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Taxation and regulation of petroleum companies under asymmetric information; a monograph

By

Petter Osmundsen

A dissertation submitted for the degree of dr. oecon.

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Petter Osmundsen

Contents

Chapter 1

Taxation and regulation of petroleum companies under asymmetric information. A discussion of incentive problems and the principles for applying principal-agent analysis *

1.1 OBJECTIVES OF THE THESIS

After the discovery of petroleum reserves on the Norwegian continental shelf the government had to choose among three basic approaches in administrating these resources; 1) auctioning drilling rights to private companies, 2) resource extraction by state-owned companies, or 3) discretionary licensing.[1] The policy chosen was a combination of 2) and 3). Drilling rights are given to Norwegian and foreign private

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[1] In the licensing process, discretion is used in the appointment of operator, the choice of licensees, the distributions of equity shares among the partners, etc.

companies after an application procedure, and the government is a direct participant through the direct state participation (SDFI) and by the state-owned petroleum company, Statoil. As foreign petroleum companies had a comparative advantage in exploration, development and production of oil and gas, an optimal division of labour implied participation by foreign companies. At the same time the government wanted to pursue an industrial policy of building up a competitive Norwegian petroleum industry. As this would require an initial favourable treatment of domestic companies, auctions were not suited for deciding the licencee structure.[2] Through their operating activities the private companies (domestic and foreign) obtain private information, i.e. information that is not available to the government (the Ministry of Industry and Energy; MIE). This information asymmetry creates special regulatory problems.

My research plans are to analyse some of the problems the government faces in designing and enforcing petroleum taxation and regulation under asymmetric information. The framework of the analysis is that of principal-agent theory. The first part of the thesis, chapter 1, discusses principal issues of asymmetric information in the petroleum industry, and the relevance of applying principal-agent theory. In the second part, chapters 2, 3 and 4, I construct theoretical models analysing optimal principles for petroleum taxation and regulation under asymmetric information. The third part, chapter 5, compares these principles with the current Norwegian system.

By discussing the relevance of incentive theory for the analysis of petroleum taxation, and by considering the necessary adjustments to be made in the general incentive theory, I will in this paper build a foundation and give motivation for the subsequent

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[2] After the transfer of technology and increased competence in Norwegian companies, this is probably no longer a valid argument against auctions. Another objection to auctions is that the bids will be too low as a consequence of imperfect competition (collusion). According to Rowland and Hann [1987], the exposures to risk, the scale, and the heavy front-end loading of costs, tend to restrict the offshore industry to an oligopolistic structure. Low bids may also be the consequence of the fact that the government is not able to commit not to tax the companies heavily after investments have been sunk. The commitment problem is discussed in section 1.8 below. Optimal auction design under asymmetric information is treated in section 2.11 and chapter 4.

analysis. To obtain interesting economic results the theory of mechanism design makes quite a few assumptions, some of which are not innocuous. In my reading of this literature I often find the introduction of these assumptions too brief. By collecting assumptions and principles in a separate paper, I will try to elaborate on the foundation for principal-agent analysis in the context of petroleum taxation and regulation.[3]

1.2 ASYMMETRIC INFORMATION

From a general point of view, asymmetric information is detrimental to welfare as it decreases the feasibility set. This is operationalised in principal-agent theory; in addition to the participation constraint of models with symmetric information, asymmetric information necessitates the introduction of incentive constraints. These constraints make truthtelling a dominant strategy for the agent. With these added restrictions we cannot reach Pareto-optimum, but must search for a second-best solution. This is known as the Hurwicz conjecture. In the following I will describe some consequences of asymmetric information for the taxation and regulation of the petroleum industry.

The government's objective is to extract the rent generated by the scarce petroleum resources (resource rent).[4] The most important means for rent extraction are the licensing conditions and the petroleum tax system. The ideal (i.e. non-distorting) tax base is pure profits, or the multiperiod equivalent; net present value of the cash flow. Pure profits from an oil or gas field depend partly on characteristics that are particular

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[3] I will focus on problems related to asymmetric information. For a general survey of economic aspects of regulation and taxation of the Norwegian petroleum industry, see Lund [1991]. This paper also gives a good overview of the present Norwegian regulatory regime in this industry. Facts about the licences and participants on the Norwegial sector, and an outline of the institutional structure in Norwegian petroleum industry is provided in Ministry of Industry and Energy [1993]. For the recent tax changes, see Ot.prp. 12, 1991-92.

[4] See section 1.4 for a more detailed discussion of the objective function.

to the field and partly on market conditions in general. With symmetric information the government can achieve the first best solution, i.e. capture all the economic rent without distorting the real decisions of the companies. This can be achieved because the symmetry of information enables MIE to calculate the true economic rent and use it as the tax base in the income taxation of oil companies.

Through their operating activities, however, the petroleum companies obtain field-specific information that is not available to the government. The asymmetry of information is derived from the source of the agency; returns to specialisation. Examples of such private information are knowledge about the estimated size and uncertainty of oil reservoirs, and costs of exploration and production. Some costs can be controlled by auditing, but this is not the case for calculated costs. Due to the enormous investments in the petroleum industry, the companies' capital costs are very important. The capital cost is typically a calculated cost that is difficult for MIE to estimate or verify.[5] Another obstacle to observing true costs in the petroleum industry, discussed in section 1.11 below, is the possibility for tax arbitrage through the use of transfer pricing. Due to the asymmetry of information about costs, the individual companies know more about the economic rent pertaining to a particular field than the government.

The institutional arrangements in Norwegian petroleum regulation, with a state-owned oil company, Statoil, and a special regulatory and controlling agency, Norwegian Petroleum Directorate (NPD), may to some extent alleviate the problem of asymmetric information. NPD has the right to participate at partnership meetings in all licences. The petroleum companies are required to submit technical and economic

[5] Lund [1991] points out that the required rate of return in the stock market for an American oil company is about 5 per cent, whereas the licencees in the Norwegian sector claim they require 10 to 15 per cent rates of return after tax. Lund makes it clear that there may be a justified divergence between overall and project-specific rate of return requirements. One of the reasons he gives is that some exploration is unsuccessful; the conditional expected rate of return after successful exploration must therefore be higher. Lund, however, notes that some of the divergence probably is due to strategic reporting of capital costs in order to argue for lenient taxation.

data to NPD. They are also required to submit all their drill tests and seismic data to the directorate. However, taking into account strategic considerations, the companies might want to distort their reports of how they interpret these data. By conducting their own technical surveys, NPD is able to check for some of these distortions, although not perfectly. Through the process of exploration and production, Statoil obtains first hand information. As the state-owned company is a large participant in most of the licences, this information is of direct importance in contributing to efficient operations in the licences where Statoil is appointed as operator. In addition, Statoil may also be instrumental for shedding light on licences where it is a participant but has not been awarded operatorship. From its operations Statoil may obtain information about the real costs of certain activities, and through the licences it operates it may gain some information about the true sizes of adjacent reservoirs. This type of information can be very useful in the regulation of the petroleum industry. An important assumption for such information to reach the government, is congruence between the objectives of the government and that of Statoil and NPD. If Statoil and NPD have agendas of their own, they may (similarly to the private companies) find it in their own interest to conceal or distort parts of this information.

Despite the efforts of the government, NPD and Statoil to have the information of the private petroleum companies revealed, they will probably have some private information left.[6] Due to this asymmetry of information, the companies may conceal their true information by masquerading as a company with different characteristics. An oil company with low costs and large reservoirs may imitate a company with high costs and small reservoirs, and must therefore be given an economic compensation (information rent) to be willing to reveal its information.[7] The firm is an information monopoly in the sense that it earns rents owing to its private information (as opposed

[6] As all information cannot be obtained through control measures, this leaves room for revelation mechanisms.

[7] In the models there will be several companies, each with a certain cost structure. An alternative interpretation is the existence of one company that may be of different types, each type corresponding to a different cost structure. The company knows its own type, whereas the government only knows the distribution of possible types.

to a natural monopoly whose rents are derived from increasing returns to scale). A consequence of the government's inability to distinguish (discriminate) between the different types of companies and types of petroleum fields is therefore that it will not be able to capture all the rents through taxation.

The high number of applicants for new licences on the Norwegian sector, may be a signal of the presence of rents. Rents in the Norwegian petroleum sector are indicated in Ot.prp.nr.12, 1991-92; the petroleum industry has a considerably higher accounting rate of return on their total investments than the industries on shore. The fact that this was the case even for the years after the oil crack in 1986, suggests that this premium is higher than necessary compensation for a possibly higher risk. Apriori it is not obvious that the petroleum industry in general is more risky than other industries. Dasgupta et al. [1980] argue that there is little evidence that extractive industries are riskier (in the relevant sense) than other industries. This seems to be true also for the present Norwegian petroleum industry. In the beginning there was much uncertainty with relation to the size and location of recoverable reserves, and the technical problem of deep-water drilling was not yet solved. This uncertainty has been drastically reduced after more than two decades of exploration, development and production.[8] With the policy of tailoring the tax rates to the petroleum prices, the government is also bearing much of the risk of price fluctuations. High volatility of petroleum prices, high front-end investments, long lead times and imperfect loss-offset, still entail a considerable risk. Some of these risks, however, are similar for commodity-based industries on shore, e.g. the production of aluminium. Johnsen [1991] has estimated the systematic risk of the individual departments of Norsk Hydro, and found that the oil and gas activities had the same beta-value (0.6) as the metal division of the conglomerate.

[8] One might argue this risk should not be compensated anyway, as it is idiosyncratic. This is discussed in section 1.8.

One might argue that presence of rents due to asymmetric information is a general phenomenon that is not especially characteristic of the petroleum industry. But the fact that this industry is extracting a scarce and exhaustible natural resource makes the presence of rents more likely than in most other industries. The imperfect competition in the industry is also part of the problem. Moreover, the complexity of deep water operations on the Norwegian sector gives relevance to the assumption of asymmetric information.

1.3 THE RELEVANCE OF PRINCIPAL-AGENT THEORY

The oil and gas deposits in the North Sea are a common resource whose ownership is shared by all Norwegians. MIE acts as a principal on their behalf in administrating the resources, and the oil companies are agents that are given the rights to extract the petroleum resources. In return they compensate the principal through production royalties and oil related income taxes. The tax system determines the economic incentives for the agents, and at the general level the problem is to design the incentive structure in such a way that the agents get incentives for exploiting the oil and gas reserves in an optimal way from the principal's point of view. This is a problem of mechanism design. The task is to endogenously decide on the optimal incentive mechanism. It is clearly a part of normative theory, and it may generate policy implications.

Incentive theory represents a simplification of a negotiation game; all the bargaining power rests with one of the parties, the principal, and it supposes that he is able to commit to a static incentive scheme.[9] Principal-agent theory can be particularly

[9] This simplification is not so restrictive as it may seem at first, as the bargaining power of the agents is taken care of by the appropriate design of participation constraints (defining the reservation utility) and incentive constraints.

relevant in this context as in the relationship between MIE and the oil companies, MIE is a natural principal; i.e. the government can be seen as a Stackelberg leader which gives a take-it-or-leave-it offer to the oil companies. The government, however, might not be able to enter into a binding *long term* take-it-or-leave-it contract, as the parliament or new governments may change the tax rules or tax rates. With this lack of commitment the companies may be less willing to reveal their private information (ratchet effect).

A common modelling of the process in Principal-agent relations is that the agent makes an announcement of his *type*, to which the principal responds with a pre-determined incentive contract. The revelation principle states that the principal can restrict his attention to mechanisms that reveal the agents' true types. Type may in this context refer to costs, efficiency, or the size of petroleum deposits. The present Norwegian petroleum regulation has features that may be characterised as revelation mechanisms. As part of the previous licence application procedure, the petroleum companies offered Statoil a certain ownership schedule (sliding scale). By the announcement of a specific gliding scale in a certain licence, a company might (to some extent) implicitly reveal its expected operational efficiency, its costs and its assessment of the reservoir size of the block. The system (still in effect) of offering a work programme as part of the licence application, may also have some characteristics of a revelation mechanism. Without having to commit to certain exploration activities within a fixed period of time, and with the present system of negligible licence fees, there would probably be a high number applicants in the licensing rounds as a licence would represent an option free of cost. The work programme therefore serves the function of sorting out (separating) the sincere applicants. Furthermore, by the announcement of what blocks the company offers to explore, it may reveal what reservoirs it considers to be profitable. In some licensing rounds, however, in return for equity shares in profitable licences, companies offer to explore some area of the continental shelf that they do not themselves consider profitable. In the 14th licensing round MIE wanted further exploration in the Barents Sea. Due to previous negative exploration results and due to large transportation costs in case of discovery of petroleum reservoirs, most companies did not consider further exploration as a profitable investment. In return for assumed profitable licences in the North Sea, some companies offered to undertake a certain exploration programme in the Barents Sea. This may be a revelation mechanism in the sense that the extent and the expected costs of the offered Barents Sea exploration, may be an indication of the companies' expected profitability of the blocks in the North Sea.

If the contracts between MIE and the oil companies may be personalised, we are not restricted to non-discriminatory tax rules. Individualised contracts give room for more complex tax schedules to be designed, and this gives better opportunities for utilising contract theory. The scope for contract theory can also be increased by permitting differential taxation of oil fields (or by applying contract theory one can check under what conditions it is optimal to differentiate taxes between different oil companies and fields). An application of general results from incentive theory, would imply that it is optimal for MIE to tailor the incentive scheme to the information structure in each separate case. As the extent of private information most likely would differ in the various licences, this would call for discrimination. Discrimination on the licence level is difficult as the tax subject in the present petroleum taxation is the company and not the individual projects. An exception is the field-specific royalty system, but this is abolished for new licences. Differential taxation also conflicts with the policy of a uniform petroleum taxation; stated in Ot.prp. 12, 1991-92. The object of a non-discriminatory tax policy is to obtain an efficient allocation of capital among existing licences and among investment in existing and new reservoirs. In addition, Ot.prp. 12, 1991-92 makes it clear that differential taxation may represent an obstacle to efficient trading of oil between the operators of different oil fields (e.g. to fulfil delivery obligations) and welfare improving inter-field projects (e.g. injections from gas to oil fields). Uniformity has also been a central objective of the recent reforms of the systems for personal and general corporate taxation.

Despite the stated policy of non-discrimination, the government has a record of tailoring the tax policy. This has been done in situations where petroleum projects have been considered to be socially profitable, but where the private petroleum companies claim it is not profitable for them given the existing taxes and regulations. These situations have been solved by selective tax reliefs. Examples of this are the preferential treatments given to supplementary projects on Ekofisk and Snorre. An indication that this discretionary policy continues is the distinction between old and new oil fields with relation to royalty (proposed in Ot.prp.nr.12 1991-92).[10] The differential policies on Ekofisk and Snorre were mainly caused by the 1986 oil price fall. Even if the discrimination was not initiated by systematic differences in asymmetric information between various petroleum fields, these differences would most likely systematically affect the extent of tax reliefs in each case needed for the government to assure development.

In evaluating the present incentive mechanisms in the petroleum industry, it is not sufficient to see the tax system in isolation. The actual incentive mechanism would consist of all the conditions and regulations that are relevant for the companies' decisions. The most important condition, beside the petroleum tax system, is the distribution of owner interests in the licences. In the present system of discretionary licensing of exploration and drilling permissions, the licencee structure is an important differentiation device. There is no official statement that this differentiation is done according to the distribution of information, but it is reasonable to assume that information considerations implicitly is one of the factors contributing to differentiation. A conclusion of this section is that MIE in the present system of petroleum regulation has necessary means to take account of asymmetric information.

[10] The royalty is abolished only for fields whose developments were approved after 1 January 1986.

There is no official policy, however, of systematically adjusting for asymmetric information.

1.4 THE GOVERNMENT'S OBJECTIVE

The government is assumed to be benevolent and to have a utilitarian welfare function, i.e. it seeks to maximise the total (unweighted) domestic surplus generated from the petroleum sector.[11] This surplus is comprised of benefits accruing to three parties; domestic consumers of petroleum products, petroleum companies, and the public in general. The benefits for the public can be represented by the government's petroleum revenue, R. This revenue is the total government take in the petroleum industry, i.e. it is the sum of petroleum taxes, royalties, licence fees, etc. People benefit from this revenue through public services, transfers, and possibly through reduction of tax rates in the non-petroleum sector.

