Rent Taxation for Nonrenewable Resources

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Abstract

The literature on taxation of rents from nonrenewable resources uses different theoretical assumptions and methods and a variety of empirical observations to arrive at widely diverging conclusions. Many studies use models and methods that disregard uncertainty, investigating distortionary effects of different taxes on whether, when, and how to explore for, develop, and operate resource deposits. Introducing uncertainty into the analysis opens a range of challenges and leads to results that cast doubt on the relevance of studies that neglect uncertainty. There are, however, several ways to analyze uncertainty regarding companies' behavior, resource price processes, and diversification opportunities, all with different implications for taxation. Methods developed in financial economics since the 1980s, though promising, are still not in widespread use. Additional topics covered in this review are optimal risk sharing between companies and governments, time consistency and fiscal stability, the relationship between taxes and discount rates, tax competition, and transfer pricing.

1. INTRODUCTION

In many countries, extraction of nonrenewable natural resources, including petroleum, coal, metals, and other minerals, is an important source of government revenue. Recent overviews by Baunsgaard (2001), Sunley et al. (2003), and Otto et al. (2006) show global use of various taxes specific to these sectors.

To minimize the need for distortionary taxes, economists have recommended maximizing rent taxes, which are supposed to be neutral. A combination of factors makes the design of these taxes, or alternative arrangements for government revenue, very challenging. When resource prices are high, large rents may lead to a strong public demand for government revenue. There is also high uncertainty in prices and geology, and technology is often owned by big multinationals. This situation raises issues about attitudes to risk and asymmetries of information, which are exacerbated by high tax rates.

This paper reviews the literature on rent taxation of nonrenewable resources published since 1975. Sections 1.1 and 1.2 delineate this topic and introduce some theories of companies' behavior, respectively. Sections 2–5 present major strands of the literature. Section 2 considers models in the Hotelling tradition. The question is, How do taxes affect the equilibrium price and extraction paths for a nonrenewable resource? Section 3 focuses on studies directed at policy reforms, some of which have been highly influential, despite attendant weaknesses (which are highlighted). Section 4 discusses various approaches to the analysis of tax effects on companies' decisions. Section 5 shows how auctions have been promoted as an alternative to taxation and presents the possible advantages of combining the two policy tools. Section 6 contains miscellaneous topics, and Section 7 offers concluding remarks.

1.1. Delineation of the Topic

Governments generate revenue from resource activities in various legal and economic forms. A company extracting a nonrenewable resource may have ownership of the resource, or the company may obtain a license to exploit it. The company's resource extraction is subject to taxation. In some cases, this taxation is part of a tax that is levied on the whole company. Taxation here means that payments depend on the realized outcomes of a given activity. If the complete payment is determined independently of realized outcomes, it is not considered taxation. In such cases, a fixed fee may be set by the government, negotiated with companies, or determined through auction. This review covers only parts of the literature on fixed-fee systems.

Because ownership rights are outside the scope of this review, equity participation by governments is not covered, even though the cash flow implications of such arrangements may be interpreted as taxation. However, even without equity participation, governments regulate many aspects of the taxed activity, which has implications for the practical interest in analysis of taxation. If all companies' choices are severely regulated, distortionary taxes may exert little influence on them. In practice, some choices are less restricted than others, but this varies greatly among countries and types of resources. If one wants to exploit the expertise found in private-sector companies, they must be allowed to make important decisions, which creates opportunity for tax distortions.

Royalty here denotes taxes on gross production value. Some of the literature uses royalty more generally to include net profits (or rent) taxes. This may be a matter of definition only, but the difference between taxes and royalties has historical roots related

to their justification. According to Watkins (2001), "royalties derive from ownership of resources by the Crown. Thus, a functional distinction can be made between royalties and general tax revenues. In this light, the principles governing taxation do not apply in equal measure to royalty incomes" (p. 29). Philosophical discussions on the justification of taxes or royalties are omitted here, although such justifications may have economic implications, for instance when the United States decides which taxes and royalties are eligible for foreign tax credit.

For analytical simplicity, it is convenient to assume that economies are open with a world market for extracted units of the resource. This allows a distinction between rent taxes and excise taxes. A rent tax is levied on rent realized when the resource is sold at the world market price. Excise taxes, not discussed here, are in addition to the world market price, increasing the consumer price. Pigouvian taxes to correct for externalities are also not discussed.

1.2. Alternative Models of the Behavior of Companies

To predict the effects on the behavior of companies, one needs assumptions about how companies make decisions. Different studies use various assumptions. This section highlights some differences that are particularly relevant to the following sections. I first discuss two alternative assumptions regarding risk. Then I mention an unconventional assumption related to the volume of rents.

The first alternative is to assume risk aversion on the part of companies. The assumption is often that companies maximize von Neumann & Morgenstern (1947) (vN-M) expected utility. Other types of preferences with aversion to risk are found in studies of taxation by, e.g., Domar & Musgrave (1944) and Emerson & Garnaut (1984, sect. 2–5). Most studies in this tradition take no consideration of the diversification possibilities of the company or its shareholders. Variance or some other measure of profit dispersion is sometimes taken as a measure of risk. As a result, three possible complications now arise. First, if the company diversifies, the covariance between one project and the rest of its portfolio takes over as the risk measure. Second, if shareholders diversify, companies will maximize market value (see next paragraph). Third, managers may act in their risk-averse self-interest, neglecting preferences of shareholders (cf. Leland 1978).

The second alternative is to assume that companies maximize market value, in the stated interest of shareholders. The market value is additive, meaning that the value of a linear combination of assets is equal to the same linear combination of separate values of those assets. This follows from theories developed since the 1950s, such as the Arrow-Debreu model of complete markets (Arrow 1953, Debreu 1959), or various models in financial economics, starting with the capital asset pricing model of Sharpe (1964), Lintner (1965), and Mossin (1966). Value additivity implies that variance cannot be a risk measure for each part of a portfolio, whereas covariance can.

For the theoretical study of taxation of companies, and for resource extraction in particular (high tax rates, high risk), the implications of making one of these assumptions are far-reaching. Because companies differ, and no model of financial economics is established as the final truth about financial markets or decision making, there are arguments for both assumptions.

Finally in this section, an assumption that has received some attention recently should be noted. Osmundsen (2005) assumes that oil companies, in order to start a project, require

some minimum volume of rent, sometimes called materiality. This assumption also has far-reaching implications: An otherwise neutral rent tax with a low rate will now cause some projects to move from being acceptable to unacceptable.

2. EQUILIBRIUM MODELS

Since Hotelling (1931), the analysis of economics of nonrenewable resources has been based on dynamic, partial equilibrium models of the resource market. The value of an unextracted unit must rise at the exogenous rate of interest. Herfindahl (1967) extends the model to include deposits with different costs, which determine the sequence of extraction.

Dasgupta & Heal (1979, ch. 12) discuss the introduction of taxes in Hotelling (1931) models. The question is, How do different taxes distort the market solution? Some neutrality results are derived. A final section in the chapter considers taxation as a means to correct for tragedy-of-the-commons problems. The main model in the chapter is of a closed economy, or worldwide taxation. All extraction is subject to the same tax. In most actual situations, this is irrelevant as policy advice. A government will consider its country either to be a price taker or, at most, to have some limited market power. Almost all subsequent theoretical studies of resource taxation have assumed exogenous prices; Gaudet & Lasserre (1986) and Lindholt (2008) are exceptions.

Few studies have analyzed resource taxation in intertemporal general equilibrium models, in which the interest rate is also endogenous. Groth & Schou (2007) have a growth model for a closed economy, which encompasses both endogenous and exogenous growth, with both produced and natural capital and a possible externality from resource use, such as global warming. All of the resource will be used in the limit in infinite time. The study shows that the resource use will decline exponentially in the long run, with the decline rate possibly affected by taxation. The model cannot analyze distortions from labor income taxation, as there is no labor-leisure choice. It suffers from the unrealistic feature that the same taxes are applied on all natural capital worldwide. In terms of resource taxation, the model implies that a tax on capital gains on natural capital leads to too little conservation of the resource, thus impeding sustainable growth.

