolized by $f_t^{...}$. If no asymmetric information and incomplete knowledge on the parameters was present, the government could always extract the total rent: $\alpha_t^F = 1$. However, due to the presence of asymmetric information, part of the rent has to be ceded to the firm (Laffont and Tirole 1993), i.e. $\alpha_t^F < 1$, and this may be done depending on the parameters involved as indicated in equation (7).

By the very nature of the rent, given by the difference between the revenue and the costs, it is possible to translate equation (7) into a more appealing form, intuitively incorporating some of the additional issues alluded to above, like additional incentives and risk-aversion. Allowing for a disproportional part of the cost to be subtracted from the revenue could further refine the incentive scheme. Thus, depending of this being disproportionally higher or lower it further increases incentives to lower costs or to maximize revenues, since a larger part of the extra profit made by these actions would stay with the firm (cf. Sappington and Weisman (1996) for the former possibility). To incorporate risk-aversion etc., one could include a fixed fee into the scheme, thus decreasing the uncertainty with regard to the amount of money paid and received respectively. Thus, we arrive at the following general formula:

$$\tilde{R}_t^F = \delta_t^F \sum_{i=1}^{K_t^F} p_{i,t} q_{i,t}^F (p_{i,t}) - \gamma_t^F C_t^F + \overline{F}_t^F, \quad (8)$$

where, in principle, the parameters δ_t^F, γ_t^F and $\overline{F}_t^F$, again to be found by solving the maximization problem, can depend on all the parameters and distribution functions in the model. This formula reflects the only possibilities there are to base a rent extraction scheme on in our setting: by relating it to the revenue (achieved by δ_t^F), to the costs (by γ_t^F) or to both (as the rent is given by the difference of these two), and to a scheme independent of them, i.e. a fixed fee ($\overline{F}_t^F$). This can be brought into an intuitively more appealing form that describes the general rent extraction scheme as a combination of a profit- (rent-) and a revenue-sharing mechanism, each with a threshold below of which no extraction takes place, and a fixed fee:

$$\tilde{R}_t^F = \gamma_t^F \left(\sum_{i=1}^{K_t^F} p_{i,t} q_{i,t}^F (p_{i,t}) - C_t^F - \overline{R}_t^F \right) + \left(\delta_t^F - \gamma_t^F\right)\left(\sum_{i=1}^{K_t^F} p_{i,t} q_{i,t}^F (p_{i,t}) - \bar{I}_t^F \right) + \\ + \left(\overline{F}_t^F + \gamma_t^F \overline{R}_t^F + (\delta_t^F - \gamma_t^F) \bar{I}_t^F \right) \quad (9)$$

Due to the break-even constraint (3), the parameters are subject to the condition $\tilde{R}_t^F \leq R_t^F$.

As above, to arrive at the total rent extracted per single period or over the whole extraction period, we have to take expectation values of this rent or of the discounted sum over the whole period of time, respectively.

Formula (8) (and (9)) give the most general rent extraction scheme within the general framework of the formalism set out in this section. It encompasses many situations discussed in the literature referred to in section 2, each of which can be reproduced in our formalism by the specification of the adequate concrete choice of parameters and boundary conditions.

One important rent extraction mechanism we have not mentioned so far is the auctioning of the natural resource. With this mechanism, it is in principle (no collusion) possible to overcome the asymmetric information problem. Thus, with an effective design of the auction, firms will have an incentive to bid the true value they assert to the resource. The problem in this setting is the long-term investments or -use und thus the huge (price) uncertainty the firms are facing. In an ideal auctioning environment, they should thus be able to predict prices and costs over many decades, which can be regarded as an impossible task. Campbell and Linder (1983) check the assertion whether resource rent taxation will discourage mineral exploration. They conclude that, if the explorer is risk neutral, a bidding process with a zero tax rate will maximize the government’s income. In contrast to the rent extraction scheme presented above, the auction is an ex-ante scheme. Due to this intrinsic different structure we do not include any bidding process in our unified formalism and its discussion.

4 Discussion of the general formalism and conclusions

In this section, we present the issues that pose major problems for the concrete implementation of the general formalism presented above and draw some conclusions.