The possible direct benefit to the consumers is an increase in the consumer surplus of petroleum products resulting from domestic petroleum production. As oil and gas are commodities that are traded internationally, an increase in consumer surplus must be the result of a reduction of world prices due to Norwegian petroleum production. I will make the simplifying assumption that Norway is a price taker in the petroleum markets, thereby abstracting from consumer surplus considerations.[12]

The government's objective function contains weights for the producer surplus, Π, and government revenue, R. It is worth noting that the incentive problems in

[11] The social welfare function will here be taken as exogenously given. The literature on social choice endogenises the social welfare function. I will not go into this theory as my focus is on incentive problems in the petroleum industry, and not on the relationship between the regulatory agency and the electorate.

[12] This assumption might be more plausible for the oil market than for the gas market, as the gas market is more segmented due to higher transport costs.

screening models where the producers have private information about their types, rest on the assumption that government revenue has higher weight than producer surplus. The incentive problem ceases to exist if Π is given at least as high weight as R. This is the result of Loeb and Magat [1979]; when a transfer between the principal and the agent can be done free of cost, the first best optimum can be achieved. It is implemented by designing the transfer so that the objective function of the agent equals the social surplus, giving him incentives to internalise all social effects.[13] This result is easily applied to our context: If Π is given at least as high weight as R, social welfare, W, is maximised when Π is maximised. The government should therefore set royalties and taxes to zero. The producers will consequently use all their private information to maximise Π.

The incentive problem arises when R is given the higher weight. MIE would now like to extract Π, but this is difficult due to the companies' strategic use of private information. There are two approaches in the incentive literature to justify that R should be given the higher weight in the welfare function. Baron and Myerson [1982], adjusted to this model, would give

(1.1) $$W = R + \alpha \Pi,$$

with $\alpha < 1$.[14] The rationale they provide for this weighting is that it is derived from the regulator's interest to serve the interests of the citizens in their jurisdiction. They further assume that all the consumers reside in the jurisdiction, but not all the owners of the firm. The regulator will accordingly give preference to consumer interests. As the jurisdiction to the government regulating the petroleum industry is comprised of the whole electorate, this approach does not seem relevant for my purpose.

[13] This is an application of the Groves mechanism to regulation.

[14] This is the approach chosen in Gaudet, Lasserre and Long [1991], in their analysis of optimal resource royalties.

In the trade-off between government revenue and rent to the petroleum companies, I will instead use the assumption made in Laffont and Tirole [1986]. In a partial model of regulating a monopolist under asymmetric information, they make use of the general equilibrium shadow cost of public funds, $1+\lambda$, and take it as exogenously given. As there generally is a considerable excess burden from raising government revenue through taxation, the marginal value of funds in the public sector is higher than in the corporate sector (the shadow cost of public funds is higher than one). The resulting welfare function is

$$W = (1+\lambda)R + \Pi \tag{1.2}$$

As in Laffont and Tirole [1986], I have taken the general equilibrium shadow cost of public funds, $1+\lambda$, as exogenously given in my partial analysis. This is reasonable in Laffont and Tirole's model for regulation of a monopolist. Due to the large revenues, this is more questionable in the petroleum sector. For simplicity, however, I will stick to this assumption.

It is worth noting that the objective of rent extraction is a result of efficiency considerations and not of distributional preferences. This is evident as the argument above is based on a utilitarian welfare function, i.e. consumer and producer surplus have been given equal weights. Taking into account the government's distributional preferences over foreign and domestic income, the objective of rent extraction is reinforced. The fact that much of the petroleum production is carried out by companies owned by foreigners makes the objective of rent extraction even more important, as foreign income does not count in domestic welfare considerations. In the context of foreign investment in a developing country, Little and Mirrlees [1974] make a distinction between net of tax profits remitted abroad and funds that are ploughed back domestically. The remitted profits are given welfare weight zero, whereas retained profits might be given some weight, since

"...such further investment yields benefits or costs for the host country, as did the original investment; moreover this further investment would not have taken place without the original investment."

This argument seems to rest on the implicit assumption that the foreign investor is financially constrained; new investments must be financed through retained earnings in the host country. I do not find this plausible in the case of multinational petroleum companies, having ample access to the international capital market. Investments will in this case not be determined by present accounting profits, but rather future net of tax cash flow. This expected cash flow must be sufficient for the foreign companies to be willing to invest. In the setting of incentive theory, however, this cash flow is not part of the principal's objective function, but rather a constraint on his optimisation problem.[15] The welfare weight of foreign income will therefore be set equal to zero. As there usually are several companies participating in a petroleum licence, forming a partnership, the regulator's welfare function will look like

(1.3) $$W = (1+\lambda)R + (1-\mu)\Pi,$$

where μ is the foreign companies' share in the licence.

The approach of distributional considerations in Baron and Myerson [1982] and the approach of a cost of public funds in Laffont and Tirole [1986], have been shown to generate similar *qualitative* results. This is because rent extraction is a government objective under both approaches. The objective function in the case of foreign participation on the continental shelf, given by equation (1.3), takes into account both distributional considerations and cost of public funds. The objective of rent extraction is therefore reinforced.

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[15] This is called the participation constraint, or the individual rationality constraint.

It is worth noting that the objective of rent extraction is of special relevance for the petroleum industry. As petroleum is a scarce and exhaustible fossil fuel, much of the income in the petroleum industry is really a resource rent. According toe MIE [1993], in 1992 the calculated Norwegian petroleum rent was 40 billion NOK. As pointed out in Dasgupta et al. [1980], the taxation of such rents is non-distortionary, if appropriately arranged. Minimisation of the dead weight loss associated with the tax system as a whole may imply that extractive industries should be taxed more heavily than other industries. This is done in the current Norwegian system of petroleum taxation; in addition to the ordinary corporate tax of 28 per cent, a special tax of 50 per cent is levied on petroleum net income.

1.5 STRATEGIC BEHAVIOUR

The rent to the petroleum companies may be derived from strategic use of private information about the size of oil and gas reservoirs and the costs of exploration, development and production. Examples of such strategic behaviour are to understate the reservoir size and overstate the costs to obtain higher profits.

In accordance with traditional incentive theory, I assume that the petroleum companies (the agents) are rational and that their objective is to maximise profits. These assumptions imply strategic behaviour. This is not to say that the companies commit crime or fraud. In measuring costs, and even more in estimating the size of a reservoir, there is not always an unquestionable truth to be found. To calculate these measures one has to choose which data to use and which measurement methods to apply. The companies may act strategically by not reporting their best estimate, but rather using a selective presentation of data and choice of methods in order to obtain highest possible profits.[16]

1.6 ADVERSE SELECTION MODELS

Adverse selection is a special type of hidden information, in which the agent obtains private information before entering into a contract with the principal. The contract is designed by the principal.

The inability to capture all the rents through taxation, due to hidden information, makes it optimal for the government to strike a balance between efficiency in resource extraction and efficiency in general taxation (i.e., a second best solution). This trade-off between efficient exploration and production on the one hand and capturing the excess returns on the other hand, can be illustrated by noting that in general it is possible to achieve the former at the expense of the latter. In other words, it is possible to design a tax system in which all petroleum companies make use of all their private information in their real decisions. To achieve this efficiency, however, the resulting government revenue may be low, as the companies must be paid off to reveal their information. Due to the objective of rent extraction, this tax system is probably not optimal for the government. At the point of efficiency, marginal changes in real decisions will have no first order welfare effects (the envelope theorem). However, changes in the real decisions of the petroleum companies with high costs and small reservoirs, may make them less favourable to mimic by efficient companies with large reservoirs. The latter type of company will

[16] This is also a common phenomenon in the relationship between petroleum companies operating different licences on the same reservoir. After the initiative from one or several of the parties, according to unitisation agreements the split of the petroleum production from the reservoir may be subject to renegotiation. The main subjects in these renegotiations are the decisions about which data and methods to apply.

therefore require less rent to be willing to reveal their information, i.e. their incentive constraints are relaxed. The reduction in information rent is captured by the government. Increased government revenue leads to a welfare increase of the first order, as it is now possible to reduce distortive taxation in the non-petroleum sector. Consequently, the second best solution to petroleum taxation with informational constraints may imply some distortions of real decisions in the industry. The optimal trade-off is to distort the real petroleum decisions to the point where the deadweight loss from these distortions equals the reduction in deadweight loss in the non-petroleum industry made possible by the increase in petroleum taxation. Or put differently, the optimal solution trades off between efficiency losses generated by the departure from the symmetric-information (efficient) real decisions and financial and distributional gains associated with increased rent extraction from the petroleum industry. This is a typical second-best result in taxation theory; it is optimal to spread the deadweight loss over several markets.

In regulation of the petroleum industry there are numerous problems related to asymmetric information. I will in the subsequent analyses of adverse selection narrow the scope to two bargaining situations that seem particularly relevant for the question of raising revenue; 1) asymmetric information about the petroleum industry in general (the geological structures and the costs and efficiency of the private companies) and , and 2) asymmetric information of a particular field. The first problem is relevant for designing and revising the general petroleum taxation and regulation. The revisions of the Norwegian petroleum tax system often come after changes in the oil price (measured in domestic currency), with tax increase after price increases and tax relief after a fall in price. The basic issue in designing and revising the general petroleum taxation is to figure out under what conditions private petroleum companies are willing to participate on the Norwegian sector. An illustration of this is the revisions following the price fall in 1986. The government wanted the Troll field to be developed, as this was considered socially profitable.

However, the operator of the licence, Shell, said that current conditions made field development unprofitable. This initiated negotiations between MIE and the private companies about revisions of the general tax system.[17]

The main problem for MIE in such negotiations is that it does not know the companies' basis for decisions. Due to the asymmetry of information the principal does not know the companies' evaluations of costs and petroleum deposits. When a company is threatening not to participate in exploration and production under the existing regulation and taxation, the principal may not be able to discern whether this is true or whether it is an empty threat used for bargaining purposes. The problem of MIE is that it does not know the real reservation points of the companies, i.e. the supply price of private petroleum investment is uncertain. In the language of the incentive theory; the Ministry does not know the private companies' types. However, it is often assumed that the government has a prior distribution over the possible types. If the social value of a project is considered so high that it should be implemented no matter what type the company is, it is a main result from the incentive theory that the company can gain a considerable rent if it happens to be of a "good type" (i.e. if it has low costs and the reservoir is large). Ex post this seems to be descriptive of the Troll field. Under certain circumstances it may be optimal for the regulator to follow a strategy of awarding production licences only to companies that announce reservoir sizes and efficiency parameters over a certain cutoff level. This mechanism will reduce the rent of efficient producers with large reservoirs, as they can no longer mimic the least efficient type, but only the cutoff type. In deciding on the cutoff levels, MIE has to trade off this gain against the loss of the field not being developed if the agent is of an unfavourable type. The cutoff strategy is most likely to be optimal for marginal fields, as in this case the loss from the field to remain undeveloped is relatively small. The recent decision (after the 14th licensing round) of not awarding participation in any new licences to Esso and Shell, due to the

[17] The results of these negotiations were to abolish royalty and to introduce a production compensation ("negative royalty") on new fields.

fact that these companies required too high net compensation, may be an indication of a more active policy from the government, in which participation is made contingent on the announced type being in a certain range.[18]

The second problem of asymmetric information to which I will bring attention, is special adjustments in the incentive structure for fields that are already in operation. As these typically are adjustments to particular fields, they will not represent revisions of the general petroleum taxation but rather exemptions from it (thus undermining stated principles of uniform petroleum taxation). An example of this practice is tax reliefs connected to the injection project on the Ekofisk field. The regulator's ability to capture the rent on such supplementary projects will depend on how private information changes over time. Exemplified by the injection, this is a supplementary project on a field that has been in production for some time. It is reasonable to assume, therefore, that the operator has gained much knowledge of this particular tract. On the other hand, the regulatory agency is also likely to have gained much information, by means of tax reports, public disclosures [19], company reports to NPD, and by NPD participation in the license committee.

Negotiations over favourable treatment for supplementary projects on licences already in production are recurrent. A usual starting point is that the partners on a licence point to a supplementary project that they claim is unprofitable for the licencees with existing regulations and taxation, but that would prove to be beneficial for the society. These marginal projects can be socially profitable as they benefit from the sunk investments in platforms and transportation systems. Reasons for deviations between social and private profits are often found in non-neutral features of the tax system. As a favourable treatment to secure realisation of such marginal projects, the companies seldom ask for reduction in tax rates but rather focus on

[18] Esso and Shell were not willing to participate in further exploration activity in the Barents Sea. This can be considered as a higher net compensation demand on the blocks in the North Sea, cf. the discussion of existing revelation mechanisms in section 1.3.
[19] E.g. to the stock market.

higher equity shares in the tract (often asking MIE not to exercise Statoil's option of a gliding scale).

An apriori result about these renegotiations of incentive contracts, is that MIE could gain (capture more rent) by keeping its strategies a secret. If the regulator gives the impression, directly or implicitly, that a certain project is to be implemented - no matter the exact costs or the reservoir size - it gives away a lot of negotiation power. Effectively it reveals that it has no reservation point with relation to the agent's type. By making the implementation contingent on the company's type being in a certain range, the regulator could capture more of the rent. If the project actually was socially profitable for all types, this reduction in rent must be traded off with the welfare loss from not implementing the project if the agent happens to be of a bad type.

The regulatory agency is instructed to serve many goals. This makes it hard to keep the regulating strategy a secret and creates difficulties for using mechanisms that are contingent on the company's type being in a certain range. Apart from capturing the resource rent, the regulator is also supposed to achieve employment and macroeconomic objectives. More specifically, the petroleum industry is given the task of securing a stable employment in the engineering and the construction industry. Hence in periods of idle capacity in the mechanic industry, the government is eager to develop new petroleum fields. As explained, this increases the bargaining power of the companies and gives them higher rent. This illustrates that introducing additional objectives in petroleum regulation may reduce the regulatory agency's ability to extract rent.

1.7 DYNAMICS

Some important aspects of petroleum regulation cannot be analysed in static models. Dynamics are important in this industry as it exploration is time consuming, and as it takes several years to develop a field which thereafter may produce in thirty years. The theory of mechanism design recommends regulating the private companies by means of incentive mechanisms. A crucial feature of dynamic models is that incentive mechanisms may be responsive to new information. As time goes by uncertainty resolves itself, and the regulator may gain information about the agent's type. Ex post it is efficient to make use of this information; if the information is perfect the regulator may set an efficient production level without leaving rent to the firm. Anticipating this, however, the agent will not reveal his type in the first place (the ratchet effect). It is, therefore, a result from dynamic incentive theory that it is ex ante efficient for the regulator to commit not to make use of new information that is revealed over time; i.e. it is optimal to stick to a fixed static scheme instead of acting opportunistically in each period (a fixed rule is better than discretion). A crucial assumption for this result is that the regulator is able to credibly commit to a long-term policy.

Norway clearly applies a discretionary regulation of the petroleum industry, as the licensing process (especially the distribution of equity shares in licences) and the tax system is responsive to changes over time in prices, technology and estimates of recoverable reserves.[20] This opportunism can be seen as the result of the regulator's inability to commit to a multiperiod mechanism. Problems with credible commitment are common for most principal-agent relationships, as ex post deviation from a

[20] An example of the tax system being responsive to price changes is the introduction of a special tax on petroleum net income (25 per cent) in 1975, in response to increased petroleum prices. After a new price increase this tax rate was adjusted to 35 per cent, and then reduced to 30 per cent in 1981 after a price fall. Similarly the royalty on gross petroleum income was abolished in 1986, but only for new licences.

committed policy often is profitable. The problem is severe in the case of regulation of petroleum companies; two additional characteristics of petroleum regulation make credible commitments especially hard to achieve in the relationship between petroleum companies and the government: 1) Irreversible investments, and 2) institutional restrictions.