There is some evidence (Krautkraemer 1998, Slade & Thille 2009) against the empirical relevance of Hotelling models and, implicitly, also of Groth & Schou (2007). Another problem with existing equilibrium models is the absence of uncertainty. Unfortunately, no established model of a dynamic equilibrium under uncertainty exists for such a market to extend the Hotelling-Herfindahl tradition. At best, taxation has been treated with an exogenous price process, although not necessarily a credible one (discussed below). Lund (1993) points out why the geometric Brownian motion (GBM) with drift is hardly an equilibrium price process. GBM is nevertheless assumed in four studies discussed below: Ball & Bowers (1983), Lund (1992), Zhang (1997), and Blake & Roberts (2006), who claim (pp. 98–99) that, although unrealistic, the GBM is acceptable for their purpose.

3. COMPARING TAX SYSTEMS, SUGGESTING TAX REFORMS

The basic problem for a country trying to collect resource rent via taxation is that a higher tax rate in one sector is likely to distort decisions by companies. One may simply set a higher tax rate for a corporate income tax (CIT) in this sector. But wedges between rates of return before and after tax increase with CIT rates. In a closed economy, this will be

counteracted if interest income and all corporate income are taxed at the same rate [cf. the Johansson-Samuelson theorem (Sinn 1987, p. 119)]. But this does not help in open economies or if one sector has a higher tax rate than the rest of the economy. A higher tax rate with an unmodified tax base implies that projects (or high-cost resource units within projects) that would be seen as profitable under a lower tax can be rejected under the higher tax.

Royalties also distort decisions. Without cost deductions, they make resource units with high costs unprofitable. In actual tax systems, there may be many complicating features, including taxes and deductions at several levels. A first approximation to the high potential for distortions is that a marginal decision on additional costs and income within the same year is distorted by the ratio $(1 - t_y)/(1 - t_c)$, where t_y is the marginal tax rate on income and t_c is the marginal tax rate on cost reductions. These are not statutory rates, but effective rates in an expected, risk-adjusted present-value sense. Clearly, the higher the rates, the more sensitive this ratio will be to small differences in the rates. Thus, there has been interest in economic analyses of how to tax resource rent optimally.

The seminal article for this part of the literature is by Garnaut & Clunies Ross (1975), who propose the Resource Rent Tax (RRT) scheme. It intends to give a deduction equal in present value to the investment itself, typically exceeding most CIT systems' depreciation allowances. A generalization of the idea is found in Boadway & Bruce (1984). Investment, indeed any yearly negative net cash flow, is carried forward for later deduction, along with interest accumulation, as soon as revenues allow. If the tax base in subsequent years is sufficient to allow complete, effective deduction of the carry-forward, this can ensure that only the rent is taxed.

Authorities must determine an interest rate for the accumulation. The intention is that companies be indifferent between receiving the refund immediately or through deductions in subsequent years. Garnaut & Clunies Ross (1975; 1979; 1983 ch. 4) acknowledge that implementation will suffer under information asymmetry. They suggest that the correct rate should be companies' required rate of return. They state that a risk premium will be included, but they have no model or precise discussion of how this is determined. The difficulties of assessing the rate of return, and the various resulting consequences, are the topics of much of the subsequent debate (Sumner 1978, Dowell 1978).

Other authors (Mayo 1979, Ball & Bowers 1983, Lund 1992, Smith 1999) focus on the possibility that the income stream in later years may be insufficient to allow for an effective deduction. Typically, RRT offers no payout if the income stream is too small. Garnaut & Clunies Ross (1979, p. 196) recognize this problem. The tax will reduce realized net value when positive, but it will not subsidize negative outcomes similarly. Mayo (1979) shows that under reasonable assumptions this asymmetry will cause distortions. The implication of the analysis is to prefer a Brown (1948) tax or some other arrangement with payout of negative taxes. (A Brown tax is a proportional tax on nonfinancial cash flow, with immediate payout of negative taxes.) Emerson & Garnaut (1984, p. 140) mention this possibility, but they seem to view negative taxes as impractical. Even then, one may want to increase the likelihood that the loss carry-forward can be effectively deducted. Mayo (1979, p. 208) argues that a company tax base would allow for deductions between projects, the opposite of "ring-fencing" (i.e., that each project/plant/deposit is taxed as a separate unit, without allowing deductions in the same company's profits elsewhere). Although aware of this, Garnaut & Clunies Ross (1979, p. 198) nevertheless advocate project-based taxation, giving priority to avoiding the possibility that companies

overinvest when the threshold rate is set too high. Saunders (1987) looks at effects of the cross-field allowance introduced in Britain in 1987. He points out deficiencies of an allowance for 10% cross-field cost relief, introduced in 1987 in the otherwise field-based British Petroleum Revenue Tax (PRT).

The inability to decide on the correct rate for interest accumulation leads to a suggestion to use two or three different rates. If and when a rate of return above a lower threshold is realized, the company starts paying RRT at a relatively low rate. If a rate of return above a higher threshold is realized, the company starts paying at a higher rate. Garnaut & Clunies Ross (1975) give several reasons for applying more than one rate. While addressing the ignorance about actual required rates of return, and the possibility that these differ between projects, they sketch an argument in which risk aversion makes progressivity desirable (Garnaut & Clunies Ross 1975, p. 280). However, despite including risk aversion in the title, Garnaut & Clunies Ross (1975) provide no formal definition of it, only an informal description of a concave objective function (p. 273). This vagueness conceals some problems. Their arguments can be contrasted with alternative approaches that existed at the time.

Domar & Musgrave (1944) show that taxation may encourage risk taking, inducing more investment than under no taxation. They do not use vN-M expected utility, but Mossin (1968), Black et al. (1982), and Fraser (1998) have similar results based on expected utility theory. Their results rely on assumptions about details of the tax structure, in particular loss offset provisions. But Garnaut & Clunies Ross (1975) state without conditions that "risk aversion causes the supply price of investment [the required expected return] to rise if a project is subject to [... various taxes or levies, e.g., ...] proportional taxes on profits" (p. 275). Becasue there is no formal argument, it is difficult to see how they arrived at a different conclusion from that of Domar & Musgrave (1944) as well as Mossin (1968) when assumptions are so similar.

Garnaut & Clunies Ross (1975) also mention other issues: the transfer pricing problem (see Section 6.3 below), the creditability of RRT payments toward taxes in other countries, and the possibility of combining RRT with CIT. Although not unimportant, the two latter topics are excluded from this review. The authors followed up with several other articles, some with other coauthors, and then a book (Garnaut & Clunies Ross 1983) which covers the field with a broad, mostly verbal discussion. The advantage of including many aspects is that hardly anything has been left out. The disadvantage is that it is difficult to arrive at a clear conclusion, neither on the optimal system nor optimal tax rate(s). A similar complaint can be issued about more recent documents from the International Monetary Fund and the World Bank.

For the International Monetary Fund, Baunsgaard (2001, p. 30) concludes that, "It is unlikely to be possible to design one optimal fiscal regime suitable for all mineral projects in all countries. Countries differ, most importantly in regard to exploration, development and production costs; the size and quality of mineral resources; and investor perception of risk. Likewise, projects may differ sufficiently that some flexibility is necessary in deriving an appropriate fiscal regime." The paper includes a table (p. 16), in part adapted from Garnaut & Clunies Ross (1983, p. 332f). It provides a comparative assessment of eight different stylized tax schemes, giving them 8×9 marks on nine different criteria. But "it is not possible to provide an overall quantitative assessment of each tax" from the table (Baunsgaard 2001, p. 16). For the World Bank, Otto et al. (2006, p. 276) conclude, "Countries' geological, economic, social, and political circumstances make each nation

unique, and an approach to royalty taxes that is optimal for one nation may be impractical for another."