In this general framework, a solution to determine the parameters involved in (8) or (9) is not possible. In more specific settings it may be accessible sometimes, but often it is likely that the economic analysis at most gives a bandwidth wherein the parameters have to lie or that the simplifications made are too strong, thus leaving the researcher with a solution to a problem of merely academic interest without much practical relevance. In both cases, the choice of definite values for the parameters has to be left to the political process. Put differently, economists can propose a general rent extraction method which leads to allocational efficiency and does not destroy the incentives to produce efficiently or to (re-) invest, but the concrete extraction rate is a question of the distribution of the rent and thus a normative one.

Thus, it is clear that the formalism in this generality does not provide much practical insight. It shows how intricate a picture of the economic reality would look like in formal language – and how intricate it will be to arrive at sound solutions of the problem posed within this setting (and how far from this general situation tractable problems are situated). However, it is a common framework for a broad range of situations. Equations (8) and (9) are the most general formulae to base on the discussion of resource rent extraction in a principal-agent framework. In this section, we discuss the main problems of such a theoretical approach: too complex a formalism to allow for a solution and the presence of crucial but intrinsically unobservable and the presence of very uncertain quantities.

The high complexity of such a general formalism makes it intractable without further assumptions on the form of the utility function (e.g. on its differentiability and derivatives) and its single terms. The advantage of the formalism at this level of abstraction is that it provides a common framework to describe more specific settings, which are characterized by a specific choice of the values for the parameters: a) the probability distributions and b) the boundary conditions. Building more specialized models in such a 'top-down' approach, starting with the most general setting, also prevents neglecting important terms and helps to ask important questions related to each simplification. In addition, it provides a framework to assess the degree of specialization achieved by the several assumptions taken.

In any realistic situation, many of the quantities at the core of the formalism are not known to the firm and the government in sufficient accuracy. For some, e.g. the cost of effort function of the firm[10], it may even be difficult to indicate the gross shape. Others, such as the cost function, the cost of effort provided and the efficiency type of the firm may be only known to the firm (adverse selection and moral hazard). The methods of incentive regulation provide some means to tackle this problem, e.g. by estimating the cost function of the firms and use this as the basis of a benchmarking. For a third group of variables, such as the future prices and interest rates, only probability distributions of the values to be expected may be known and these also only with very limited accuracy.

There are mainly two possibilities to deal with these problems. The first, most often applied in the literature, is to make further assumptions and restrictions to arrive at a tractably simplified setting, which allows getting more information on optimal rent extraction schemes but bears the danger of being of mostly academic interest if the simplifications undertaken are not adequate. Examples are the references given in section 2.

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[10] Formally, it may be absorbed in the general cost function (Laffont and Tirole 1993) but this only complicates the structure of the latter and contributes more to hide than to solve the problem.

The other is, although being aware of the very useful insights a theoretical model can give, to admit the shortcomings of an exclusively theoretical treatment, which often cannot be solved at all or only under unrealistic simplifications. The general formalism may allow for some realistic simplifications, depending on the concrete situation, and may help to avoid gross errors, but it is of primary importance to assess each problem in its particularity, to duly incorporate its specific institutional setting and to discuss it under participation of all the actors involved. A common approach is to take only the basic results from the economic analysis, such as the fact that the resource rent is by economic criteria a good concept to base such an extraction system on (e.g. Amundsen et al. (1992)), the fact that a combination with a fixed fee secures against too big volatility or the fact that due incentives for efficient production or measures to reduce uncertainty (of revenue and amounts to be paid, respectively) have to be provided. Thus, the rent extraction system has the same form as given in (8) or (9), but it is admitted that there is no framework that allows for identifying the exact values of the parameters by means of solving the maximization problem, because of the lack of knowledge on the n utility functions for the government and the firm. Nevertheless, the theoretical model covers many possible principal-agent situations, and could be applied in many sectors or cases, depending on the respective market conditions and situation.

In the end, some boundaries or hints for the values may be deduced from specialized versions of the formalism or other concrete cases known, but the concrete values are a matter of discussion and will be found in a political process rather than an economic analysis.

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