A large fraction of the costs in the petroleum industry is made up of capital investments. Important among these are platforms designed and constructed to drill on a specific field on the deep water of the Norwegian continental shelf. Due to this specialisation, which is most profound for concrete gravity platforms, the investments have a low alternative value (the investments are specific to the relationship with MIE). This irreversibility implies a low elasticity ex post, i.e. once the investments are made (sunk) the money generated can be taxed without creating any static excess burden (only income effects). As the government's welfare maximisation implies raising a given revenue at lowest possible dead-weight loss, it is difficult to credibly commit not to tax the petroleum sector heavily after large investments have been done.[21] Due to the considerable size of the petroleum income such a confiscatory policy would be especially tempting in this industry. Institutional characteristics make this problem even worse as the principal is the present government, and as the present administration is restricted in making commitments concerning the politics of future administrations. Another aspect of the commitment problem is the fact that MIE is restricted to incomplete contracting. Full commitment would require complete long term state-contingent contracts. As it is impossible today to foresee all future contingencies with relation to costs, technology, proven reserves and petroleum prices, the contracts between the regulator and the petroleum industry will necessarily have to be incomplete.

[21] The problem with the commitment game is that it is not subgame perfect.

Norwegian authorities have chosen a policy of gradual extraction of petroleum reserves, and it is mostly the same companies that apply in each licensing round. The licensing process may therefore be approximated as a repeated game. Given the impediments to commitment, it may seem difficult to build reputation for sticking to a certain rule in petroleum regulation. As commitments are not likely to be credible, the companies will expect MIE to act opportunistically in each period. Given these expectations, opportunism would also be the best action for the principal. This equilibrium will be characterised by suboptimal investments. MIE will therefore have a strong incentive to establish a credible commitment for a non-confiscatory tax policy. In principle, this can be achieved by establishing a reputation for sticking to a non-confiscatory tax rule, or by creating institutional arrangements that punish the government in case of deviations from such a rule. Reputation or institutional arrangements may substitute for long-term contingent contracts, and to some extent mitigate the underinvestment effect.

An institutional arrangement suggested for committing governments is to use the constitution. The idea is that this will commit the government as changing the constitution would be time-consuming and would require a qualified majority in the parliament. Due to the long horizon in petroleum production (exploration may take several years, development up to five years, and the production phase may last for more than thirty years), the fact that it takes up to four years to amend the constitution does not help much. The need for a qualified majority in parliament may also not be an effective restriction due to the temptation of higher short-term revenue. Most likely MIE would therefore have to use reputation effects to build commitment.

As Norway has an open economy and is an integrated member of the international community, the Norwegian government is not likely to nationalise foreign investments in the Norwegian petroleum sector, because this would cause serious diplomatic problems and may provoke economic retaliations. As there is a strong political support for a mixed economy, the government is also not likely to nationalise private domestic investments on the continental shelf. Although MIE is generally believed not to choose the drastic means of nationalisation, and therefore has more credibility than politically unstable and less internationally integrated countries, it will still have to build reputation for not choosing less dramatic means like heavy ex post taxation of irreversible investments.

In analysing the dynamic taxation problem, I will consider two categories of games: Games of complete and incomplete information with respect to the government's type. The government is per assumption free to reoptimise in each period, i.e. commitment is ruled out. To start with complete information games; the petroleum companies are assumed to know equation (1.3), i.e. they know that the government's objective is rent extraction. In a finite horizon model (T periods), we will inevitably get suboptimal investments. The government's strategy in period T cannot affect the future. Period T is therefore a one-shot game, and MIE will play the dominant strategy of heavy ex post taxation. The petroleum companies, having complete information, will figure out the government's period T strategy. Consequently, the equilibrium of period T-1 cannot affect the future. MIE will again choose its dominant strategy, and by backward induction the equilibrium is characterised by heavy taxation and suboptimal investments in each period.

In an infinite horizon model, however, the underinvestment problem may be alleviated by appropriate trigger strategies. Strictly speaking, the game between MIE and the private petroleum companies does not have an infinite horizon as petroleum is an exhaustible resource. Nevertheless, the infinite horizon can be justified by a random termination date. In the process of exploration and production, new recoverable reservoirs are discovered and the estimated size of existing reservoirs is increased. It is therefore reasonable to assume that the players always expect the game to extend one more period with a high probability.

A sequentially rational equilibrium without underinvestment can possibly be characterised by the following expectations: The companies expect a reasonable taxation if this has been observed in the past. If the government defects from this pattern, heavy taxation is expected for the *n* subsequent periods. The government may not want to choose the dominant one-period policy of heavy taxation, as the gain in that period may not be sufficient to compensate for the underinvestment in the following periods.

Another model solving the underinvestment problem, is a finite horizon model in which MIE can be of two types; soft or tough (incomplete information of type may be a reasonable assumption for newly elected governments). The soft type would like to leave the companies with a reasonable rate of return in each period, whereas the tough type's preferences are given by clear cut rent extraction. In the last period there is no use of building a reputation, hence the tough type will tax the companies heavily. In the early part of its incumbency, however, the tough type may have an incentive to masquerade as being soft. This is achieved by imposing a reasonable tax policy, thereby building a reputation for softness. Heavy taxation would give high revenue, and consequently an immediate efficiency gain as the taxation of the non-petroleum sector can be reduced. This short term gain, however, must be traded against long term costs of losing the reputation for reasonable taxation, as revelation of a tough type would cause suboptimal investments. If the government has a high reputation when it enters office, and if it can be assumed to be a patient player, it is likely to be willing to incur short-term costs to build this reputation. We get a pooling equilibrium in which both types play the reasonable strategy in the first periods. Hence reputation can substitute for commitment in sustaining an equilibrium with private investments.

Common for the models of complete and incomplete information is that they depend on the government to be a patient player in order to solve the underinvestment problem. A government is perhaps patient within its incumbency period. The length of that period, however, is uncertain. Due to long lead times and long production periods on the continental shelf, the incumbency periods of Norwegian governments are under all cricumstances likely to be small compared to the planning horizon in petroleum investment projects.

The large private investments made and the high number of applications for new licences on the Norwegian continental shelf, combined with high revenue from the industry, indicate that the Norwegian government has succeeded in establishing a credible commitment for a reasonable tax policy. The policy has been to tailor the taxes and licence requirements to the existing economic conditions in the industry. The purpose of this implicit contract has been to attract new investments, and the policy has therefore taken into account the development in costs, technology, proven extractable (recoverable) reserves and petroleum prices.

As the prices of oil and gas have been the most volatile of these figures, there has typically been a change in taxation and regulation following price increases (tax increases in 1975 and 1980) and price reductions (tax relief in 1986). In each of these tax revisions, however, consideration has also been given to changes in costs, technology, and proven reserves.

Lund [1991] argues that the main reason for the need to tailor the tax system is that it is not neutral. In the case of neutrality the tax base is equal to the rent, and will consequently not distort development and operating decisions. A non-neutral system leads to distortions, and these distortions become more serious when prices fall. An important feature of the petroleum tax system in this respect is imperfect loss-offset. Losses can be carried forward, but are not compensated for inflation and opportunity costs of capital. Due to the long lead times, this is a particular problem in the petroleum industry. If the company is unsuccessful in generating profits, an initial loss will never be deducted.

The tailoring may look like a policy-rule that effectively commits the government. This is not so as this policy is subject to discretion, and hence does not represent a complete conditional contract.[22] The policy of tailoring resembles the "fair mechanism" characterised in Baron [1989]: "The fairness condition prohibits the regulator from offering a policy in the second period that would yield non-negative profits to a firm with the type revealed in the first period." This mechanism lies in between full commitment and pure opportunism. In Baron's model the private company can choose to withdraw from the relationship in each period, and the principal is not able to commit to future policies. The parties enter into a voluntary arrangement in which the firm exchanges its right to withdraw from the relationship for restrictions on the opportunism of the regulator. Due to the huge irreversible investments on the Norwegian continental shelf, the private petroleum companies do not have the option of withdrawing. Instead the companies may deny participation in new licences. The government therefore has an incentive to restrict its opportunism.

The "fair mechanism" is a possibility in situations where full commitment in the form of complete contingent contracting is not possible. It is important to note that it does not completely solve the commitment problem, as it requires that the principal is able to credibly commit to leave non-negative profits to the companies after revelation of their types (or analogously: After irreversible investments). Baron justifies this by assuming that the "fair mechanism" is written as a legal contract between the parties, and that procedural requirements and legal precedents restrict the government's ability to alter it ex post. This may be of relevance in our context as procedural requirements in Norwegian law protect firms from arbitrary and capricious actions by the regulator.

[22] The latter would have to prescribe the exact percentage change in the tax parameters that were to follow a certain percentage change in petroleum prices, costs, proven reserves, etc.

However, much of the regulation of the petroleum industry is not in the form of explicit legal contracts, but rather an implicit contract between MIE and the industry.

Of relevance to the question of commitment, is the controversial issue of asymmetric treatment of old and new fields with relation to royalty. As pointed out by Lund [1991], in the tax reform of 1986-87, following a price fall of petroleum, a negative instead of a positive royalty was introduced. However, this was only applied to licences with a development plan approved after January 1986. This represents an asymmetry, as tax increases in 1975 and 1980, following a rise in petroleum prices, were made effective for all fields. This ratchet effect can be seen as an opportunistic policy: High taxes on irrevocable investments. This is clearly harmful for the credibility of the government' s tax rule. The problem is that the tax changes are made on an ad hoc basis. If progressivity is an important objective for the government, it would be better to construct a clearly defined and stable progressive tax system.[23] Lund [1991] concludes that this asymmetric policy will reduce the petroleum companies' interest in new licences. To keep the investment levels, the government would have to lower its revenue. It would be possible to maintain a higher tax level if the government avoided the reputation for asymmetric treatment of gains and losses.

An argument in favour of asymmetric tax treatment of price increases and decreases is that the extraordinary price increases represent windfall gains. Such gains are totally unexpected and can therefore be taxed without creating any distortions. However, Rowland and Hann [1987] argue that the windfall nature of additional profits is questionable in a North Sea context, as company plans will consider various oil price trends. Hence sharp increases in petroleum prices are unlikely to be totally unforeseen. Imposing extra taxes on these profits will therefore act as a tax on incentives and thereby deter development plans.

[23] The uplift proposed in Ot. prp.nr 12 represents a progressive element in the petroleum taxation.

The principle of uniform taxation of all fields, old or new, stated in Ot. prp.nr 12, 1991-92, can be seen as an attempt to build reputation for non-discrimination. Such a commitment, if assumed credible by the companies, could increase government revenue. In spite of this statement of uniformity, MIE upholds the discrimination between fields whose developments were approved before or after 1 January 1986 (royalty is abolished only for the latter). However, no new asymmetries were proposed.

Much of the analysis above concerns situations of symmetric information, as the oil and gas prices probably are observable for both the principal and the agent. The principles of commitment, however, are similar for factors that are subject to asymmetric information. To get sufficient incentives to reveal a good type (large reservoir and low costs) in the first period, a company must be given a considerable first period compensation (rent) as an opportunistic government is expected to use this information to eliminate all rent in the next period. The first period rent can be reduced if the government is able to commit not to take advantage of the information revealed in the first period.[24]

The inability to commit imposes restrictions on means of regulation. For example, the inability to commit has been used as an argument against the use of auctions in petroleum regulation; an oil company is not willing to offer much front-end payment for a petroleum licence as the government cannot commit not to tax the company hard once the production starts (political risk).

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[24] This is shown in Laffont and Tirole [1993], chapters 1 and 9. A broader treatment of credibility problems in economic policy is given in Persson and Tabellini [1990].

1.8 RISK

As a prerequisite for the discussion of moral hazard models in section 1.9, I need evaluations of the relevant risk in petroleum projects for private companies and for the government. I also need to know whether the degree of risk aversion is different for the two parties.

Bøhren and Ekern [1987] argue that, from the government's standing point, the relevant risk for investment projects in the petroleum industry is the macroeconomic (systematic) risk. The macroeconomic risk is defined as the covariance between the project's payoff and the payoff of a reference portfolio. The relevant reference portfolio from the government's perspective is the national wealth, including the Norwegian international diversification of risk through investments and financial operations abroad.[25] According to Bøhren and Ekern, macroeconomic risk in the petroleum industry is income risk, i.e. risk related to fluctuations in petroleum prices and the exchange rate of the US dollar. Microeconomic (idiosyncratic) risk, i.e. risk related to production and costs, is not relevant as it is diversified in the country's total portfolio of petroleum projects.

Due to the absence of a complete set of contingent markets (incomplete markets), all of the income risk cannot be eliminated by the use of hedging strategies. Some of the exposure to exchange rate fluctuations, however, can be eliminated by long term funding in dollar. Some of the price risk might be diversified by investing in the stock markets of countries that are net importers of oil.[26] The Norwegian

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[25] The authors make an exception for especially large petroleum project; in this case the project's variance will have a direct effect on the variance of the national wealth. For small projects the variance term is negligible, only the covariance term counts.

[26] According to Obstfeld [1993], the correlation coefficient between the change in the log real price of oil and the change in the log of world real per capita consumption, for the period 1973-1988, is -0.6. This indicates an opportunity for international diversification of petroleum income risk by investing abroad.

government, however, does not seem to pursue a strategy for diversification of the petroleum income risk. On the contrary, the exposure to risky petroleum income is increased by a relatively high pace in the development of the North Sea, and by building up a large domestic petroleum industry. In the analysis of the government's risk aversion in petroleum projects, I will have to choose the relevant reference portfolio; is it the present national wealth or is it an internationally diversified portfolio? By choosing the present portfolio, with a relatively high exposure to petroleum income risk, one would require a significant risk premium for petroleum investments. I will argue, based on conventional portfolio theory for investments under uncertainty, that diversifiable risk should be taken care of by international diversification possibilities. The choice of real investments on the continental shelf should not be affected by such risk, only undiversifiable risk should be taken into account.

From the perspective of a petroleum company, Bøhren and Ekern [1987] states that the relevant risk for a petroleum project may consist of both project specific risk and the project's covariance with the company's portfolio. However, the authors argue that if the company has a portfolio of 10-15 imperfectly correlated projects of about the same size, most of the idiosyncratic risk (risk with relation to production and costs) will be diversified. From the shareholders' point of view, this risk is irrelevant even if the company has a smaller portfolio of projects, as the shareholders can diversify on their own behalf. By letting the petroleum component of their portfolios consist of several companies, possibly on different continental shelves, most of the idiosyncratic risk should disappear. The shareholders would prefer companies that stick to areas where they have most competence, preferring to diversify their own portfolios rather than purchasing shares in diversified companies. They will therefore object to the wide-spread vertical integration in the petroleum industry, if this process cannot be justified by vertical synergy and reduced probability of bankruptcy. To some extent, this integration process may be explained by agency problems. The wealth of a company manager (the agent) is likely to depend on the company's profits. As the manager probably has imperfect means for diversification of his human capital, and is assumed to be risk averse, he will have a preference for projects with low idiosyncratic risk. Bøhren and Ekern [1987] point out that due to the same agency problems for the project managers, the companies may diversify not only at the company level but also at the project level. That is, project managers may take irrelevant (idiosyncratic) risk into account. This, however, will only pose a real problem if both of the following two conditions are fulfilled: 1) If the project manager tries to eliminate idiosyncratic risk through the choice of certain technical solutions, it cannot be detected by the company managers, and 2) the agency problem cannot be counteracted by appropriate design of the incentive mechanism for the project manager. An example of a detectable strategy for reduction of idiosyncratic risk is the use of outdated but safer production technology. On the other hand, asymmetric information about the geology in a certain licence, may give the project manager some leeway in choosing technological solutions that reduce idiosyncratic risk.

The corporate systematic risk is given by the covariance between the rate of return on the company stocks and the rate of return on the market portfolio. As for the government, this will be an income risk that cannot be fully diversified due to incomplete markets. Some of the exchange rate risk can be eliminated by long term funding in US dollars. The price risk is difficult to hedge, as listed oil futures have a maximum maturity date of one year. Due to high specific investments in pipelines, gas is mostly sold on long term contracts. Price uncertainty still exists, however, as in these contracts the price of gas often is indexed to the oil price.

With the perspective of optimal risk sharing, one would also like to compare the relevant risk for foreign versus domestic private petroleum companies. If petroleum companies were only owned by citizens of the country where they have their head office, and if the market portfolios in various countries differed in their correlation with petroleum income, companies of different nationalities could have different systematic risk. According to Johnsen [1990], this is not very likely due to increasing financial integration in general and the multinational nature of most petroleum companies in particular. An increasing financial integration with petroleum companies being traded in many countries (e.g. Norsk Hydro is quoted on the stock exchanges in London and New York), and with high correlation between the various stock exchanges, petroleum companies of different nationalities are likely to have about the same systematic risk.