Kemp (1992) provides a representative paper in the tradition of comparing tax systems. Petroleum taxes in the United Kingdom, Norway, Denmark, and the Netherlands are compared. A set of scenarios for oil prices, as well as extraction and cost data for five representative fields, is constructed on the basis of the author's experience and judgment. After-tax internal rates of return and net present values at a 10% real discount rate are calculated for companies, under the alternative assumptions of no other activity or full tax deductability against other income. There is no analysis of uncertainty, and the high real discount rate applies to all cash flows. The conclusions on average tax rates and progressivity are determined by the choice of these methods (see Section 6.2 below). A curious weakness in the results is that "the Danish system collects a very substantial share of any economic rents to the state," when, in fact, the rent tax in Denmark collected very close to nothing as a result of its generous uplift (Lund 2006).

4. HOW TAXES DISTORT DECISIONS

Whereas Kemp (1992) considers only whether a project is started or not, several studies look at more detailed analyses of distortions to decisions, using a variety of methods. Analyses of marginal tax rates have a general scope, in that they illustrate (non)neutrality without specifying the production possibilities. However, to quantify average tax rates and the effects on extraction output or rent, one must specify production possibilities. Along such lines, several studies leave the exploration phase out of the analysis, some focus on whether and when to start development, and others neglect this and focus on scale of development or time paths of extraction after development.

Boadway et al. (1987) define a marginal effective tax rate as a relative wedge between the rate of return before and after tax for a marginal project. This is a different concept from the two marginal rates t_y, t_c mentioned in the beginning of Section 3, above. Those rates are simply the percentage to be paid of a marginal change in gross income and the percentage to be refunded through deduction of a marginal change in cost. In a two-period version, the Boadway et al. (1987) concept is $(t_y - t_I)/(1 - t_I)$, where t_I is the marginal tax on reduced investment cost one period ahead of the income. The simpler concept was, e.g., used by Smith (1997) to analyze Russian petroleum taxation. For a neutral cash flow tax of 80%, the marginal effective rate would be zero according to the definition of Boadway et al. (1987), whereas the marginal tax rates would be 80% on both income and costs according to the simpler concept.

Boadway et al. (1987) consider a deterministic model of mining and calculate tax rates for various mining assets in the Canadian provinces of Ontario and Quebec. The findings are that many marginal effective rates were negative, so that taxes are distortionary (but in the direction of subsidies) and do poor jobs of collecting rent. Boadway & Keen (2008) extend the discussion. One qualification they mention is that typical analyses of such taxation concentrate only on host country tax rates, neglecting taxation of an international company by its home country as well as taxation of the shareholder.

Krautkraemer (1990) studies the theoretical impact of taxation on ore selection, tilting of the time profile of extraction, and total depletion from a mine. He includes a useful overview of related studies. Slade (1984) estimates a cost function for copper mines, taking both the intertemporal constraint and the processing of ore into the model.

[She admits (p. 146) to ignoring the important exploration phase.] On the basis of the estimated model, she calculates what distortions will occur due to imposition of various taxes and price controls. Taxes will typically lead to intertemporal tilting, less extraction, and less intensive processing (i.e., less final metal output). The second and third of these effects, i.e., effects on total final output, not the tilting, dominate. In terms of tilting, there is the unexpected result that royalty leads to higher extraction in earlier years and lower extraction in later years. Whether the results also hold for petroleum, coal, or other metals is an empirical question. Deacon (1993, p. 173) confirms that tilting is the less important distortion from a royalty on oil.

Inspired by Hotelling (1931), interest has concentrated on the intertemporal profile. An alternative focus on the scale of investment in each project is supported not only by findings in Slade (1984) and Deacon (1993), but also by reference to Campbell (1980). Campbell finds that the most important decision is investment, i.e., installation of extraction capacity. Afterward, operating costs are often so low that extraction takes place at full capacity. Many other studies use either the intertemporal profile or the scale of investment to describe the opportunity set for companies. Sumner (1978) assumes an exogenous total extraction from a field, with companies choosing the constant yearly rate at which to extract. Lund (1992), on the other hand, assumes that companies choose scale of development of an oil field and that total extraction is an increasing, concave function of this, but that the intertemporal profile is constant in relative terms.

Deacon (1993) may have the broadest scope of any of the deterministic tax distortion studies. He estimates and calibrates an optimization model of exploration and extraction by a representative oil company, using data for the contiguous 48 states of the United States from 1859 onward. He considers distortionary effects of CIT (found to be small), royalty (medium), and property tax (severe). Besides several improvements in methods, the inclusion of property taxes is interesting. Whereas most studies neglect property taxes, they turn out to have significant effects.

The remainder of Section 4 covers authors who use models inspired by financial option theory. Generally, they find tax distortions exacerbated by uncertainty, effects that could not be discovered by most of the authors cited above, who neglect uncertainty.

Ball & Bowers (1983) observe that an RRT has imperfect loss offset and that the tax claim is similar to a European call option. Using standard assumptions from financial economics, the authors quantify the market value of the government's tax claim under price uncertainty. Green & Talmor (1985) and Majd & Myers (1985) use a similar approach for the CIT. MacKie-Mason (1990) studies nonlinear taxes with the U.S. depletion allowance as an example. Later contributions with applications to rent taxation include Jacoby & Laughton (1992), Lund (1992), Zhang (1997), Bradley (1998), Blake & Roberts (2006), and Samis et al. (2007).

Besides similar assumptions, the common theme in these studies is valuation of nonlinear tax claims, occurring, e.g., as a result of imperfect loss offset or progressive tax schedules. In most cases, the tax claim is convex (for an exception, see MacKie-Mason 1990), implying that the tax claim increases in value with increased uncertainty. Jensen's inequality is all one needs to show this, but the studies are more elaborate, using the risk adjustment method from modern asset pricing (MAP). This is explained in detail in Jacoby & Laughton (1992) and is the topic of a special issue of the *Energy Journal* in 1998 (see Laughton 1998, Salahor 1998). [MAP and related methods are also called market-based valuation, contingent-claims analysis, and derivative assets analysis

(Rubinstein 1987, footnote 1).] The method is used for real options in resource economics, but among the cited authors, only MacKie-Mason (1990) and Zhang (1997) consider this, i.e., managerial flexibility. Both obtain analytical results in stylized models. Jacoby & Laughton (1992), Lund (1992), Bradley (1998), Blake & Roberts (2006), and Samis et al. (2007) analyze taxes with option-like cash flows using Monte Carlo simulations. These differ from typical Monte Carlo simulations in that the simulated price process is not intended to emulate actual prices. When the drift term is reduced, this is known in financial economics as the risk-neutral process. Under standard assumptions, this yields market values of the company's cash flows after tax.

Lund (1992) considers Norwegian petroleum taxes before and after 1987. He finds large tax distortions if measured as deviations in costs, but smaller in net value, because there are decreasing returns to scale within fields. Blake & Roberts (2006) use the same type of production function to analyze petroleum taxes in Alberta (Canada), Papua New Guinea, São Tomé and Principe along with Nigeria, Tanzania, and Trinidad and Tobago. They find strong distortionary effects for the latter two, less for the others.

Zhang (1997) studies the effects of two different taxes on the choices of when and whether to invest in a stylized project. One tax is the RRT; the other is a simplified version of the British PRT. The result is that RRT cannot be neutral, but a stylized PRT can, provided that the uplift is set so as to allow for the option value. It must be assumed that the nonneutrality result for RRT is the result of imperfect loss offset. As explained in Section 6.2 with reference to Fane (1987), a tax will be neutral if the loss offset and other deductions are nonstochastic and the deviation from a constant-rate cash flow tax has a present value of zero at a riskless interest rate. This neutrality also holds in real option models.