Summing up, in the absence of agency problems, the relevant risk for the companies and the government is systematic risk, given by the project's covariance with a reference portfolio. This may give different measures of risk as the two parties do not have the same reference portfolios; the market portfolio versus national wealth. On an apriori basis it is hard to judge the relative size of these two risk measures. Based on analyses on data from the stock market and the national accounts, Johnsen [1991] argues that the Norwegian national wealth probably is less exposed to petroleum income risk than is the Oslo Stock Exchange. The systematic risk, therefore, will be higher for private companies than for the government. In addition, if company or project managers, due to agency problems, take irrelevant (idiosyncratic) risk into account, there is another reason to believe that the companies assign a higher amount of risk to a given petroleum project than the government. Having discussed the relevant risk measures for the principal and the agents, I now turn to the comparison of the two parties' risk aversion for a given amount of risk.

In a generalised version of the model in Sandmo [1972], Lund [1993] shows that uncertainty should be taken into account in cost-benefit evaluation of projects. He argues that in petroleum projects one can base the analysis on a representative individual (as the revenues are collected by the government), and that covariance between the project rate of return and the rate of return on the national wealth is the relevant risk measure. Referring to Bøhren and Ekern [1987], he agrees that price and currency fluctuations are the factors generating macroeconomic risk. As a way of implementing this macroeconomic risk measure, Johnsen [1991] suggests using stock exchange data for the private Norwegian petroleum company, Saga. Lund [1989, 1993] argues that Norwegian citizens in their implicit claims on the government's petroleum revenues already have a considerable component of petroleum in their portfolios.[27] As short-sale is prohibited on the Norwegian stock exchange, Norwegians have imperfect means of diversification of their petroleum wealth. Consequently, only Norwegians with especially high wealth and low risk aversion will choose to own stocks in Saga (clientele effect). In aggregating the risk preferences, the expected return on stocks in Saga will therefore represent a lower bound on the social discount rate in petroleum projects.[28] Johnsen [1991] agrees with the statement that Norwegians have imperfect means of diversification of their petroleum wealth. He points out that Norwegians in the short run can diversify oil wealth by use of options in petroleum companies. But in the long run this is not possible due to the prohibition of short sales and by the inexistence of stocks with a negative correlation with petroleum incomes. The representative Norwegian will therefore be locked in with a too high petroleum component in their portfolios, thus violating a central assumption for CAPM.[29]

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[27] In the government's Long-Term Programme for 1994-1997, the petroleum wealth is estimated at 550 billion 1993-NOK, or about 130.000 NOK per citizen. There is considerable uncertainty in these calculations. Moreover, it will overestimate the claim on government revenue, as the government, due to asymmetric information, is not able to extract all of this wealth. Nevertheless, the estimate indicates a substantial petroleum component in the individuals' portfolios.

[28] One might argue that this is a result of an inefficient regulation (prohibition of short-sales), and that the resulting corner solutions (imperfect diversification of risk) therefore should not be taken into account in calculating the social discount rate.

[29] Nevertheless, Johnsen, stressing the lack of implementable alternatives, finds CAPM useful for calculating the social discount rate for petroleum projects. This is because of the availability of relevant data from the stock market, and because the lock-in effect is counteracted by the observation that the systematic petroleum risk is higher in the stock market than in the national wealth.

An implication of the argument in Lund [1989, 1993] is that the government, for a given relevant risk in a petroleum project, will have a higher degree of risk aversion than a private petroleum company. However, as concluded above, the companies might assign a higher amount of risk to a given petroleum project than the government. The overall comparison of risk calculations in project evaluation of the two parties is therefore inconclusive.

1.9 MORAL HAZARD

Ceteris paribus the tax system will determine the number and types of operative companies and oil/gas fields. The optimal tax system should then attract the most efficient companies and induce all socially profitable fields to be exploited in an optimal way. In addition, efficiency would call for the resource extraction to be carried out in a cost-minimising way. The government may here face additional information costs, as it may only be able to monitor the companies' efforts to reduce costs in an imperfect way. If the government neither directly can monitor the actions of the agents, nor is able to deduce these actions from observable outcomes (as the outcomes are the joint product of an action that only the agent knows and of uncertainty), it faces the problem of moral hazard.

Imperfect monitoring (hidden action) plays an important role in incentive theory models. Laffont and Tirole [1993] assume the following function for total costs, C:

$$(1.4) \qquad C = \beta - e$$

They assume that the principal is able to observe total costs, but due to asymmetric information he cannot observe (separate) the two cost components; efficiency (the agent's type, β, an adverse selection parameter) and effort (e, a moral hazard parameter). These assumptions seem reasonable for the relationship between MIE and the petroleum companies. The presence of asymmetric information with relation to a company's type was pointed out in section 1.6, and in this section I will argue for the presence of hidden actions in the petroleum industry. Although the model of Laffont and Tirole contains both an adverse selection parameter and a moral hazard parameter, it is basically a model of adverse selection (screening). The reason is that the focus of the model is not the trade-off between incentives and risk sharing, as in pure moral hazard models, but rather an analysis of information rent accruing to the agent following asymmetric information about his type, as in screening models. Laffont and Tirole [1993] can be viewed as an extension the model of Baron and Myerson [1982]. Baron and Myerson construct an adverse selection model in which there is asymmetric information with respect to costs. Laffont and Tirole, however, assume costs are observable. Still, the principal can not directly infer the agent's type, as the costs are a linear function of two separate variables (β and e), and it is assumed that the principal can observe neither of these.

There is a large literature focusing directly on the problem of moral hazard. A well-known paper in this tradition is Grossman and Hart [1983]. The paper analyses the problem of an owner of a firm (principal) who delegates the running of the firm to a manager (agent). The authors assume a risk neutral principal and a risk averse agent. This assumption can be explained by a difference in the two parties' possibilities for diversification of risk; the owners of the firm can diversify their financial portfolios whereas the manager cannot diversify his wealth due to an incomplete market for human capital. Under symmetric information (i.e. in the absence of moral hazard) an optimal risk sharing between the principal and the agent is given by equality of the two parties' marginal rates of substitution of income between the different states of nature. With a risk neutral principal and a risk averse agent, it implies complete insurance for the agent. As the agent's income in this case is independent of effort, it is problematic if the principal cannot observe or deduce the effort (moral hazard). To induce the agent to exert effort, his income must be made dependent on the only observable variable; the output. As the output is stochastic, the agent no longer receives complete insurance, i.e. we deviate from the Pareto-optimal sharing of risk. Grossman and Hart [1983] show that with the presence of moral hazard, the second best solution is given by a trade-off between risk sharing and incentives.

In my opinion it is reasonable to believe that there are important moral hazard problems in the relationship between MIE and the petroleum companies. To justify this I will have to argue for: a) The existence of hidden actions in the petroleum industry, and b) outcomes being the joint product of actions that only the agent knows and of uncertainty. To start with b), the outcomes I have in mind are output (tons of oil equivalents; toe) and costs (for a given output). In this context I will assume that the information about output and costs is symmetric.[30] As asserted in a), however, there is asymmetric information when it comes to effort; MIE has imperfect means for observing the company's effort to increase output and to reduce costs. Furthermore, due to uncertainty with relation to technology and the geologic structure, it is reasonable to consider output and costs in the petroleum industry as being stochastic. If MIE observes high costs and low production, it will therefore not know whether this is due to a low effort of the firm or due to technological problems or an adverse geological structure. As the sizes of petroleum reservoirs are hard to estimate before the point of drilling, and as there still are unsolved technological problems, the problem of discerning the effort seems particularly relevant to this industry. Having discussed point b), I will now provide more detailed arguments in favour of point a); the presence of hidden actions.

MIE has imperfect observability of the companies' efforts contributing to the production volume, i.e. exploration and production efforts. It is possible to observe the amount of seismic data collected, the number of exploration (appraisal and

[30] This may be an unreasonable assumption for calculated costs, cf. section 1.2.

wildcat) and production wells drilled, etc.[31] But the government cannot perfectly monitor the amount of internal resources the companies allocate in the exploration and production processes. An example of these internal resources is the number and the competence of the personnel (geologists, geophysicists and reservoir engineers) allocated to interpret seismic data and results from exploration wells. Further examples of imperfect observability are the amount of gas injected into an oil field to increase extraction, and the amount of management resources allocated to a certain exploration or production process. Another observability problem is that a multinational petroleum company may choose technical solutions for a Norwegian petroleum field as part of the company's research process. Such technical experiments may be beneficial for the company's activities on other continental shelves, but may be detrimental to the production of the Norwegian experimental well (suboptimal technology). The present petroleum taxation, where costs can be deducted at an effective marginal tax rate of 78 per cent, makes it profitable for multinational companies to perform such experiments in Norway.[32] If such experiments can lead to increased revenue in the company's petroleum activities in countries with a lower marginal tax rate, the company would also like to do more experiments than in a no-tax world.

MIE cannot perfectly monitor the companies' efforts to reduce costs. This is especially relevant for the development stage. In this stage the companies make large investments in pipelines and platforms for production and accommodation. These investment goods are not standard commodities with established costs. On the contrary, these are complex goods whose costs will depend on the operator's effort in design, management and procurement. The specific nature of these investment goods

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31 The companies are required to report this information to NPD.

32 For costs that can be deducted in the same year as they accrue, the effective marginal tax rate is equal to the statutory marginal tax rate, i.e. 78 per cent. This presupposes that the company is in a tax-paying position. For costs that have to be depreciated over a number of years, investments, the effective marginal tax rate have to be determined by calculations. With the assumption of a company with positive profits that has a nominal before-tax opportunity cost of capital of 11.11 per cent, Stensland et al. calculate an effective tax rate of 77.2 per cent on investment costs.

makes it hard for MIE to deduce this effort by looking at the costs of comparable projects. Lund[1991] points out that the high marginal tax rates lead to incentives for transferring the training of new personnel to the Norwegian petroleum sector, while the resulting benefits will occur in other sectors with lower marginal tax rates. Again, costs may be high as a result of hidden actions.

With asymmetric information with respect to the companies' efforts to increase production and to reduce costs, and with production and costs being stochastic, the second best optimum is given by a trade-off between risk-sharing and incentives. This follows from a direct application of models for moral hazard, cf. the above discussion of Grossman and Hart [1983]. From the discussion in section 1.8, however, the total risk in petroleum projects is the sum of risk related to production and costs (idiosyncratic risk) and income risk (systematic risk). It is important to note that the problem of moral hazard is only attached to the former of these risks. For the companies, assumed to be price takers, the income risk (i.e. price and exchange rate risk) is exogenous. It is therefore not affected by the companies' effort. Furthermore, petroleum prices and the exchange rate of US dollar can be observed in the markets, and the income risk is therefore subject to symmetric information.[33] As the one type of risk is subject to symmetric information, and information of the other type of risk is asymmetric, the risk sharing should be taken care of by two separate contracts.[34]

The sharing of the income risk should be arranged by a contract contingent on petroleum prices and the US dollar exchange rate. Due to symmetric information, the optimal sharing of income risk between MIE and the petroleum companies is given by equality of the two parties' marginal rates of substitution of income between the different states of nature. In section 1.8, I argued that both parties should be averse to the systematic risk. The problem of sharing income risk is therefore likely to have

33 The gas prices agreed on in long term supply contracts are not directly observable, but the companies are required to submit this information to MIE.

34 I am thankful to Frøystein Gjesdal for this idea.

an interior solution. Furthermore, in the section on risk I also argued that the systematic risk is higher for private companies than for the government, but that the government, for a given relevant risk in a petroleum project, will have a higher degree of risk aversion than a private petroleum company. Consequently, the overall comparison of the two parties' attitudes to systematic risk is inconclusive, and the exact optimum of income risk sharing cannot be decided on an apriori basis.

The sharing of the risk related to idiosyncratic risk should be arranged by a contract contingent on costs and production. As argued in section 1.8, in absence of agency problems in the companies, both parties will be neutral towards idiosyncratic risk. We will therefore not get the usual trade-off between incentives and risk sharing; the contract should be designed to achieve the single objective of providing optimal incentives for the agent. The solution to this problem is provided by the residual claimant principle; the agent should be made residual claimant for all increases in production and for all of its cost savings. This solution implies a contract in which the company carries all the idiosyncratic risk, and can be implemented by ex ante contracting on a fixed quantity of production and a certain cost. If the company (due to agency problems) takes idiosyncratic risk into account in its decision making, the objectives of incentives and risk sharing go in different directions (from the perspective of optimal risk-sharing the company should receive a fixed payoff, whereas to provide optimal incentives the company should be made residual claimant), and we get an interior solution. On the basis of the discussion in section 1.8, however, I will argue that companies are not very likely to take into account idiosyncratic risk. At the level of company managers most of this risk is diversified by the composition of the companies' portfolios of petroleum projects. At the level of project managers, the problem of aversion to irrelevant risk can be counteracted by the probability of detection and by appropriate design of incentive mechanisms.

The present Norwegian policy

The problem of inobservability is that it may result in a level of company effort that is suboptimal from the government's point of view. MIE tries to counteract the problem of suboptimal effort by use of direct regulation, but is restricted to regulate observable efforts, e.g. by establishing a detailed exploration work programme as part of the licensing conditions. To induce the company to exert the optimal level of unobservable effort, the government must provide it with an appropriate incentive structure. The most important incentive feature in the present regulatory policy is to give the companies equity shares in the licences in which they operate. This mechanism will give correct incentives if 1) the operator and the other partners are refunded their true costs in their internal accounting (cash calls), and 2) the petroleum tax system is neutral.[35] With the present regulation, however, the operator is in some instances refunded more than true costs, and the other partners are not refunded the costs they incur in their monitoring of the operator. Moreover, from the theory of corporate taxation, we know that it is difficult to implement a neutral profits tax.

It is important to note that the risk measure and risk attitude proposed for the government in section 1.8, are based on normative considerations. As I will focus on normative theory, the current risk attitudes and risk sharing on the Norwegian sector will be compared with these normative analyses. The practice of the Norwegian government is clearly not in line with the theoretical recommendations. The official policy for risk evaluations in public investments, stated in NOU 1983:25, resembles risk neutrality in recommending that the social rate of discount is not to be adjusted for risk. Risk is only to be accounted for by use of sensitivity analysis. The present

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[35] Dasgupta et.al. [1980] show that a constant tax rate levied on a company's true profits, is neutral with respect to the company's choice of extraction path. The corporation income tax, however, may distort the decisions on exploration. As shown in Heaps and Helliwell [1985], the exploration decision will be undistorted is the company (assumed in a tax-paying position) is allowed immediate expensing of exploration costs.

practice in evaluations of petroleum projects, however, is better described as risk seeking behaviour. This is due to a high direct state participation in the petroleum industry, and is also a result of the procedures chosen for regulation of the private petroleum companies.

In the beginning of the development of the petroleum sector, the private foreign companies bore a large part of the risk on the Norwegian continental shelf. This was the result of a relatively low marginal tax, use of a gliding scale, and regulation establishing that the foreign companies were to carry Statoil's exploration costs. The experience from several decades of exploration, development and production, has significantly reduced the idiosyncratic risk in Norwegian petroleum activities. Simultaneously, there has been a change in policy; risk bearing has been shifted from the companies to the state: Bearing and the gliding scale have been abolished, and in the present Norwegian petroleum taxation system with high marginal taxes on net income (78 per cent), much risk is borne by the government. The policy of tailoring the tax level to the economic conditions entails an additional shifting of risk from the companies to the government. There is also a high risk attached to the direct state participation (SDFI) in the petroleum industry (Statoil and the State's Direct Financial Interest takes up 80 per cent of the licences, and according to MIE [1993] SDFI is likely to account for approximately 45 per cent of all investments offshore in 1993). Adding the fact that SDFI and the offshore activities of Statoil are self-insured, and observing that the Norwegian government is not attempting any diversification of petroleum risk through investments and financial operations abroad, one might argue that this reveals a pattern of risk-seeking. In a total evaluation of the risk sharing between the government and the petroleum companies, however, one must take into account the risk borne by the companies due to high front-load investments and imperfect loss-offset.

From the analysis of optimal risk sharing, I concluded that the companies should bear all the idiosyncratic risk. When the diversifiable risk was reduced on the continental shelf, it is in line with the theoretical recommendations that the government were to bear a larger fraction of the total risk. Though hard to quantify, it seems that too much risk-bearing now has been shifted to the government. There is no theoretical justification for the government to carry most of the undiversifiable price risk, and contrary to normative theory the government is also carrying much of the idiosyncratic risk.

The problem of low cost consciousness is of special relevance in the present tax regime due to the high marginal tax rates, as the partnership in this case is residual claimant only for a small fraction (22 per cent) of its cost savings. Seen from the perspective of the operator, this fraction is even smaller. Letting t be the marginal tax rate and the a the operator's equity share, the operator is residual claimant for the fraction $a(1-t)$. With a marginal tax rate of 78 per cent and an equity share of 20 per cent[36], the fraction is only 4.4 per cent. Clearly, this system may cause low cost consciousness and excessive testing of new technology.

An alternative means of extracting rent from the petroleum sector, in which more of the risk is borne by the private companies, is to introduce a system of front-end payments. This could be a pure auctioning system, or could be implemented in the framework of the present system of discretionary licensing (by use of licence fees).

[36] Often the equity share is considerably lower.

1.10 INDUSTRIAL ORGANISATION

Most applications of principal-agent analysis in regulation theory analyse the situation of a principal regulating one agent or several homogeneous agents. The case of one agent will in the terms of industrial organisation be a monopoly. The case of several heterogeneous agents, oligopoly (collusion), is not yet settled in the theory of mechanism design. Hart and Holmström [1987] explain that the traditional contract theory approach, in which the agent's reservation utility is taken as exogenously given, has a methodological advantage relative to models of imperfect competition. Analytically contract theory is an optimisation problem, whereas in imperfect competition it is an equilibrium problem. Methods for optimisation are substantially more advanced than methods for solving equilibrium problems. In the subsequent analyses I will therefore make the simplifying assumption that the regulatory agency faces a monopoly. As there are many companies that participate on the Norwegian continental shelf, this assumption can only be justified if the companies form a stable cartel in negotiations with MIE. In the context of the screening models sketched out in section 1.6, the partnership must form a cartel in negotiations with the government in a particular licence, and the petroleum companies must form a cartel in the negotiations over general offshore regulation and taxation.

To start with the negotiations over the general economic conditions on the Norwegian continental shelf, the operators often act as a cartel through their interest organisation; the Norwegian Oil Industry Association (OLF). In some instances the operators have a common interest in their negotiations with the government, and the cartel will be stable. This will be the case for regulations and taxes that affect the companies in the same way. Due to different portfolios (large versus marginal fields, old versus new licences) and differences in ownership (private or state-owned, foreign or domestic), the companies may also have conflicting interests. In such situations, the cartel assumption cannot be justified. A recent example of such disagreement is the negotiations following the proposed tax changes in Ot.prp. 12, 1991-92. The group of operators were in this instance split into factions. A possible strategy for MIE to increase its negotiating power is to increase the potential conflict of interest between the companies (divide and rule).[37] Such discrimination does in fact exist, cf. the discussion of tax discrimination between old and new fields.[38] Another example is the principle of "revenue neutrality" for tax reforms, i.e. maintaining the same revenue as in a reference case. This is achieved by changing two or more parameters simultaneously, implying more tax for some companies and less for others.

The choice of modelling the petroleum companies as a cartel raises the question of how to treat state-owned companies; are they to be considered as part of the principal or as a member of the cartel (agent)? Are the objective functions of the state-owned companies aligned with that of the government, or do they have an agenda of their own? Norsk Hydro is 51% state owned, but clearly acts as a private company. Consequently it will be analysed as belonging to the agent group. Statoil mostly acts on a commercial basis. In many respects it can therefore be considered equal to the other companies; i.e. as a member of the cartel (Statoil is in fact a member of OLF). It may seem unnatural that Statoil is part of a cartel negotiating with MIE, as the Minister of Industry and Energy is head of the board in Statoil. This gives the impression that the government is negotiating with itself. Most of the decision taking in Statoil, however, is delegated to a management group that is instructed to act on a commercial basis. Statoil is responsible for operational and financial administration of SDFI. It was established as a means of keeping part of the petroleum cash flow outside Statoil. It has been asserted, however, that this is mainly a book-keeping device, and not an effective economic regulation. In the question of industrial organisation I will therefore consider SDFI as an integrated part of Statoil.

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[37] I am thankful to Gunnar Stensland for this idea.

[38] As pointed out in section 1.8, this is probably not an optimal means of discrimination, as ad hoc tax changes may have adverse dynamic effects.

I will proceed with a discussion of the cartel assumption in negotiations between the government and the partners of a particular licence. Licences are awarded to groups of companies, partnerships. If a partnership is to be analysed as a cartel, it must be justified that the licencees have common interests. The operator may have conflicting interests with the other partners, as it has an incentive to charge too high costs on the licence. The other partners are therefore monitoring the cost consciousness of the operator; this is one of the intentions of awarding licences to partnerships. A conflict between the partners may also arise from the fact that they have different portfolios of petroleum deposits (if one or several of the partners participate in adjacent licences) and different investments in infrastructure (e.g. competing transport and refining facilities). However, the licencees normally have a common interest in securing a highest possible information rent. In negotiations with the government they can therefore be considered to form a cartel. This presupposes that Statoil acts on a commercial basis. In some special situations of vital economic or political importance, however, Statoil may be instructed to vote in accordance with a decision reached by the Minister of Industry and Energy. In such cases Statoil has veto power in the partnership. In these rare cases Statoil acts at the direct orders of the principal, but mostly Statoil acts on a commercial basis. As it mostly is the operator that obtains private information, I will assume that it has an implicit understanding with the other partners to use this information strategically (tacit collusion).

1.11 TRANSFER PRICING AND TAX ARBITRAGE

A special monitoring problem pertaining to multinational petroleum companies, due to imperfect international harmonisation of the national tax systems, is the problem of international tax arbitrage through the use of tax-minimising transfer pricing, e.g. borrowing at a high interest rate or purchasing expensive insurance from an affiliated company located in a tax haven. An incentive for transfer pricing exists when the effective tax rates, taking into account procedures for credit of taxes paid to foreign governments, vary between countries. As pointed out in Horst [1971], a distinguishing feature of multinational corporations is that the interfirm transactions are not valued in an open market. Instead, within the limits established by the monitoring opportunities and efforts of the national tax authorities, these firms choose an optimal transfer price. Such monitoring problems are also relevant for the Norwegian companies as they have economic activities both onshore and offshore. Due to the large difference in marginal tax rates, 28 versus 78 per cent, this gives possibilities of tax arbitrage; the companies would like to transfer petroleum income to the mainland and transfer costs from the mainland to the sea. This can be achieved by appropriate choice of internal pricing. As the offshore activities of Norwegian petroleum companies are not organised as separate companies, the monitoring problem of domestic companies may be more difficult than those of the foreign companies (most of the foreign companies are organised as separate Norwegian limited companies). However, the profits of the domestic companies have a positive weight in the government's objective function. As the weight of foreign profits is zero, the monitoring problem of the foreign companies may nevertheless be more important.

The problem of transfer pricing has been solved for oil revenues, by establishing norm prices to secure arm's length prices. The norm price is set by the Petroleum Price Board, and according to MIE [1993] the norm price shall correspond to the value that petroleum could have been traded at between independent parties in a free market. For other revenues and costs, the authorities try to restrict the use of strategic internal pricing by detailed audits of the companies' accounts.

By strategic use of internal pricing companies can masquerade their true costs, thus gaining private information. The traditional government response is to mitigate this problem of asymmetric information by control measures and norm prices. Monitoring of reported costs and revenues is a generic problem for profits taxation. Due to the international nature of the petroleum industry, and the high degree of vertical integration, the problems of international tax arbitrage are bound to be more pervasive in this industry. Furthermore, many of the inputs in the offshore industry are not standard commodities with an established market price, making it hard to monitor costs or impose norm prices.[39] Taking into account the limitations on control measures in the petroleum industry, and the monitoring costs, it may be fruitful to consider the approach suggested by regulation theory: Revelation of true costs is obtained by offering the companies incentive contracts.

Most likely, optimal regulatory policy will involve a mixture of monitoring and incentive mechanisms. The design of incentive contracts, however, may affect the extent of the ex post monitoring problems. The principal-agent models generate qualitative solutions to a regulatory problem under asymmetric information. Often there are various ways of implementing this solution. For reasons of simplicity, I will assume that the monitoring problems can be taken into account in the implementation phase, i.e., I assume that the monitoring problem can be separated from the qualitative decisions on mechanism design.

The present system for petroleum taxation, a profits tax with a very high effective marginal tax rate, provides strong incentives for transfer pricing. Instead of mitigating the monitoring problems, the present regime is making it worse. To counteract the incentives for transfer pricing, one needs lower marginal tax rates. To

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39 Examples are tailor made parts or modules to production platforms, and specialised consulting services.

keep up the revenue, the change in tax rates would have to be combined with the introduction of some type of fixed payments from the companies.

Another example of tax arbitrage that is prevalent in the US oil industry is design of cost-sharing arrangements in order to minimise tax payments. A typical arrangement, described by Scholes and Wolfson [1992], is the "functional allocation": Limited partners (passive investors with a high marginal tax rate) pay for 100 per cent of drilling costs that are immediately deductible, and general partners (active investors with a lower marginal tax rate) pay for completion costs that must be capitalised. Scholes and Wolfson argue that this arrangement creates an incentive problem; as the general partner bears 100 per cent of the completion costs but gets only a fraction of the resulting benefits, the general partner may complete fewer wells than is optimal from the society's point of view.

This incentive problem is a result of pure tax arbitrage, it is not a result of information asymmetries. The problem does not appear in the present Norwegian licensing system. After abolition of carried interest, a partner has the same share of costs and revenues.

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Chapter 2

Taxation and regulation of petroleum companies under asymmetric information. A static adverse selection model.*

2.1 AN ADVERSE SELECTION MODEL OF PETROLEUM REGULATION

I will in this chapter focus on adverse selection problems in the petroleum industry. Due to the presence of calculated costs and the possibility of affecting reported costs by means of transfer pricing, the petroleum companies are likely to have private information about their costs.[1] Exploration and extraction costs depend on a company's efficiency level and the quality of the reservoir (the geological structure). Those are factors known to the company, but only imperfectly observable by the government. A low cost company may conceal its information by imitating a high cost company, and must therefore be given an economic compensation (information rent) to be induced to reveal its information.

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[1] See section 1.2 on asymmetric information and section 1.11 on transfer pricing.

The specific regulatory problem to be analysed is the design of optimal incentive contracts for a partnership after a production license has been awarded by discretionary licensing.[2] The partners are assumed to form a cartel in negotiations with the government.[3] The negotiating parties, the partnership and the Ministry of Industry and Energy (MIE), are assumed risk neutral. The production license covers a petroleum deposit with a resource base of a deterministic size, K.[4] The resource base is the total amount of petroleum that is present in the reservoir. This definition of the petroleum stock is independent of economics and technology, and can therefore be taken as exogenously given. Furthermore, I assume there is symmetric information with relation to K. This assumption may not be realistic, cf. the discussion in section 1.2. The main point of this analysis, however, is asymmetric information about costs; and since asymmetric information in two dimensions will generate technical difficulties, I make the simplifying assumption of symmetric information with relation to K. As to the quality of the reservoir, however, there might be asymmetric information.

This article is inspired by an article on regulation of the mining industry by Gaudet, Lasserre and Long [1991]. The structure of their two-period model is similar to that of Baron and Myerson [1982] and Baron [1989], with an added resource constraint. The changes I make in the model of Gaudet et al. [1991] are: a) The introduction of a general cost function $C(q,\theta)$, b) The elimination of one constraint, and c) Some minor changes in the government's objective function. By developing comparative statics, characterising the optimal cutoff rate, analysing the effect of market power, and discussing alternative implementation mechanisms; I also make a number of extensions to the model of Gaudet et al. [1991].

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[2] Auctioning of production rights is treated in section 1.11.
[3] Cf. the discussion of industrial organisation in section 1.10.
[4] Petroleum is formed by geological processes that take millions of years. For decision purposes we can therefore view these resources as having a fixed stock of reserves. At the time of contracting, however, the reservoir size will be uncertain. To keep the model simple, I will treat K as a deterministic parameter.

The purpose of this chapter is to make the model of Gaudet, Lasserre and Long [1991] more accessible to the profession of economists in general and to provide economic intuition. The model will also be adjusted for technical and economic differences between the mining and the petroleum industry. Gaudet et al. assume a quadratic cost function. By introducing a general cost function, I examine whether their results can be generalised. Elaborating on the static version, I also provide information about the dynamic model. Finally, through simplifications of the static model, I hope to provide a basis for generalising the dynamic model of Gaudet, Lasserre and Long [1991] to allow for the private information parameters to be correlated over time.

2.2 STATIC VERSUS DYNAMIC MODEL

The focus of attention in this chapter is on models in a timeless world, or equivalently, models in which the focus of attention is on a single period. Such models may generate useful insights by themselves, and they also serve as building blocks for dynamic models. Since the dynamic models tend to be complex, some aspects of regulation can still only be satisfactorily treated in static models. In interpreting static models, however, one should be aware that in ignoring the time dimension, these models abstract from important aspects of regulation. Expanding the model to more than one period adds well-known complexities of renegotiation and lack of credible commitment. In the present model of petroleum regulation, which contains a resource constraint, a static model will also abstract from considerations of an optimal exploration path. The focus will be on the extent rather than the rate of extraction.

2.3 ASSUMPTIONS

I introduce a general function for total costs (capital and operating costs), $C(q,\theta)$, where q is the quantity of petroleum extracted, and where θ is a cost parameter. The cost parameter is determined either by the quality of the reservoir or the companies' internal efficiency, and is private knowledge for the petroleum companies. The support $\theta \in [\underline{\theta},\overline{\theta}]$ and the distribution of types, $F(\theta)$, however, is common knowledge. For the costs and the distribution, I make the following assumptions:

A1: $\dfrac{\partial C(q,\theta)}{\partial \theta} > 0$ Monotonicity

A2: $\dfrac{\partial^2 C(q,\theta)}{\partial \theta \partial q} > 0$ Single crossing property

A3: $\dfrac{\partial^2 C(q,\theta)}{\partial q^2} > 0$ Convexity

A4: $\dfrac{\partial^3 C(q,\theta)}{\partial \theta \partial q^2} \geq 0$ and $\dfrac{\partial^3 C(q,\theta)}{\partial \theta^2 \partial q} \geq 0$

A5: $\dfrac{d}{d\theta}\left(\dfrac{F(\theta)}{f(\theta)}\right) \geq 0$ Monotone hazard rate

The motivation for these assumptions is as follows. Assumption A1 reduces the set of participation constraints to a single constraint. Assumption A2 is a sufficient condition for the local and global second order conditions for incentive compatibility. Sufficient conditions for the regulator's optimisation problem are secured by assumptions A3 and A4, whereas assumptions A2, A3, A4, and A5 are sufficient conditions to fulfil the monotonicity constraint.

The economic explanation of assumption A1 is that total costs, for a given q, are increasing with θ, i.e., the average cost is increasing in θ. The parameter θ can therefore be interpreted as an efficiency parameter. The types are distributed on an interval $[\underline{\theta},\overline{\theta}]$, where $\underline{\theta}$ is the most and $\overline{\theta}$ is the least efficient. The marginal costs are also assumed to be increasing with the partnership type, as is clear from A2. The term single crossing property is derived from the observation that assumption A2 is a sufficient condition for the isoprofit curves of two different types to intersect only once.[5] Convex costs, assumption A3, are common in petroleum extraction. When production increases, the reservoir pressure is reduced. The producers are dependent on a certain level of reservoir pressure to pump up oil and gas. The reservoir pressure must therefore be maintained, e.g., by pumping water or associated gas into the reservoir. These measures are costly. The injections needed to compensate for the loss of reservoir pressure from one unit of petroleum production, are increasing with the extraction level. Hence, total extraction costs are convex. Assumption A4 contains third derivatives, and has no clear economic interpretation. Sufficient conditions for the principal's optimisation program will involve restrictions on third-derivatives, since the principal under asymmetric information optimises his utility function subject to the agent's optimisation problem (the first-order approach). Assumption A5, monotone hazard rate, is satisfied by many standard distributions, e.g., uniform, normal, logistic, chi-squared, exponential, and Laplace. An interpretation, given in Laffont and Tirole [1993], section 1.4, is decreasing returns in technological improvements. Let $\overline{\theta}$ be the basic technology, and let $\overline{\theta}-\theta$ stand for the number of improvements. Assumption A5 says that the conditional probability that there are more improvements, given that there have already been $\overline{\theta}-\theta$ improvements, $d(f(\theta)/F(\theta))/d\theta$, is decreasing.