Bradley (1998) and Samis et al. (2007) give detailed accounts of the method and apply it to stylized projects, oil and copper/gold, respectively. Both consider two alternative resource price processes, GBM and mean reversion. Both highlight the merits of the method relative to traditional discounted cash flow (DCF) analysis, for which there is no theoretical justification in a world of uncertainty. Emhjellen & Alaouze (2003) also compare these methods, but they ignore the fact that most taxes are nonlinear.

Nakhle (2008) includes both DCF (ch. 5–6) and MAP (ch. 7). She claims without explanation that, compared with DCF, MAP is "controversial" (p. 116), but also "more useful" (pp. 117, 128). In spite of its usefulness, the newer method is "unlikely to capture many sponsors" (p. 148). Apart from chapters 5–7, the book gives an account of the history and politics of petroleum taxation from a U.K. perspective, also comparing against other nations.

5. RISK SHARING: FIXED FEES OR TAXES?

Many contributions consider taxation without mentioning fixed fees as an alternative. Because fixed fees are not a focus here, only the literature that discusses auctions as alternative to, or in combination with, taxation is considered.

Leland (1978) provides a seminal paper with a thorough theoretical analysis of optimal combinations of taxation and fixed fees when both companies and government (the nation) are risk averse or, in extreme cases, risk neutral. Both parties are assumed to maximize vN-M expected utility. At the outset, Leland considers the possibility of perfect markets for state-contingent claims, so that companies would instead maximize market

value in the interest of shareholders. He dismisses this idea because a "variety of considerations conspire to make the actual environment diverge from the perfect market paradigm" (Leland 1978, p. 414). He mentions transaction costs, information asymmetries, bankruptcy costs, and managers' self-interests as reasons to assume risk aversion instead.

Leland considers various sets of assumptions on information asymmetries and the effect of taxation on companies' actions. Companies compete to the extent that they get no increase in expected utility as a result of winning a lease. Knowing companies' patterns of behavior, authorities announce payment schedules before the bidding to maximize expected utility for the nation. One result is that only if companies are risk neutral will authorities rely solely on fixed fees. Only if authorities are risk neutral will they rely solely on taxes. If both parties are risk averse to some extent, both types of payments will be used. There are further results on the concavity of the optimal payment schedule, which depends on the relation between risk tolerances of companies and authorities. There are also results on the effects of shifts in the probability distributions of values. With decreasing absolute risk aversion for both parties, a higher value (in expected utility terms) leads to higher optimal tax schedules, also in relative terms.

Emerson & Garnaut (1984) extend Leland (1978) to include more detailed policy recommendations. In addition to Leland's reasons for recommending taxes on rents, they consider sovereign risk, the possibility experienced by companies of unannounced changes in taxes. They claim that the "most nearly ideal system of conditional payments *in current application* is the Resource Rent Tax" (Emerson & Garnaut 1984, p. 140; emphasis in original), in part because tax payments come late, thus reducing sovereign risk.

Fraser (1998) considers vN-M risk-averse firms. Deposit size is uncertain, whereas price is assumed known. [Fraser (2000) considers price uncertainty in a similar model.] He studies how an RRT with imperfect loss offset could be combined with fixed fees, set discretionarily or through auctions. Thus, RRT can lead to over- or underinvestment compared with a no-tax situation. For constant relative risk aversion less than unity, there are interior solutions for the pairs of tax rate and threshold rate which achieve neutrality in this sense. This means that for a given threshold rate the company's optimal investment choice is first an increasing, then a decreasing, function of the tax rate as this goes from zero to unity. The Domar-Musgrave effect dominates for tax rates close to zero, but the concave after-tax profit function dominates for higher tax rates.

Fraser (1998, p. 116) goes on to "investigate the potential for the government to choose the structure of the RRT so as to maximise expected government revenue from the allocation of a mining lease subject to the RRT, while at the same time leaving the firm's preferred level of investment unchanged." The constraint imposed in the last part of this sentence is not well explained. Risk aversion will restrict investment in absence of a tax. It is not clear why authorities would not want to encourage a higher investment level.

Using the results of Leland (1978), Emerson & Garnaut (1984), and Fraser (1998) for policy recommendations entails some problems. Whether risk aversion describes the behavior of these companies better than does market value maximization is unclear. But even then, generating a precise recommendation remains difficult. There is no reason to believe that all companies under one jurisdiction have the same risk aversion at any point in time or that risk aversion does not vary over time. How to measure it, or that of the government, is unclear.

Sunnevåg (2000) observes that a combination of RRT and auctions may be preferable to relying on auctions only, because of political (i.e., sovereign) risk. If only a fixed fee is

paid, and realized prices or quantities then turn out favorably, there will be political pressure to capture windfalls. Companies may suspect that this is, in effect, asymmetric, with no compensation for bad outcomes (Lund 1999, p. 218; Sunnevåg 2000, p. 15). It may be more credible to combine a fixed fee with a tax at such a high rate that it captures much of the *ex post* variation. One point not mentioned in the literature is that the very existence of rent taxes may lead bidders to expect asymmetries and thus reduce bids. If so, this is an argument against the combination of fixed fees and rent taxes. If a rent tax is in place from the outset, companies may perceive that this makes it easier for governments to increase its rate in case of large discoveries or price increases. For more on the credibility issue, see Section 6.1 below.

Mead (1994) is a prominent example of an author who considers the alternatives but draws a clear conclusion in favor of cash-bonus bidding alone. The article has several suggestions for improvements in the U.S. system but concludes that a bidding-based system is superior to taxation-based alternatives. Partly theoretical, these arguments are also based on empirical research, in particular Mead et al. (1983), who investigate whether there are indications that auctions of petroleum leases on the U.S. outer continental shelf have not captured the whole rent. Leases were acquired from 1954 to 1969, with production data ending in or before 1979 and with projections made for the subsequent period when needed. The finding is that the average after-tax return on equity was 10.74%, whereas it was 11.8%, on average, in the U.S. manufacturing sector.

Low returns are claimed to indicate that there is sufficient competition, so that lease payments capture the rent. Mead et al. (1983) recognize that oil price increases in the 1970s were not anticipated, so bidding was probably based on expectations well below those that were realized. But in the return calculations, the 1970s count less than earlier years, which saw declining real prices. Whatever the reasons are, the fact that returns are lower than in other sectors in spite of higher risks may be seen (but see Section 6.2 for a discussion of tax effects on after-tax required returns) as indications of a "strong winner's curse" (as noted by Thaler 1988). This is not a good outcome for anyone in the long run. Nevertheless, a test based on one output price path is insufficient to settle the question. Mead (1994) dismisses the argument from Leland (1978) that companies may be so risk averse that they are willing to pay only a low price for leases. Again, the empirical evidence is used in the argument. A more recent account of the U.S. experience is found in Boué (2006). He is critical of the area-wide leasing introduced in the early 1980s and summarizes evidence that tax reductions have weak incentive effects.

Considering risk sharing, another approach exists. Blitzer et al. (1984) ask the same question as do Leland, Emerson and Garnaut, and Fraser, but they rely on different assumptions in their analysis. Instead of using the concept of risk aversion alone, they rely on portfolio theory and, to some extent, financial markets, but with incomplete international diversification. They observe that both countries and the shareholders of companies hold portfolios, but that these are not similar, contrary to predictions in standard finance models. Some authorities act on behalf of countries that are heavily reliant on a few natural resources for much of their national income, whereas other countries import those same resources for the foreseeable future. The covariances between the resource price and the national portfolios have different signs and magnitudes. Shareholders' portfolios also have different national biases, which are held for various reasons. All of this has implications for who is better suited to bear the risk. Blitzer et al. (1984) do not go into detail on

tax systems, but instead they look at the broader question of contracts, including contract risks and political risks.

6. OTHER TOPICS

Although the topics below are important, others of similar import have been left out owing to space limitations. There is, e.g., no mention of taxation under imperfect competition, a situation prevalent in many markets for nonrenewable resources.

6.1. Time Consistency, Fiscal Stability, and Progressivity

Many of the cited studies contain passages on the importance of stability in tax systems. Garnaut & Clunies Ross (1981) provide a historical account of this and related issues. Whereas governments may increase taxes after positive outcomes for prices or reserves (windfall profits taxes), they might not decrease them after negative outcomes. High payments that must be paid to authorities up front (typically found under an auction system), in addition to large investments, exacerbate the problem. This situation helps explain why auctions are found most often in stable political environments with perceived reluctance to impose additional taxes.

Boadway & Keen (2008) point out that having companies realize that governments cannot credibly commit to not increasing taxes will lower investment, thereby hurting both parties. This may be overcome by noncarried equity participation by the government (an up-front payment in the opposite direction of the one mentioned above) or by acquiring a reputation for keeping a stable system. Osmundsen (2008) sketches the game-theoretic argument, which allows for an equilibrium without underinvestment in an infinite-horizon game supported by trigger strategies. But these are not unique equilibria, and many conditions need to be satisfied; thus one cannot say that the problem has found its solution. He goes on to consider Norwegian petroleum taxation, finding that "[o]ver the past decade, Norway has shifted to a policy of absolute commitment, where the tax system is unchanging." But he is aware that there may be country-specific problems related to attaining this solution.

In some countries, governments offer explicit fiscal stability clauses in contracts, promising renegotiations or immunity in the event of future tax increases. One problem is the short lifetime of governments compared with that of many resource projects, as highlighted by Daniel & Sunley (2008). They argue that fiscal stability clauses are prone to being overridden by changed circumstances. They mention that clauses are sometimes best seen as smoke screens, which may be circumvented by government actions not covered by the clauses.

When Denmark introduced a fiscal stability clause in 2003, Lund (2003) stressed two potential problems. First, companies paid both CIT and a rent tax. If international competition later forced authorities to lower the CIT rate, a simultaneous increase in the rent tax rate would be prohibited by the clause. Such a pair of tax-rate changes happened in Norway in 1992, and a switch from mobile to immobile tax bases is a well-known prediction in the public economics literature. Second, the clause could complicate the introduction of Pigouvian taxation.

In addition to questions of whether and how a government may commit itself comes the broader issue of political support. There may be considerable unrest if companies earn

large after-tax rents ("windfalls") due to resource price increases or large discoveries. This has led some authors (notably those connected to the International Monetary Fund and the World Bank) to recommend progressive taxes. Boadway & Keen (2008, p. 45) argue that "progressive rate schedules may be more robust against political pressures in the event of high return outcomes than are proportional schemes." Similarly, Sunley et al. (2003, pp. 159–60) point out that "[p]roponents argue that the RRT can enhance contract stability because it automatically increases the government share in highly profitable projects." Daniel & Sunley (2008, p. 6) stated [and Land (2008, p. 4) argues similarly] that a "robust fiscal regime is therefore adaptable and progressive."

Possible benefits from progressivity must be weighed against distortionary effects. Using models without uncertainty, Conrad & Hool (1984) show that taxes with variable rates have distortionary effects, and Sumner (1978, p. 9) states that "the basic objection to the resource rent tax is that it cannot simultaneously provide neutrality and progressivity." Under uncertainty, progressivity combined with imperfect loss offset will give the convexity that implies that the tax claim's value increases with higher uncertainty (cf. Section 4, above). Bond & Devereux (1995, pp. 58, 67f) show theoretically that "neutrality with a non-constant tax rate requires that the investment project generates a non-negative tax base in every period." Blake & Roberts (2006, p. 101) find that "the two most distorting systems, Tanzania's and Trinidad's, contain a common fiscal component which attempts to capture more revenues for the host government with increasing production."

6.2. Risk Attitudes and Discount Rates

As mentioned in Section 1.2, there is a fundamental difference between two sets of assumptions regarding companies' behavior under uncertainty. This section discusses these consequences in more detail.

The assumption that companies behave as risk averse implies that almost all tax systems are nonneutral. Most actual taxes are distortionary under conditions of full certainty, typically by having higher marginal tax rates on the revenue side than on savings on various costs [but see Boadway et al. (1987) for examples of the opposite distortion]. Under uncertainty, there will be a counteracting effect of sharing risk with the government, encouraging higher activity. Under some circumstances, this leads to an interior solution to the problem of neutral taxation: A set of tax rates may exist for which the two effects cancel each other out at the margin (Fraser 1998), although this is of little practical interest (Smith 1999).

An assumption that companies maximize market value has markedly different implications. Value additivity is assumed to be standard knowledge in the business community, mentioned by Brealey et al. (2008, p. 968) as one of the seven most important ideas in finance. For tax authorities, it is a crucial question whether taxes should be designed based on the assumption that companies behave according to the textbook. Value additivity has been assumed in analysis of corporate taxation under uncertainty in public economics since Fane (1987). He shows that a Brown (1948) cash flow tax is then neutral, because it acts in cash flow terms as just another shareholder. Maintaining the neutrality is possible if some cash flows (e.g., tax value of deductions) are postponed in time, provided that interest accumulates so as to leave companies indifferent to the postponement. Bond & Devereux (1995), building on Boadway & Bruce (1984), generalize this result.

What interest rate is needed? On the basis of value additivity, the postponement can be valued separately. If it happens with full certainty, the appropriate rate is the riskless interest rate. The tax system is neutral if deviations from a cash flow tax are nonstochastic and have zero net present value at that interest rate. Although this result by Fane (1987) is theoretically uncontroversial, it seems to be disconnected from much of the preceding literature on rent taxation and also from the practice of many companies. In general, practice is to apply one (and the same) discount rate to (all elements of) the net cash flow of a company, regardless of the specific risk of each element (cf. Graham & Harvey 2001). Garnaut & Clunies Ross (1975) have a similar idea: The rate at which deductions (or losses) are allowed to accumulate is ideally the "supply price of investment," which depends on "investors' attitude to risk" (p. 273) among other things. Although RRT deductions are not risk free, it is equally true that they do not have the same risk characteristics as before-tax cash flows.

Most real-world tax deductions are risky, although to different degrees (cf. Lund 2009). Intuitively, a deduction is almost risk free when the net tax base is much larger, depending also on correlations. If the tax code includes one or more specified interest rates, at which losses are carried forward, no practicable suggestion exists for how the rate(s) could depend on project-specific details affecting riskiness of deductions.

In a policy perspective, it may be possible to ensure that the deductions are (perceived as) close to risk free. Summers (1987, p. 298) argues that "[o]n balance, it seems fair to conclude that deprecation tax shields represent an essentially riskless asset." This is usually not the case for all deductions in resource extraction, owing to higher tax rates, high uncertainty, and, in many countries, ring-fencing. The petroleum tax reform suggestions in Norway in 2000 and in Denmark in 2001 tried to get closer to certainty for deductions, and accordingly, they applied a riskless interest rate for carry-forward. Lund (2002a) and Bjerkedal & Johnsen (2005) give details. This could be obtained by no ring-fencing, sale of negative tax positions, or refund of tax values of unused deductions. A possible objection is that apparently wasteful expenditures would be partly subsidized, possibly allowing experimentation paid by reduced taxes, which is useful for companies. This may be prevented by government regulations or equity participation; the latter would also allow governments to learn.

For reform efforts in these countries, it was crucial to apply separate discounting for different cash flow elements. Although the reforms went far to achieve neutrality, this could not be understood by oil companies (or anyone) who applied one discount rate to the net cash flow. Using the finance-theoretic approach, Lund (2002c) shows how this is a mistaken practice when companies operate in jurisdictions that differ (signficantly) in tax rates and investment-related deductions, which companies in resource extraction typically do. Systematic risk (and thus the correct discount rate) of the net after-tax cash flow depends on the tax system. Lund (2002c) gives analytical solutions for stylized linear tax systems, whereas Lund (2009) extends the analytical solutions to nonlinear cases with imperfect loss offset. When taxes are nonlinear in many periods, numerical methods are needed, and risk-adjusted discount rates are no longer practical tools. Jacoby & Laughton (1992) and Bradley (1998) give numerical examples for several realistic cases. Typically, the correct discount rate for the expected net cash flow after tax is less than before tax, and it decreases the tax rate.