[5] This is verified below in the text explaining figure 2.2.

2.4 THE SYMMETRIC INFORMATION CASE

In the case of symmetric information, the government knows the cost parameter θ. I will use the objective function discussed in section 1.4:

$$(1.3) \qquad W = (1+\lambda)R + (1-\mu)\Pi .$$

W is the benevolent government's welfare function, and R is the net total government take from the petroleum industry.[6] Whereas Gaudet, Lasserre and Long [1991] base the motive for rent extraction on the government having distributional preferences in favour of the consumers, I use the approach of Laffont and Tirole [1993]: The government has a utilitarian objective function, but still has an objective of rent extraction as the shadow cost of public funds, $1+\lambda$, is greater than one. I introduce an additional motive for rent extraction; foreign owner share in the license, μ. There will be no consumer surplus generated from domestic petroleum production, as I assume that Norway is a price taker in the petroleum market. The rent of the licensees, Π, is given by

$$(2.1) \qquad \Pi = pq(\theta) - C(q(\theta),\theta) - R.$$

By solving equation (2.1) with respect to R, and inserting it in equation (1.3), the government's objective function becomes

$$(2.2) \qquad W = (1+\lambda)(pq(\theta) - C(q(\theta),\theta)) - (\lambda + \mu)\Pi .$$

[6] Gaudet, Lasserre and Long [1991] use the term *royalty* for R. In the literature on petroleum taxation this term is used for payments of a certain percentage of the value of the resources extracted (see e.g., Dasgupta and Heal [1979], chapter 12). As rent extraction can be implemented by a variety of instruments (license fees, income tax, royalties etc.), I will instead use the general term *net total government take*.

The welfare generated from the petroleum sector consists of two terms. The first term, $(1+\lambda)(pq(\theta)-C(q(\theta),\theta))$, is the welfare we would get if the government were to keep all the revenue. The second term is a correction term taking into account the loss to society caused by the petroleum companies keeping parts of the rent. The loss caused by imperfect rent extraction is equal to the partnership's rent, Π, multiplied by the difference between the welfare weights for income accruing to the partnership and the government, $(1-\mu)-(1+\lambda)=-(\lambda+\mu)$. The welfare function clearly illustrates the government's motive for rent extraction; one unit of income transferred from the companies to the government will, ceteris paribus, increase the welfare by $\lambda+\mu$.

The regulatory problem under symmetric information is given by

(2.3) $$\underset{q(\theta),R}{Max}[(1+\lambda)(pq(\theta)-C(q(\theta),\theta))-(\lambda+\mu)\Pi\}.$$

subject to

(2.4) $$\Pi = pq(\theta)-C(q(\theta),\theta)-R(\theta)\geq 0$$

(2.5) $$q(\theta)\leq K,$$

where (2.4) is the participation constraint, and (2.5) is the resource constraint. Owing to the fact that negative production is possible in the petroleum industry, we do not need a non-negativity constraint on q.[7] This represents a simplification of the mining industry model of Gaudet, Lasserre and Long [1991]. Under symmetric information, R will be set such that the

[7] Negative production can be achieved by pumping petroleum back into the reservoir. This is often done with associated gas in order to maintain the reservoir pressure, and in some occasions gas is pumped into another reservoir for temporary storage (gas banking). We do not observe petroleum companies having a negative net production over long periods. This is because it is obviously not an optimal extraction strategy. Note that non-negative production is not the result of a technical constraint, but is a consequence of the objective function.

participation constraint will be binding for all types in optimum. By inserting $\Pi = 0$ in the objective function, I get the Lagrangian

(2.6) $$L = (1+\lambda)(pq(\theta) - C(q(\theta),\theta)) + \gamma(\theta)(K - q(\theta)),$$

where $\gamma(\theta)$ is the Lagrange multiplier for the resource constraint. The necessary Kuhn-Tucker conditions are given by

(2.7) $$\frac{\partial L}{\partial q(\theta)} = (1+\lambda)(p - \frac{\partial C(q(\theta),\theta)}{\partial q(\theta)}) - \gamma(\theta) = 0$$

(2.8) $$\gamma(\theta) \geq 0, \quad K - q(\theta) \geq 0, \quad \gamma(\theta)(K - q(\theta)) = 0.$$

The second-order condition is satisfied by assumption A3. It is worth noting that the first-order condition implies

(2.9) $$p - \frac{\partial C(q,\theta)}{\partial q} = \frac{\gamma}{1+\lambda},$$

which simply states a binding resource constraint ($\gamma(\theta) > 0$) implies a positive marginal resource rent in optimum.

To solve, I make a conjecture about the structure of the solution, and thereafter seek an extraction schedule with this structure satisfying the conditions. My conjecture is that it will be optimal to empty the reservoir if the partnership is of a low-cost type. For less efficient producer types, it will, due to convex production costs, be optimal to leave parts of the reservoir unextracted.

Proposition 2.1

There exists a θ^* such that

$$(2.10)\qquad \begin{array}{lll} q(\theta)=K, & \dfrac{dq(\theta)}{d\theta}=0, & \text{for } \underline{\theta}\le\theta\le\theta^* \\ q(\theta)<K, & \dfrac{dq(\theta)}{d\theta}<0, & \text{for } \theta^*\le\theta\le\overline{\theta} \end{array}$$

I have assumed that $\theta^* \in [\underline{\theta},\overline{\theta}]$. This is satisfied for reasonable values of petroleum price, net cost of public funds, and the foreign equity share; see comparative statics analyses in section 2.7.

In solving the problem, I start by finding an expression for the interior solution of the extraction level $q(\theta)$. When $q(\theta)<K$, (2.8) implies $\gamma(\theta)=0$. Then from (2.7),

$$(2.11)\qquad G \equiv \gamma(\theta) = (1+\lambda)\left(p - \frac{\partial C(q(\theta),\theta)}{\partial q(\theta)}\right) = 0, \qquad \theta^* \le \theta \le \overline{\theta}.$$

Since we from assumption A3 have that

$$(2.12)\qquad G_q = -\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)^2} \neq 0,$$

equation (2.11) implicitly defines extraction level q as a function of the licensees' type θ, for the types $\theta^* \le \theta \le \overline{\theta}$. Hence, from implicit derivation, I get

$$(2.13)\qquad \frac{dq}{d\theta} = -\frac{G_\theta}{G_q} = -\frac{\dfrac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}}{\dfrac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)^2}} < 0,$$

where the sign is determined by assumptions A2 and A3.

I continue with a characterisation of θ^*. From the case of a non-binding resource constraint, equation (2.11), I get the following expression in θ^* for the limiting case $q \to K^-$:

$$(2.14) \qquad (1+\lambda)(p - \frac{\partial C(q(\theta^*),\theta^*)}{\partial q(\theta^*)}) = 0.$$

When $q(\theta)=K$, we have from (2.7)

$$(2.15) \qquad \gamma(\theta) = (1+\lambda)(p - \frac{\partial C(K,\theta)}{\partial q(\theta)}) \geq 0, \qquad \underline{\theta} \leq \theta \leq \theta^*.$$

Non-negativity of $\gamma(\theta)$ is required by (2.8). Making use of the fact that in optimum we have bunching (i.e., pooling; $dq(\theta)/d\theta = 0$) for $\underline{\theta} \leq \theta \leq \theta^*$, I get

$$(2.16) \qquad \frac{d\gamma(\theta)}{d\theta} = (1+\lambda)(-\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}) < 0, \qquad \underline{\theta} \leq \theta \leq \theta^*,$$

where the sign is determined by assumption A2. This sign has a clear economic interpretation: $\gamma(\theta)$, which is the Lagrange multiplier for the resource constraint, expresses the marginal value of petroleum in optimum. When θ is increasing, the partnership's efficiency diminishes. Consequently, the marginal value of petroleum is reduced, i.e., $\gamma(\theta)$ is decreasing in θ. From (2.15), I therefore get a second equation for determining θ^* by noting that non-negativity is assured, provided

$$(2.17) \qquad (1+\lambda)(p - \frac{\partial C(K,\theta^*)}{\partial q(\theta^*)}) \geq 0.$$

Hence, the set of constraints in equation (2.15) has been reduced to the single constraint (2.17). The critical type is determined by equations (2.14) and (2.17), and together they yield the condition

$$p - \frac{\partial C(K,\theta^*)}{\partial q(\theta^*)} = 0. \tag{2.18}$$

The critical type θ^* is implicitly defined by equation (2.18).

The economic interpretation of this section is straight forward: For the most efficient producer types it is optimal to empty the reservoir. Due to constant marginal income, p, and convex extraction costs, less efficient producer groups should extract only a fraction of the petroleum deposits, and this percentage is lower the less efficient the partnership is. From condition (2.18), it is clear that the critical type θ^*, is the partnership whose efficiency parameter implies that price is equal to marginal extraction costs for $q = K$. For the more efficient producer groups it is optimal to empty the reservoir, since price exceeds marginal extraction costs for all $q \leq K$. For producer groups that are less efficient, optimal extraction level is determined by price equal to marginal extraction costs. For these types there will be some petroleum left in the reservoir, as $p < \partial C(K,\theta) / \partial q(\theta)$.

These results are hardly surprising. The problem has been solved formally for the purpose of comparison with the asymmetric information case.

2.5 ASYMMETRIC INFORMATION

The partnership is assumed to know their own type, θ, whereas the regulator only knows the distribution, given by the probability density function $f(\theta)$, $\theta \in [\underline{\theta}, \overline{\theta}]$. In this case, the regulator will recognise that if he tried to implement the first best solution, the companies would have incentives to overstate their costs to obtain higher profits. The analysis to follow is facilitated by the revelation principle, which states that the principal can restrict his attention to the class of mechanisms in response to which the firms report their types truthfully. The regulatory agency, i.e., the Ministry of Industry and Energy (MIE), offers the self-selection mechanism $M=\{(q(\theta),R(\theta),\theta\in[\underline{\theta},\overline{\theta}]\}$, i.e., a menu of type-revealing contracts in $q(\theta)$ and $R(\theta)$ that the partnership can choose among.

Let $\Pi(\hat{\theta},\theta)$ be the profit of a partnership of type θ when it reports type $\hat{\theta}$. The regulatory problem is now given by

$$(2.19) \qquad \underset{q(\theta),R(\theta)}{Max}\int_{\underline{\theta}}^{\overline{\theta}}[(1+\lambda)(pq(\theta)-C(q(\theta),\theta))-(\lambda+\mu)\Pi(\theta)]dF(\theta)$$

subject to

$$(2.20) \qquad \Pi(\theta)\equiv\Pi(\theta,\theta)\geq 0, \qquad \forall\theta\in[\underline{\theta},\overline{\theta}]$$

$$(2.21) \qquad \Pi(\theta)\geq\Pi(\hat{\theta},\theta), \qquad \forall\hat{\theta},\theta\in[\underline{\theta},\overline{\theta}]$$

$$(2.22) \qquad q\leq K.$$

From the symmetric information case, we recognise the participation and the resource constraints; conditions (2.20) and (2.22), respectively, . Asymmetric information generates an additional set of constraints; incentive constraints, given by equation (2.21). As is clear from this equation, for the class of incentive compatible mechanisms it is a dominant strategy for the partnership to reveal their true type.

The only action of the firms in the model is to select one of the contracts offered by MIE. In real life petroleum companies would also make decisions about their effort levels, and these decisions will affect the costs and the extraction level. As I argued in section 1.9, MIE cannot perfectly monitor these efforts. Since the focus of this chapter is adverse selection, and not moral hazard, the effort decision is not explicitly modelled. If I nevertheless were to include moral hazard in the model, it would create complexity without new economic insights. Analogous to section B2.1.1 in Laffont and Tirole [1993], an effort variable, e, can be included in the model by making costs a declining function of the effort level, $C(q(\theta),\theta,e)$, and by adding a function for disutility of effort, $\psi(e)$. Since the regulatory agency is not able to observe costs or effort, it has no direct control over the cost-reducing and production-enhancing efforts. The contract offered to the partnership must instead be made contingent on the observable extraction level, and the effort decision is delegated to the partnership. The partnership's decision problem is now given by $\underset{\hat{\theta},e}{Max}\ \Pi(\theta,\hat{\theta}) = pq(\hat{\theta}) - C(q(\hat{\theta}),\theta,e) - R(\hat{\theta}) - \psi(e)$. The effort decision is determined by $-\partial C(q(\theta),\theta,e)/\partial e = \psi(e)$, yielding a function $e^*(q)$. With the cost of added complexity, we are now back where we started; substituting for the optimal effort in the cost function gives us a cost function that exhibits only adverse selection: $\tilde{C} \equiv C(q(\theta),\theta,e^*(q)) + \psi(e^*(q))$.

In solving the original program, equations (2.19) to (2.22), I will begin by characterising the class of mechanisms that satisfy the incentive constraints (implementable allocations). This characterisation is facilitated by the differentiability of the policies $R(\theta)$ and $q(\theta)$. Proof of differentiability is provided in appendix 2.1.

Proposition 2.2[8]

An allocation $\{R(\theta), q(\theta)\}$ satisfies the incentive constraints if and only if

[8] This is an analogous application of the approach in Fudenberg and Tirole [1991], chapter 7. I also benefit from the presentation of this approach in Schmidt [1992].

(2.23) $$p\frac{dq(\theta)}{d\theta}-\frac{\partial C(q(\theta),\theta)}{\partial q}\frac{dq(\theta)}{d\theta}-\frac{dR(\theta)}{d\theta}=0, \quad \forall\theta\in[\underline{\theta},\overline{\theta}]$$

(2.24) $$\frac{dq(\theta)}{d\theta}\leq 0, \quad \forall\theta\in[\underline{\theta},\overline{\theta}] \quad \text{Monotonicity}$$

<u>Proof</u>

I will start with the necessary conditions, i.e., I will show that the incentive constraints, equation (2.21), imply the constraints (2.23) and (2.24). The partnership's profit maximisation problem is given by

(2.25) $$\underset{\hat{\theta}}{Max}\, \Pi(\hat{\theta},\theta)=pq(\hat{\theta})-C(q(\hat{\theta}),\theta)-R(\hat{\theta})$$

First- and second-order conditions are

(2.26) $$\frac{d\Pi(\hat{\theta},\theta)}{d\hat{\theta}}=p\frac{dq(\hat{\theta})}{d\hat{\theta}}-\frac{\partial C(q(\hat{\theta}),\theta)}{\partial q(\hat{\theta})}\frac{dq(\hat{\theta})}{d\hat{\theta}}-\frac{dR(\hat{\theta})}{d\hat{\theta}}=0$$

(2.27) $$\frac{d^2\Pi(\hat{\theta},\theta)}{d\hat{\theta}^2}=p\frac{dq^2(\hat{\theta})}{d\hat{\theta}^2}-\frac{\partial^2 C(q(\hat{\theta}),\theta)}{\partial q(\hat{\theta})^2}\left(\frac{dq(\hat{\theta})}{d\hat{\theta}}\right)^2-\frac{\partial C(q(\hat{\theta}),\theta)}{\partial q(\hat{\theta})}\frac{d^2q(\hat{\theta})}{d\hat{\theta}^2}-\frac{dR^2(\hat{\theta})}{d\hat{\theta}^2}\leq 0$$

For truth telling to be optimal, the first- and second-order conditions have to be satisfied at $\hat{\theta}=\theta$. Substituting θ for $\hat{\theta}$ in (2.26) gives (2.23). Equation (2.23) must hold for all values of $\theta\in[\underline{\theta},\overline{\theta}]$. Differentiating this identity yields

(2.28) $$p\frac{dq^2(\theta)}{d\theta^2}-\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)^2}\left(\frac{dq(\theta)}{d\theta}\right)^2-\frac{\partial^2 C(q(\theta),\theta)}{\partial\theta\partial q(\theta)}\frac{dq(\theta)}{d\theta}$$
$$-\frac{\partial C(q(\theta),\theta)}{\partial q(\theta)}\frac{d^2q(\theta)}{d\theta^2}-\frac{dR^2(\theta)}{d\theta^2}=0$$

By substituting θ for $\hat{\theta}$ in (2.27), and inserting this expression into (2.28), we can rewrite the second-order condition as

$$(2.29) \qquad -\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}\frac{dq(\theta)}{d\theta} \geq 0.$$

By assumption A2, the single crossing property, $\partial^2 C(q(\theta),\theta)/\partial q(\theta)\partial\theta \geq 0$, we get $dq(\theta)/d\theta \leq 0$. Thus (2.29) implies (2.24).