Another topic that has received much less attention is whether the interest rate should be an after-tax interest rate. Lund (2002a) shows how the views of the petroleum tax

reform commissions in Norway and Denmark differed at this point, and he relates it to the more general literature on taxation of companies and their shareholders. If the marginal investors' alternatives are taxed, an after-tax interest rate should be used (cf. Dasgupta & Heal 1979, equation 12.11; see also Gaudet & Lasserre 1986, p. 242).

6.3. Transfer Pricing and Income Shifting

Rent taxation exacerbates the problem of transfer pricing, which is well known in international taxation, but also occurs between sectors in one country. The problem is one important argument for relying on fixed fees instead of higher tax rates (Mead 1994). To avoid transfer pricing, authorities require use of "arm's length" prices, i.e., prices as they would have been between unrelated parties. Establishing these is easier for resource output than for costs. Costs are made up of numerous inputs, which are often tailor-made. Thus, the problem is bigger on the cost side, borrowing costs and insurance included. Income shifting is broader than transfer pricing and also includes real transfers, such as testing new equipment in a sector with high tax rates, which can also represent a distortion. Using the notation from the beginning of Section 3, one should distinguish among $t_c > t_y$ (overinvestment incentives), $t_c > 1$ (gold plating incentives), and t_c exceeding the t_c of another sector or jurisdiction (transfer incentives).

Osmundsen (1995, 1998) includes principal-agent models, in which authorities impose tax schedules that do not rely on reported costs (see also Dowell 1978, p. 136). This approach follows from the somewhat extreme assumption that traditionally monitored self-reporting of costs contains no useful information. Authorities must regulate under asymmetric information on the basis of only probability distributions of costs. The optimal solution is to present companies with a schedule of payment obligations, conditional on output value. This can be implemented as alternative combinations of fixed fees and royalties. Osmundsen (1998) extends this to a two-period model, inspired also by Gaudet et al. (1995).

Lund (2002b), building on Gordon & MacKie-Mason (1995), has a model in which taxes allow deductions for traditionally reported operating (or investment) costs. Companies can shift income from a jurisdiction with a high marginal tax rate to one with a low rate, but only at a (nontraditional) transfer cost, quadratic in the amount to be shifted. The model is constructed such that, were it not for the possible income shifting, authorities would want a rent tax at a rate arbitrarily close to 100%. Introducing costly income shifting can lead to two different results, depending on model parameters. If the output price and/or the transfer cost is high, relative to operating costs, then royalty is not used, but instead a rent tax is set arbitrarily close to 100%. If not, there will be a combination of rent tax at some lower rate and a royalty. Both the possible reliance on a rent tax alone and a discontinuity in the solution are surprising theoretical results. The model is difficult to apply in practice, as admitted by Lund (2002b).

Boadway & Keen (2008, p. 43) are skeptical of principal-agent contracts in this connection. They claim that a "reasonably good tax audit system" will allow "a profit tax system to collect reasonable rents." Fraser (1999, p. 273) has a third alternative: The "government and the firm negotiated an agreement over the allowable cost per unit of production." This may suffer from asymmetric information problems and needs frequent revisions.

In summary, the arguments for any of the approaches seem incomplete. The theoretical models are stylized, and some empirical research would be welcome to decide how to tackle the problem of income shifting.

6.4. Is Tax Competition a Concern?

Within the literature on taxation in open economies, tax competition among countries has an important role. Whereas mobile factors can escape high tax rates by moving to other countries, immobile factors cannot. This provides a separate, strong reason for imposing higher tax rates on resource extraction, in addition to those that apply to closed economies.

Osmundsen (2005) argues that companies have unique factors of production, such as skills and technology, that they use only where it is most rewarding. He implies that a country is limited in its ability to tax resource extraction by the tax level in other countries competing for the attention of the same companies. Boadway & Keen (2008, p. 48) have reservations about this: One "would expect high rewards to expand the supply of these scarce factors, at least in the medium term, just as one would expect a shortage of oil rigs to lead to an increase in their price."

Lund (2001) asks why a company in (a previous publication of) the model of Osmundsen (2005) undertakes only the projects that give the highest reward after tax to its scarce factors of production. The question is why factors cannot be duplicated. Technology can be duplicated, and the skills of employees can be transferred to others through training. Those skills that cannot are the property of the employee and would not result in profits for the company in a competitive model. Monopsony in the market for engineers may explain part of the problem, but its scale is insufficient to explain much. Dowell (1978, p. 136) also has a discussion of these issues. Another point in Lund (2001) is that the Norwegian experience seems to contradict Osmundsen's model. Comparing Britain and Norway reveals fairly similar offshore petroleum prospects and political and regulatory environments. In spite of higher taxes for long periods (see Kemp 1992), Norway has been able to attract a lot of foreign investment in the sector.

6.5. What Is the Optimal Tax Rate?

Perhaps surprisingly, many studies referenced above pay little attention to the tax level. Governments and companies both regard this as very important, whereas economists who focus on tax neutrality have nothing to say about the optimal tax rate. Zhang (1997, p. 1107) states that "under such a neutral up-lift rate, varying the tax rate has no effect on the development trigger." Although Garnaut & Clunies Ross (1975) are quite policy oriented, their discussion of tax rates (pp. 280–81) is vague. Instead, they argue strongly about neutrality—even more so in Garnaut & Clunies Ross (1979).

Theoretical models with international comparisons (Sections 6.3 and 6.4) lead to recommendations on tax rates. Even for closed economies, there can be interior optima for the tax rate in models that combine fixed fees with taxes (Leland 1978, Fraser 1998).

Boadway & Keen (2008, p. 10) write, "There is another aspect of the international nature of the resource business that is more puzzling. Host countries evidently care very much how their tax systems compare with others, and are often concerned not to offer regimes that are substantially more onerous. Quite why this is so, however, is by no means obvious." Maximization of rent tax revenue would reduce the need for other, distortionary taxes. This also raises doubt about the relevance of analyzing a revenue neutral rent tax reform (Deacon 1993).

Several authors compare the tax level of one jurisdiction with that of others in order to find whether the level is "reasonable." For example, Watkins (2001, p. 28) finds that

resource tax regimes in Newfoundland and Nova Scotia "do not suffer by comparison with those in other offshore regions, such as the North Sea and Australia." He adds, "Overall, then, the regimes are sensible." Otto (2000, p. 2) states that "[m]ost governments try to strike a balance between government and investor revenue needs by implementing a 'fair and equitable' system. Unfortunately, no one has yet been able to determine what an ideal fair and equitable system is." It is likely that advice to authorities will be more valuable if it is able to address such issues.

7. CONCLUDING REMARKS

As discussed above, there are important problems related to our lack of knowledge of the objective functions of companies under uncertainty. The economics profession has not found one model of company behavior that is valid for all those which extract nonrenewable resources. In part, this has to do with observable differences between companies, such as small mining operations versus multinational oil companies. Such differences can be modeled. But the different theoretical traditions and various interpretations of empirical evidence also result in the wide variety of policy recommendations in the literature.

Even for a simple problem like the valuation of depreciation tax shields, Summers (1987) finds that companies deviate from the methods that have been suggested in textbooks since the 1970s. He asks how tax policies should respond to the fact that companies seem to make mistakes, but he does not arrive at a definite conclusion. More generally, the question is, What is an optimal tax policy if (a substantial fraction of) companies do not behave according to a neoclassical model? In such cases, the standard theory of optimal taxation no longer works, so many standard results need to be amended.