I have shown the necessary conditions, i.e., that the local first- and second-order conditions for incentive compatibility are satisfied. To prove that any allocation $\{R(\theta), q(\theta)\}$ that satisfies the constraints (2.23) and (2.24) is implementable, I also need to derive the sufficient conditions. I must prove that the global second-order condition for maximisation is satisfied. Suppose that truth telling is not optimal for type θ, i.e., there exists a $\hat{\theta}$ such that $\Pi(\hat{\theta},\theta) > \Pi(\theta,\theta)$. Then

$$(2.30) \qquad \begin{aligned} \Pi(\hat{\theta},\theta) - \Pi(\theta,\theta) &= \int_{\theta}^{\hat{\theta}} \frac{\partial \Pi(\tilde{\theta},\theta)}{\partial\tilde{\theta}} d\tilde{\theta} \\ &= \int_{\theta}^{\hat{\theta}} \left(p\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{\partial C(q(\tilde{\theta}),\theta)}{\partial q(\tilde{\theta})}\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{dR(\tilde{\theta})}{d\tilde{\theta}} \right) d\tilde{\theta} > 0 \end{aligned}$$

Suppose $\hat{\theta} > \theta$. We get the contradiction

$$(2.31) \qquad \begin{aligned} \Pi(\hat{\theta},\theta) - \Pi(\theta,\theta) &= \int_{\theta}^{\hat{\theta}} \left(p\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{\partial C(q(\tilde{\theta}),\theta)}{\partial q(\tilde{\theta})}\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{dR(\tilde{\theta})}{d\tilde{\theta}} \right) d\tilde{\theta} \\ &\leq \int_{\theta}^{\hat{\theta}} \left(p\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial q(\tilde{\theta})}\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{dR(\tilde{\theta})}{d\tilde{\theta}} \right) d\tilde{\theta} = 0, \end{aligned}$$

The inequality in equation (2.31) is explained by noting that $\tilde{\theta} \geq \theta$, and by applying equation (2.24), $dq(\theta)/d\theta \leq 0, \forall \theta \in [\underline{\theta}, \overline{\theta}]$, and assumption A2, $\partial^2 C(q,\theta)/\partial\theta\partial q > 0$. The second equality in (2.31) follows from (2.26). Similarly, suppose that $\hat{\theta} < \theta$. We now get

(2.32)
$$\Pi(\hat{\theta},\theta) - \Pi(\theta,\theta) = -\int_{\hat{\theta}}^{\theta}\left(p\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{\partial C(q(\tilde{\theta}),\theta)}{\partial q(\tilde{\theta})}\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{dR(\tilde{\theta})}{d\tilde{\theta}}\right)d\tilde{\theta}$$
$$\leq -\int_{\hat{\theta}}^{\theta}\left(p\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial q(\tilde{\theta})}\frac{dq(\tilde{\theta})}{d\tilde{\theta}} - \frac{dR(\tilde{\theta})}{d\tilde{\theta}}\right)d\tilde{\theta} = 0,$$

again a contradiction. Therefore it is optimal to announce $\hat{\theta} = \theta$, and $\{R(\theta), q(\theta)\}$ is incentive compatible.

■

Using proposition 2.2, the regulatory problem can now be reformulated as

(2.19)
$$\underset{q(\theta),R(\theta)}{Max}\int_{\underline{\theta}}^{\overline{\theta}}[(1+\lambda)(pq(\theta) - C(q(\theta),\theta)) - (\lambda+\mu)\Pi(\theta)]dF(\theta)$$

subject to

(2.20) $\qquad \Pi(\theta) \geq 0, \qquad \forall \theta \in [\underline{\theta}, \overline{\theta}]$

(2.23) $$p\frac{dq(\theta)}{d\theta} - \frac{\partial C(q(\theta),\theta)}{\partial q}\frac{dq(\theta)}{d\theta} - \frac{dR(\theta)}{d\theta} = 0, \qquad \theta \in [\underline{\theta}, \overline{\theta}]$$

(2.24) $$\frac{dq(\theta)}{d\theta} \leq 0$$

(2.5) $\qquad q \leq K$.

Let $\Pi(\theta) \equiv \Pi(\theta,\theta) = pq(\theta) - C(q(\theta),\theta) - R(\theta)$. From the envelope theorem, i.e., by using the first order condition for incentive compatibility (equation (2.23)), we get

$$(2.33) \qquad \frac{d\Pi(\theta)}{d\theta} = \frac{\partial \Pi(\theta)}{\partial \theta} = -\frac{\partial C(q(\theta),\theta)}{\partial \theta}.$$

We see that the rent, due to assumption A1, is decreasing in θ, i.e., to be willing to reveal their true type, efficient partnerships must be rewarded with a higher rent than inefficient partnerships. The economic interpretation is that instead of revealing its true efficiency θ and produce accordingly, the partnership may choose to camouflage as a less efficient producer group $\theta + d\theta$, where $d\theta$ is small and positive. Mimicking the less efficient producer group is done by selecting the combination of production level and net taxes intended for this type; $\{q(\theta + d\theta), R(\theta + d\theta)\}$. From the monotonicity constraint, this implies a lower level of extraction, i.e., installation of a smaller capacity (smaller or fewer platforms) or a less extensive use of extraction enhancing techniques in the production phase (e.g., injections). An interpretation of the rent function, therefore, is that in order to get incentive compatibility, the partnership group, when they reveal their true type, must be paid up front the rent difference they would get if they instead were to mimic a less efficient type. For a type θ this rent difference is equal to its cost advantage relative to the less efficient type $\theta + d\theta$. For a type θ, therefore, the total information rent is equal to a cumulation of cost differences, given by equation (2.35) below.

Integrating both sides of equation (2.33), yields

$$(2.33') \qquad \int_{\theta}^{\bar{\theta}} \frac{d\Pi(\tilde{\theta})}{d\tilde{\theta}} d\tilde{\theta} = -\int_{\theta}^{\bar{\theta}} \frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial \tilde{\theta}} d\tilde{\theta},$$

or

(2.34) $$\Pi(\theta)=\Pi(\overline{\theta})+\int_{\theta}^{\overline{\theta}}\frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial\tilde{\theta}}d\tilde{\theta}.$$

By assumption A1, $C(q,\theta)$ is increasing in θ. If the participation constraint, equation (2.20), is satisfied for type $\theta=\overline{\theta}$, it is therefore satisfied for all $\theta\in[\underline{\theta},\overline{\theta}]$. Since MIE wants to extract rent, the participation constraint will be binding for type $\theta=\overline{\theta}$. Hence, the set of participation constraints in equation (2.20) is reduced to the single constraint $\Pi(\overline{\theta})=0$. By combining the first order condition for incentive compatibility, equation (2.21), and the participation constraint, equation (2.20), we get

(2.35) $$\Pi(\theta)=\int_{\theta}^{\overline{\theta}}\frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial\tilde{\theta}}d\tilde{\theta}.$$

Since $\Pi(\theta)=pq(\theta)-C(q(\theta),\theta)-R(\theta)$, we get

(2.36) $$R(\theta)=pq(\theta)-C(q(\theta),\theta)-\int_{\theta}^{\overline{\theta}}\frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial\tilde{\theta}}d\tilde{\theta},$$

I have shown that the class of mechanisms satisfying the incentive and the participation constraints, is composed of those policies in which the quantity of extraction is non-increasing in type, and where the fixed government charge $R(\theta)$ satisfies (2.36).

As $R(\theta)$ now is determined, the regulatory problem can be rewritten as

(2.37) $$\underset{q(\theta)}{Max}\int_{\underline{\theta}}^{\overline{\theta}}[(1+\lambda)(pq(\theta)-C(q(\theta),\theta))-(\lambda+\mu)\Pi(\theta)]dF(\theta)$$

subject to

(2.38) $$\Pi(\overline{\theta}) = 0,$$

(2.39) $$\frac{d\Pi(\theta)}{d\theta} = -\frac{\partial C(q(\theta),\theta)}{\partial \theta},$$

(2.22) $$\frac{dq(\theta)}{d\theta} \leq 0,$$

(2.5) $$q \leq K.$$

Equation (2.38) is the participation constraint (transversality condition). Equations (2.39) and (2.22) are the first- and second-order conditions for incentive compatibility. Equation (2.5) is the resource constraint. I will ignore (2.22) at first, and later, in appendix 2.3, show that the solution to the less constrained problem satisfies this condition. I will here show the necessary conditions for optimum, the sufficient conditions are given in appendix 2.2. I will use a control theoretic approach to solve the regulatory problem, and choose $\Pi(\theta)$ as a state variable and $q(\theta)$ as a control variable.[9] The Hamiltonian is written as

(2.40) $$H = [(1+\lambda)(pq(\theta) - C(q(\theta),\theta)) - (\lambda + \mu)\Pi(\theta)]f(\theta) - \eta(\theta)\frac{\partial C(q(\theta),\theta)}{\partial \theta},$$

where $f(\theta)$ is the probability density function and $\eta(\theta)$ is the costate variable associated with constraint (2.39). The regulator's problem is equivalent to maximising the Hamiltonian, subject to the resource constraint.[10] The Lagrangian for this problem is

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[9] An alternative derivation of the optimal production schedule $q^*(\theta)$, without using optimal control theory, is given in section 2.8.

[10] I am following the approach in Kamien and Schwartz [1981], section 10.

(2.41) $$L=[(1+\lambda)(pq(\theta)-C(q(\theta),\theta))-(\lambda+\mu)\Pi(\theta)]f(\theta)$$

$$-\eta(\theta)\frac{\partial C(q(\theta),\theta)}{\partial \theta}+\gamma(\theta)(K-q(\theta)),$$

where $\gamma(\theta)$ is the multiplier for the resource constraint.

The necessary Kuhn-Tucker conditions for a constrained maximum with respect to $q(\theta)$ are given by

(2.42) $$\frac{\partial L}{\partial q(\theta)}=(1+\lambda)(p-\frac{\partial C(q(\theta),\theta)}{\partial q(\theta)})f(\theta)-\eta(\theta)\frac{\partial^2 C(q(\theta),\theta)}{\partial \theta \partial q(\theta)}-\gamma(\theta)=0,$$

(2.43) $$\gamma(\theta)\geq 0,\quad K-q(\theta)\geq 0,\quad \gamma(\theta)(K-q(\theta))=0.$$

By applying Pontryagin's maximum principle on this non-linear programming problem, I obtain the additional condition

(2.44) $$\frac{d\eta(\theta)}{d\theta}=-\frac{\partial H}{\partial \Pi}=(\lambda+\mu)f(\theta).$$

I integrate on both sides of equation (2.44)

$$\int_{\underline{\theta}}^{\theta}\frac{d\eta(\tilde{\theta})}{d\tilde{\theta}}d\tilde{\theta}=\int_{\underline{\theta}}^{\theta}(\lambda+\mu)f(\tilde{\theta})d\tilde{\theta},$$

and by applying the transversality condition $\eta(\underline{\theta})=0$ (since the boundary of $\Pi(\theta)$ is unconstrained for all $\theta\neq\overline{\theta}$), I get

(2.45) $$\eta(\theta)=(\lambda+\mu)F(\theta).$$

Substituting from (2.45) into (2.42) and rearranging, yields

$$(2.46) \qquad p-\frac{\partial C(q(\theta),\theta)}{\partial q(\theta)}=\frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}+\frac{\gamma(\theta)}{(1+\lambda)f(\theta)}.$$

To understand the second-best optimum in (2.46), it is useful to start with interpretation of the case where the resource constraint is non-binding ($\gamma(\theta)=0$). MIE faces a trade-off between maximising total production value $(pq(\theta)-C(q(\theta),\theta))$ and minimising the petroleum companies' information rent $\Pi(\theta)=\int_{\theta}^{\bar{\theta}}\frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial\tilde{\theta}}d\tilde{\theta}$. Consider any type $\theta>\underline{\theta}$. If MIE reduces $q(\theta)$ over the interval $[\theta,\theta+d\theta]$ by a small amount Δq, the expected total value-weighted production value is reduced by

$$(2.47) \qquad (1+\lambda)\left(\frac{\partial[pq(\theta)-C(q(\theta),\theta)]}{\partial q(\theta)}\Delta q(\theta)\right)f(\theta)d\theta.$$

However, the value-weighted rent of type $\theta+d\theta$ is reduced by

$$(2.48) \qquad (\lambda+\mu)\frac{\partial}{\partial q(\theta)}\left(\frac{\partial C(q(\theta),\theta)}{\partial\theta}\right)\Delta q(\theta)d\theta.$$

The weight, $\lambda+\mu$, is the value of transferring one unit of income from the companies to the government. The rent is reduced for all types $\theta\in[\underline{\theta},\theta+d\theta]$, having probability $F(\theta+d\theta)$, so the expected reduction in value-weighted information rent is

$$(2.49) \qquad (\lambda+\mu)\frac{\partial C^2(q(\theta),\theta)}{\partial q(\theta)\partial\theta}\Delta q(\theta)d\theta F(\theta+d\theta).$$

At the optimum, the marginal reduction in value-weighted production value is equal to the marginal reduction in value-weighted information rent, i.e.,

$$(2.50)\qquad \begin{aligned}&(1+\lambda)\left(\frac{\partial[pq(\theta)-C(q(\theta),\theta)]}{\partial q(\theta)}\Delta q(\theta)\right)f(\theta)d\theta\\ &=(\lambda+\mu)\frac{\partial C^2(q(\theta),\theta)}{\partial q(\theta)\partial\theta}\Delta q(\theta)d\theta F(\theta+d\theta)\end{aligned}$$

By taking the limit, i.e., letting $\Delta q(\theta)$ and $d\theta$ approach zero, we see that this equation is equivalent to (2.46), provided a non-binding resource constraint.

To solve for $q(\theta)$, I first make a conjecture about the structure of the solution, and thereafter seek a path that has this structure and satisfies the conditions. The conjecture will be based on economic intuition. By comparing equation (2.46) with the solution to the symmetric information case, equation (2.9), we see that asymmetric information generates a new term in the second best optimum. The new term, $\frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}$, is the marginal information cost, and it creates an additional wedge between price and marginal production costs, for all types $\theta>\underline{\theta}$. This will, for a non-binding resource constraint, give lower production for all types but the most efficient. The economic explanation for this distortion in $q(\theta)$ is that it makes it less favourable for efficient companies to mimic inefficient companies. This is clear from the expression of the partnership's rent:

$$(2.35)\qquad \Pi(\theta)=\int_{\theta}^{\bar{\theta}}\frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial\tilde{\theta}}d\tilde{\theta}.$$

As explained above, equation (2.35) satisfies the first-order condition for incentive compatibility. From assumption A2 (the single crossing property), the rent is increasing in $q(\theta)$:

(2.51) $$\frac{d\Pi(\theta)}{dq(\theta)} = \int_{\theta}^{\bar{\theta}} \frac{\partial^2 C(q(\tilde{\theta}),\tilde{\theta})}{\partial q(\tilde{\theta})\partial\tilde{\theta}} d\tilde{\theta} > 0.$$

Type θ can masquerade as type $\theta + d\theta$ by producing $q(\theta + d\theta)$ at cost $C(q(\theta + d\theta), \theta)$. By inserting in the profit function (2.1), we see that relative to type $\theta + d\theta$ this strategy yields a rent equal to $\Pi(\theta) - \Pi(\theta + d\theta) = C(q(\theta + d\theta), \theta + d\theta) - C(q(\theta + d\theta), \theta)$. As the incentive constraint is binding, i.e. type θ is indifferent between announcing θ and $\theta + d\theta$, the same rent difference will appear when the partnership announces its true type (a separating equilibrium).