To end on a positive note, there are some situations in which the same tax policy may be beneficial in relation both to neoclassical companies and others. The companies that behave as risk averse, i.e., not taking advantage of diversification possibilities in capital markets, will typically underexploit investment opportunities and take on too little unsystematic risk. The Domar-Musgrave effect means that a Brown cash flow tax with full, immediate loss offset will encourage investment by these companies. At the same time, this tax is neutral in relation to companies that are well diversified. Lund (2000, sect. 8.2) points out that the tax works in the right direction for both types of companies. Sørensen (2005) has a model of this, which leads to an optimal tax policy. Although the information needed to implement an exactly optimal tax rate may be difficult to obtain, this is at least an example that all is not dark.

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The author was a member of the petroleum tax commissions in Norway from 1999 to 2000 and in Denmark in 2001. The views expressed in this review are those of the author, not necessarily those of the commissions or the authorities who appointed him.

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LITERATURE CITED

Arrow KJ. 1953 (1964). The role of securities in the optimal allocation of risk-bearing. *Rev. Econ. Stud.* 31(2):91–96 (Transl. from French)

Ball R, Bowers J. 1983. Distortions created by taxes which are options on value creation: the Australian Resources Rent Tax proposal. *Aust. J. Manag.* 8(2):1–14

Baunsgaard T. 2001. *A primer on mineral taxation*. Work. Pap. 01/139, IMF

Bjerkedal N, Johnsen T. 2005. The petroleum tax system revisited. See Glomsrød & Osmundsen 2005, 8:157–75

Black JM, Jones G, Rodriguez F, Woodward RS. 1982. Taxation of high risk ventures: some results using an expected utility approach. *Public Financ.* 37(1):1–17

Blake AJ, Roberts MC. 2006. Comparing petroleum fiscal regimes under oil price uncertainty. *Resour. Policy* 31(2):95–105

Blitzer CR, Lessard DR, Paddock JL. 1984. Risk-bearing and the choice of contract forms for oil exploration and development. *Energy J.* 5(1):1–28

Boadway R, Bruce N. 1984. A general proposition on the design of a neutral business tax. *J. Public Econ.* 24(2):231–39

Boadway R, Bruce N, McKenzie K, Mintz J. 1987. Marginal effective tax rates for capital in the Canadian mining industry. *Can. J. Econ.* 87(1):1–16

Boadway R, Keen M. 2008. *Theoretical perspectives on resource rent tax design*. Presented at the Int. Monet. Fund Conf. Tax. Nat. Resour., Washington, DC

Bond SR, Devereux MP. 1995. On the design of a neutral business tax under uncertainty. *J. Public Econ.* 58(1):57–71

Boué JC. 2006. *A Question of Rigs, of Rules, or of Rigging the Rules*? Oxford, UK: Oxf. Univ. Press

Bradley PG. 1998. On the use of modern asset pricing for comparing alternative royalty systems for petroleum development projects. *Energy J.* 19(1):47–81

Brealey RA, Myers SC, Allen F. 2008. *Principles of Corporate Finance*. Boston, MA: McGraw-Hill/Irwin. 9th ed.

Brown EC. 1948. Business income, taxation, and investment incentives. In *Income, Employment and Public Policy: Essays in Honor of Alvin H. Hansen*, ed. LA Metzler, pp. 300–16. New York: Norton

Campbell H. 1980. The effect of capital intensity on the optimal rate of extraction of a mineral deposit. *Can. J. Econ.* 13(2):349–56

Conrad RF, Hool RB. 1984. Intertemporal extraction of mineral resources under variable rate taxes. *Land Econ.* 60(4):319–27

Daniel P, Sunley EM. 2008. *Contractual assurances of fiscal stability*. Presented at the Int. Monet. Fund Conf. Tax. Nat. Resour., Washington, DC

Dasgupta PS, Heal GM. 1979. *Economic Theory and Exhaustible Resources*. Cambridge, UK: Cambridge Univ. Press

Deacon RT. 1993. Taxation, depletion, and welfare: a simulation study on the U.S. petroleum resource. *J. Environ. Econ. Manag.* 24(2):159–87

Debreu G. 1959. *Theory of Value: An Axiomatic Analysis of Economic Equilibrium*. New Haven, CT: Yale Univ. Press

Domar ED, Musgrave RA. 1944. Proportional income taxation and risk-taking. *Q. J. Econ.* 58(2):388–422

Dowell R. 1978. Resources rent taxation. *Aust. J. Manag.* 3(2):127–46
Emerson C, Garnaut R. 1984. Mineral leasing policy: competitive bidding and the Resource Rent Tax given various responses to risk. *Econ. Rec.* 60(2):133–42
Emhjellen M, Alaouze CM. 2003. A comparison of discounted cashflow and modern asset pricing methods—project selection and policy implications. *Energy Policy* 31(12):1213–20
Fane G. 1987. Neutral taxation under uncertainty. *J. Public Econ.* 33(1):95–105
Fraser R. 1998. Lease allocation systems, risk aversion and the resource rent tax. *Aust. J. Agric. Resour. Econ.* 42(2):115–30
Fraser R. 1999. The state of resource taxation in Australia: "an inexcusable folly for the nation"? *Aust. J. Agric. Resour. Econ.* 43(3):259–78
Fraser R. 2000. Is risk-sharing resource taxation in society's best interests if prices are log-normally distributed? *Resour. Policy* 26(4):219–25
Garnaut R, Clunies Ross A. 1975. Uncertainty, risk aversion and the taxing of natural resource projects. *Econ. J.* 85(338):272–87
Garnaut R, Clunies Ross A. 1979. The neutrality of the Resource Rent Tax. *Econ. Rec.* 55(150): 193–201
Garnaut R, Clunies Ross A. 1981. Relationships between governments and mining investors. *Mater. Soc.* 5(4):437–47
Garnaut R, Clunies Ross A. 1983. *Taxation of Mineral Rents*. Oxford, UK: Oxf. Univ. Press
Gaudet G, Lasserre P. 1986. Capital income taxation, depletion allowances, and nonrenewable resource extraction. *J. Public Econ.* 29(2):241–53
Gaudet G, Lasserre P, Long NV. 1995. Optimal resource royalties with unknown and temporally independent extraction cost structures. *Int. Econ. Rev.* 36(3):715–49
Glomsrød S, Osmundsen P. 2005. *Petroleum Industry Regulation within Stable States*. Aldershot, UK: Ashgate
Gordon RH, MacKie-Mason JK. 1995. Why is there corporate taxation in a small open economy? The role of transfer pricing and income shifting. In *The Effects of Taxation on Multinational Corporations*, ed. M Feldstein, JR Hines Jr, RG Hubbard, 3:67–91. Chicago, IL: Univ. Chicago Press
Graham JR, Harvey CR. 2001. The theory and practice of corporate finance: evidence from the field. *J. Financ. Econ.* 60(2–3):187–243
Green RC, Talmor E. 1985. The structure and incentive effects of corporate tax liabilities. *J. Financ.* 40(4):1095–114
Groth C, Schou P. 2007. Growth and non-renewable resources: the different roles of capital and resource taxes. *J. Environ. Econ. Manag.* 53(1):80–98
Herfindahl OC. 1967. Depletion and economic theory. In *Extractive Resources and Taxation*, ed. M Gaffney, pp. 63–90. Madison, WI: Univ. Wis. Press
Hotelling H. 1931. The economics of exhaustible resources. *J. Polit. Econ.* 39(2):137–75
Jacoby HD, Laughton DG. 1992. Project evaluation: a practical asset pricing method. *Energy J.* 13(2):19–47
Kemp A. 1992. Development risks and petroleum fiscal systems: a comparative study of the UK, Norway, Denmark and the Netherlands. *Energy J.* 13(3):17–39
Krautkraemer JA. 1990. Taxation, ore quality selection, and the depletion of a heterogeneous deposit of a nonrenewable resource. *J. Environ. Econ. Manag.* 18(2):120–35
Krautkraemer JA. 1998. Nonrenewable resource scarcity. *J. Econ. Lit.* 36(4):2065–107
Land BC. 2008. *Resource rent taxation—theory and experience*. Presented at the Int. Monet. Fund Conf. Tax. Nat. Resour., Washington, DC
Laughton DG. 1998. The potential for use of modern asset pricing methods for upstream petroleum project evaluation: Introductory remarks. *Energy J.* 19(1):1–11
Leland HE. 1978. Optimal risk sharing and the leasing of natural resources, with application to oil and gas leasing on the OCS. *Q. J. Econ.* 92(3):413–37

Lindholt L. 2008. *Maximizing the discounted tax revenue in a mature oil province*. Discuss. Pap. 544, Res. Dep. Stat. Norway, Oslo
Lintner J. 1965. The valuation of risk assets and the selection of risky investment in stock portfolios and capital budgets. *Rev. Econ. Stat.* 47(1):13–37
Lund D. 1992. Petroleum taxation under uncertainty: contingent claims analysis with an application to Norway. *Energy Econ.* 14(1):23–31
Lund D. 1993. The lognormal diffusion is hardly an equilibrium price process for exhaustible resources. *J. Environ. Econ. Manag.* 25(3):235–41
Lund D. 1999. Taxation and regulation of an exhaustible natural resource: the case of the Norwegian petroleum. In *Economic Rents and Environmental Management in Mining and Natural Resource Sectors*, ed. E Figueroa, pp. 189–244. Santiago/Edmonton: Univ. Chile, Santiago/Univ. Alberta
Lund D. 2000. Nøytralitet i petroleumsskattleggingen (Neutrality in petroleum taxation). In *Skattlegging av Petroleumsvirksomhet (Taxation of Petroleum Activity)*, Nor. Public Rep. 2000:18, append. 1, pp. 185–226. Oslo: Minist. Financ.
Lund D. 2001. Petroleumsskatt—flere uavklarte spørsmål (Petroleum tax—further undecided issues). *Økonom. Forum* 55(9):34–40
Lund D. 2002a. Petroleum tax proposals in Norway and Denmark. *Energy J.* 23(4):37–56
Lund D. 2002b. Rent taxation when cost monitoring is imperfect. *Resour. Energy Econ.* 24(3):211–28
Lund D. 2002c. Taxation, uncertainty, and the cost of equity. *Int. Tax Public Financ.* 9(4):483–503
Lund D. 2003. Testimony on consequences of a fiscal stability clause in Danish petroleum. In *Høring om de Statsretlige Aspekter af Nordsøaftalen*, pp. 43–47. Copenhagen: Energipolit. Udvalg, Folket. http://www.ft.dk/img20031/udvbilag/lib3/20031_25563/20031_25563.pdf (In Danish)
Lund D. 2006. Neutral company taxation under uncertainty, with some experiences from the petroleum sectors of Norway and Denmark. In *Yearbook for Nordic Tax Research 2006*, ed. R Påhlsson, pp. 116–23. Oslo: Universitetsforlaget
Lund D. 2009. *Marginal versus average beta of equity under corporate taxation*. Memo. 12/2009, Dep. Econ., Univ. Oslo
MacKie-Mason JK. 1990. Some nonlinear tax effects on asset values and investment decisions under uncertainty. *J. Public Econ.* 42(3):301–27
Majd S, Myers SC. 1985. *Valuing the government's tax claim on risky corporate assets*. Work. Pap. 1553, NBER
Mayo W. 1979. Rent royalties. *Econ. Rec.* 55(150):202–13
Mead WJ. 1994. Toward an optimal oil and gas leasing system. *Energy J.* 15(4):1–18
Mead WJ, Moseidjord A, Sorensen PE. 1983. The rate of return earned by lessees under cash bonus bidding for OCS oil and gas leases. *Energy J.* 4(4):37–52
Mossin J. 1966. Equilibrium in a capital asset market. *Econometrica* 34(4):768–83
Mossin J. 1968. Taxation and risk-taking: an expected utility approach. *Economica* 35(137):74–82
Nakhle C. 2008. *Petroleum Taxation. Sharing the Oil Wealth: A Study of Petroleum Taxation Yesterday, Today and Tomorrow*. London, UK: Routledge
Osmundsen P. 1995. Taxation of petroleum companies possessing private information. *Resour. Energy Econ.* 17(4):357–77
Osmundsen P. 1998. Dynamic taxation of non-renewable natural resources under asymmetric information about reserves. *Can. J. Econ.* 31(4):933–51
Osmundsen P. 2005. Optimal petroleum taxation subject to mobility and information constraints. See Glomsrød & Osmundsen 2005, 2:12–25
Osmundsen P. 2008. *Time consistency in petroleum taxation—the case of Norway*. Presented at the Int. Monet. Fund Conf. Tax. Nat. Resour., Washington, DC
Otto J. 2000. *Mining taxation in developing countries. Study prepared for UNCTAD, November*. New York: United Nations
Otto J, Andrews C, Cawood F, Doggett M, Guj P, et al. 2006. *Mining Royalties: A Global Study of Their Impact on Investors, Government and Civil Society*. Washington, DC: World Bank

Rubinstein M. 1987. Derivative assets analysis. *J. Econ. Perspect.* 1(2):73–93
Salahor G. 1998. Implications of output price risk and operating leverage for the evaluation of petroleum development projects. *Energy J.* 19(1):13–46
Samis MR, Davis GA, Laughton DG. 2007. Using stochastic discounted cash flow and real option Monte Carlo simulation to analyse the impacts of contingent taxes on mining projects. *Proc. Proj. Eval., AusIMM, Melbourne, 2007*:127–37 Carlton, VIC: Australas. Inst. Mining Metallurgy
Saunders M. 1987. Oil taxation: the cross-field allowance. *Fisc. Stud.* 8(4):55–68
Sharpe WF. 1964. Capital asset prices: a theory of market equilibrium under conditions of risk. *J. Financ.* 19(3):425–42
Sinn HW. 1987. *Capital Income Taxation and Resource Allocation*. Amsterdam: North-Holland
Slade ME. 1984. Tax policy and the supply of exhaustible resources: theory and practice. *Land Econ.* 60(2):133–47
Slade ME, Thille H. 2009. Whither Hotelling: tests of the theory of exhaustible resources. *Annu. Rev. Resour. Econ.* 1:239–59
Smith B. 1999. *The impossibility of a neutral Resource Rent Tax*. Work. Pap. Econ. Econom. 380, Aust. Natl. Univ. Canberra
Smith JL. 1997. Taxation and investment in Russian oil. *J. Energy Financ. Dev.* 2(1):5–23
Sørensen PB. 2005. Taxation of shareholder income and the cost of capital in an open economy: theory and applications to the Nordic countries. *Nationaløkon. Tidsskr. (Danish J. Econ.)* 143(3):433–47
Summers LH. 1987. Investment incentives and the discounting of depreciation allowances. In *The Effects of Taxation on Capital Accumulation*, ed. M Feldstein, pp. 295–304. Chicago, IL: Univ. Chicago Press
Sumner MT. 1978. Progressive taxation of natural resource rents. *Manchester Sch. Econ. Soc. Stud.* 46(1):1–16
Sunley EM, Baunsgaard T, Simard D. 2003. Revenue from the oil and gas sector: issues and country experience. In *Fiscal Policy Formulation and Implementation in Oil-Producing Countries*, ed. JM Davis, R Ossowski, A Fedelino, 6:153–83. Washington, DC: IMF
Sunnevåg KJ. 2000. Designing auctions for offshore petroleum lease allocation. *Resour. Policy* 26(1):3–16
Thaler RH. 1988. Anomalies: the winner's curse. *J. Econ. Perspect.* 2(1):191–202
von Neumann J, Morgenstern O. 1947. *Theory of Games and Economic Behavior.* Princeton, NJ: Princeton Univ. Press. 2nd ed.
Watkins GC. 2001. Atlantic petroleum royalties: fair deal or raw deal? *Oil Gas Pap. 2*, Atl. Inst. Mark. Stud., Halifax, NS
Zhang L. 1997. Neutrality and efficiency of Petroleum Revenue Tax: a theoretical assessment. *Econ. J.* 107(443):1106–20

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