To interpret equation (2.51), note that the single crossing property implies that the marginal extraction costs are increasing in θ. Hence, a producer of type θ has lower marginal costs than type $\theta + d\theta$. The relative cost advantage of type θ, $C(q(\theta + d\theta), \theta + d\theta) - C(q(\theta + d\theta), \theta)$, i.e., the rent difference, is therefore increasing in q, as illustrated in figure 2.1 below.

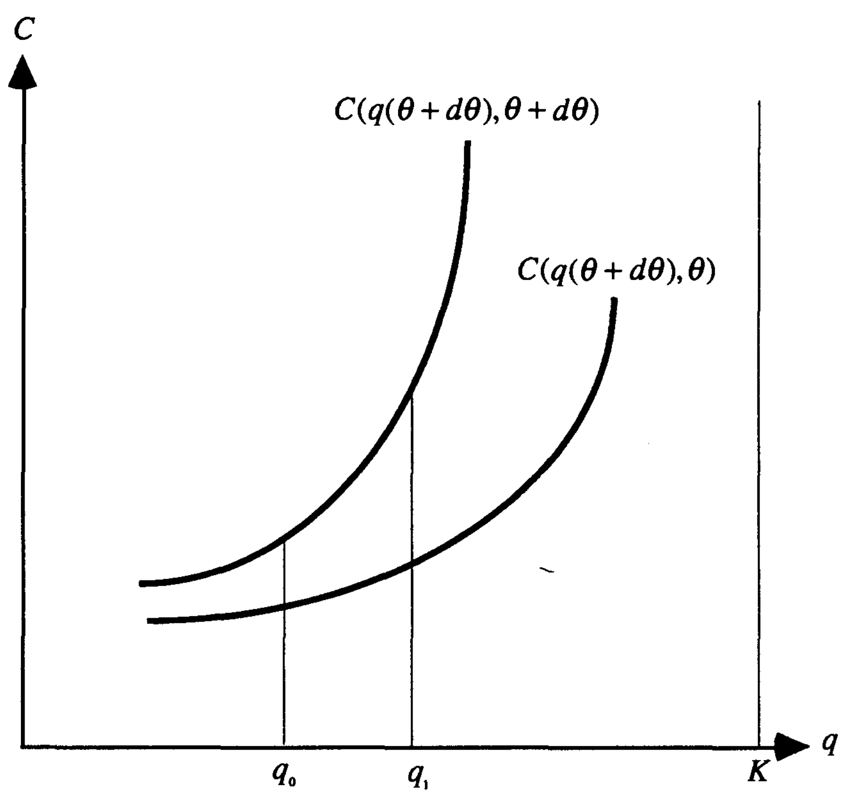

Figure 2.1: Illustration of relative cost advantage (rent difference), $C(q(\theta + d\theta), \theta + d\theta) - C(q(\theta + d\theta), \theta)$ (the vertical distance between the two cost curves), as an increasing function of the extraction level q.

By reducing the extraction level, partnership $\theta + d\theta$ is now less favourable to mimic by a partnership θ. The latter type of company will therefore require less rent to be willing to reveal their information, i.e., their incentive constraints are relaxed. The consequent reduction in information rent is captured by the government. The optimal trade-off is to distort the real petroleum decisions to the point where the marginal deadweight loss from these distortions (the left hand side of equation (2.50)) equals the marginal reduction in deadweight loss in other sectors of the economy, made possible by the increase in government take from the petroleum sector (the right hand side).[11]

If the resource constraint is non-binding for all θ, we have $\gamma(\theta) = 0$. The regulatory solution is in this case analogous to that of Baron and Myerson [1982]; compared to the model with symmetric information, the quantity is reduced for all types $\theta > \underline{\theta}$. To provide additional economic intuition for this result, it is useful to start with the optimal regulatory solution under symmetric information and a non-binding resource constraint. From equation (2.9) we know that this first-best interior solution is characterised by price equal to marginal production cost. At this starting point we introduce asymmetric information. At the initial point of efficiency, marginal changes in real decisions will have no first order welfare effects (the envelope theorem). However, changes in the real decisions of the petroleum companies (reduction in $q(\theta)$ for $\theta > \underline{\theta}$) will relax the incentive constraints. The consequent increase in government revenue leads to a welfare increase of the first order, since it is now possible to reduce distortive taxation in the non-petroleum sector. Hence, the second best solution to petroleum taxation with informational constraints will imply some distortions of real decisions for all types $\theta > \underline{\theta}$.

The interior solution to the regulatory problem can be illustrated in the extraction-revenue space, for the case of two possible partnership types, $\underline{\theta}$ and $\overline{\theta}$, where $\overline{\theta} > \underline{\theta}$. I start by characterising the companies' isoprofit curves:

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[11] This optimal trade-off is more thoroughly discussed in section 1.6.

(2.52) $$\Pi(\theta) = pq(\theta) - C(q(\theta),\theta) - R(\theta) = \Pi_k,$$

for a given profit level Π_k. The slope of the isoprofit curve is $dR/dq(\theta) = p - \partial C(q(\theta),\theta)/\partial q(\theta) \geq 0$, and the curvature is given by $d^2R/dq(\theta)^2 = -\partial^2 C(q(\theta),\theta)/\partial q(\theta)^2$, which is negative due the convexity assumption A3. The isoprofit curves, therefore, are concave and upward-sloping. The profits are increasing when we move south-east in the diagram: For a given extraction level, rents are increasing with a reduction in net taxes, and for a given level of net taxes, rents are increasing in the extraction level as the price exceeds marginal extraction costs. The isoprofit curves intersect only once. A sufficient condition for single crossing is that the isoprofit curve for type $\underline{\theta}$ is steeper than the curve for type $\overline{\theta}$, for all q. This is satisfied, since $d^2R/d\theta dq(\theta)\big|_{q(\theta)=q_k} = -\partial^2 C(q(\theta),\theta)/\partial\theta\partial q(\theta) < 0$, for all q_k, due to the single crossing property assumption A2.

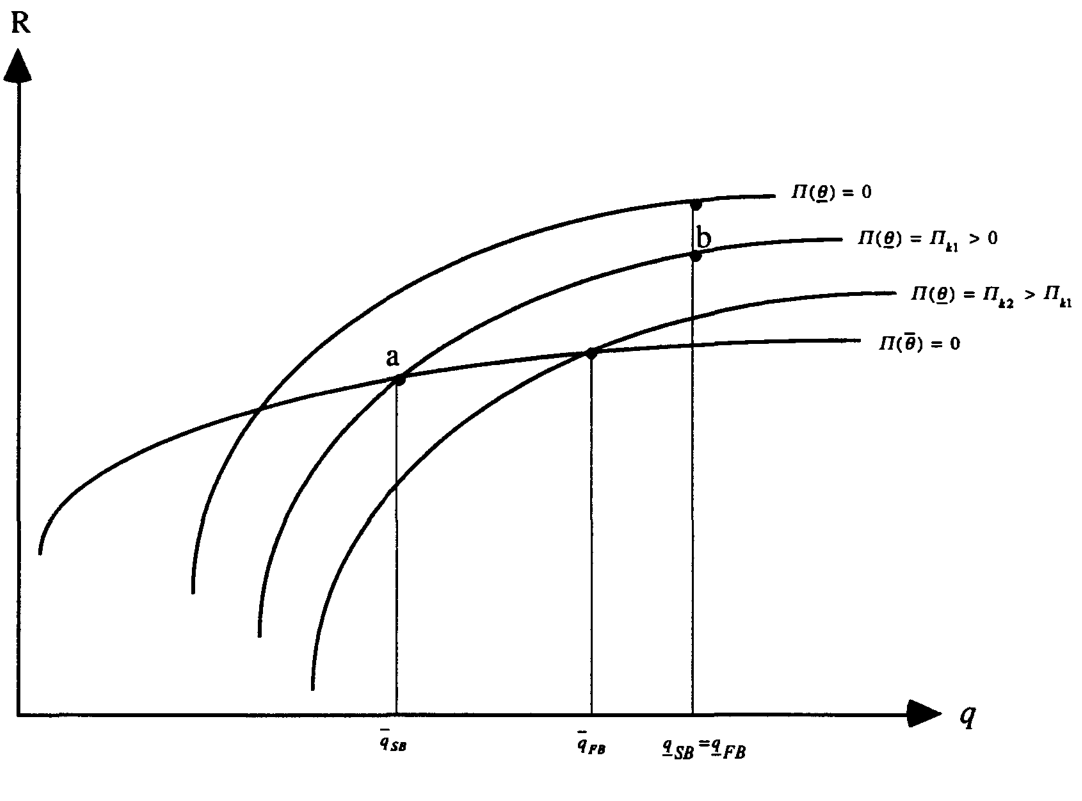

Figure 2.2: Illustration of optimal regulatory mechanism in the case of two types, $\underline{\theta}$ and $\overline{\theta}$.

Figure 2.2 is analogous to figure 1.2 in Laffont and Tirole [1993]. The first-best solution of the regulatory problem, which is possible in the case of symmetric information, is given by $\{(\underline{q}_{FB},\underline{R}_{FB}),(\bar{q}_{FB},\bar{R}_{FB})\}$. The optimal quantities $\underline{q}_{FB}$ and $\bar{q}_{FB}$ have been marked off in the diagram. The corresponding net total government take, $\underline{R}_{FB}$ and $\bar{R}_{FB}$, can be read off the R-axis. With this allocation price equals marginal extraction costs for both types, and they are left with no rent. When we introduce asymmetric information, this solution is no longer feasible, since it is not incentive compatible for the efficient producer to select $\underline{q}_{FB}$. Instead he will mimic the inefficient producer by choosing $\bar{q}_{FB}$, and thereby gain a positive information rent Π_{k2}. The regulator can reduce the rent of type $\underline{\theta}$ by reducing the extraction level for type $\bar{\theta}$, i.e., by moving leftwards along the indifference curve $\Pi(\bar{\theta})$=0. This implies a loss of production efficiency, however, since price is now higher than marginal extraction cost if the producer is of type $\bar{\theta}$. The regulator is therefore not likely to reduce $\bar{q}$ until all the rent of the efficient type has been eliminated. The second best solution, trading off production efficiency and rent extraction, will be somewhere in between, like point a and b in figure 2.2. We get the same economic conclusions as in the continuum type case: The efficient type's extraction level is efficient (no distortion at the top), and he obtains a positive economic rent. The inefficient type is left with no rent, and the extraction level is lower than the efficient level.

If the resource constraint is binding for some types ($\gamma(\theta) > 0$ for some θ), we get bunching (partial pooling) at $q(\theta)=K$.. For an interval of the most efficient producer groups, the optimal contract is to extract all the petroleum resources in the reservoir. The economic intuition is as follows. With the symmetric information starting point, we already have a wedge between price and marginal production costs:

(2.9) $$p-\frac{\partial C(q,\theta)}{\partial q}=\frac{\gamma}{1+\lambda}.$$

Applying the envelope theorem, we now see that a distortion (reduction) in $q(\theta)$ will produce a first-order welfare loss (equal to the wedge). This is different from the case with no binding resource constraints; in that case price is equal to marginal cost if there is symmetric information. A marginal reduction in $q(\theta)$ will therefore have no first-order welfare effects, and to reduce rent, $q(\theta)$ will therefore be reduced for all $\theta > \underline{\theta}$. With a binding resource constraint, however, in determining whether to reduce $q(\theta)$, the first-order loss in production efficiency must be traded off against the marginal reduction in the information costs. The arguments for distortions in $q(\theta)$ have therefore been weakened. My conjecture is that we, as in the symmetric information case, get bunching for the most efficient types. Compared with the symmetric information case, the extraction levels for the less efficient types will be distorted (reduced), and the critical type for which the resource constraint is binding, θ^*, is lower.

Proposition 2.3

There exists a θ^* such that

(2.53)
$$\begin{aligned} &q(\theta) = K, \frac{dq(\theta)}{d\theta} = 0, \quad \text{for } \underline{\theta} \le \theta \le \theta^* \\ &q(\theta) < K, \frac{dq(\theta)}{d\theta} < 0, \quad \text{for } \theta^* \le \theta \le \overline{\theta}, \end{aligned}$$

Parallel to the solution procedure applied in section 2.4 of the symmetric information case, I start by finding an expression for the interior solution of the extraction level $q(\theta)$. When $q(\theta)<K$, (2.43) implies $\gamma(\theta)=0$. Then from (2.46),

(2.54)
$$\gamma(\theta) = (p - \frac{\partial C(q(\theta),\theta)}{\partial q(\theta)})(1+\lambda)f(\theta) - (\lambda+\mu)F(\theta)\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta} = 0, \quad \theta^* \le \theta \le \overline{\theta}.$$

Equation (2.54) implicitly defines extraction level q as a function of the licensees' type θ. The extraction level is decreasing in the efficiency parameter, i.e., the partnership extracts more petroleum from the reservoir if it is efficient than if it is inefficient, see appendix 2.3.

I continue with a characterisation of θ^*. From the case of a non-binding resource constraint, equation (2.54), I get the following expression in θ^* for the limiting case $q \to K^-$:

$$(2.55) \qquad (p - \frac{\partial C(q(\theta),\theta^*)}{\partial q(\theta)})(1+\lambda)f(\theta^*) - (\lambda+\mu)F(\theta^*)\frac{\partial^2 C(q(\theta),\theta^*)}{\partial q(\theta)\partial\theta} = 0.$$

When $q(\theta)=K$, we have from (2.46)

$$(2.56) \qquad \gamma(\theta) = (p - \frac{\partial C(K,\theta)}{\partial q(\theta)})(1+\lambda)f(\theta) - (\lambda+\mu)F(\theta)\frac{\partial^2 C(K,\theta)}{\partial q(\theta)\partial\theta} \geq 0, \quad \underline{\theta} \leq \theta \leq \theta^*.$$

Non-negativity of $\gamma(\theta)$ is required by (2.43). In appendix 2.4, I show that under assumption A(2.16), $\gamma(\theta)$ is decreasing in θ for $\underline{\theta} \leq \theta \leq \theta^*$. This has a clear economic interpretation: $\gamma(\theta)$, the Lagrange multiplier for the resource constraint, expresses the social marginal value of petroleum in optimum. When θ is increasing, the partnership's efficiency diminishes. Consequently, the social marginal value of petroleum is reduced, i.e., $\gamma(\theta)$ is decreasing in θ. From (2.56), therefore, I get a second equation for determining θ^*, by noting that non-negativity is assured, provided

$$(2.57) \qquad (p - \frac{\partial C(K,\theta^*)}{\partial q(\theta)})(1+\lambda)f(\theta^*) - (\lambda+\mu)F(\theta^*)\frac{\partial^2 C(K,\theta^*)}{\partial q(\theta)\partial\theta} \geq 0.$$

Hence, the set of constraints in equation (2.56) has been reduced to the single constraint (2.57). The critical type is implicitly determined by equations (2.55) and (2.57), and together they yield the condition

$$(2.58) \qquad (p - \frac{\partial C(K,\theta^*)}{\partial q(\theta)})(1+\lambda.)f(\theta^*) - (\lambda+\mu)F(\theta^*)\frac{\partial^2 C(K,\theta^*)}{\partial q(\theta)\partial\theta} = 0,$$

or

(2.58') $$p-\frac{\partial C(K,\theta^*)}{\partial q(\theta)}=\frac{\lambda+\mu}{1+\lambda}\frac{F(\theta^*)}{f(\theta^*)}\frac{\partial^2 C(K,\theta^*)}{\partial q(\theta)\partial\theta}.$$

This is to be compared with the symmetric information case, condition (2.18). Since the marginal extraction cost is increasing in θ by assumption A2, evidently the critical type is reduced when we introduce asymmetric information. The economic rationale is that the reduction in θ^* implies a reduction in extraction levels for the types $\theta \in [\theta_A^*, \theta_S^*)$, where θ_S^* and θ_A^* are the critical types under symmetric and asymmetric information, respectively. These reductions in $q(\theta)$ are optimal since they enhance rent extraction. In determining how much to reduce θ^*, MIE must trade off the marginal reduction in information costs (the right hand side of (2.58')) against the production inefficiency (the left hand side).

To obtain explicit solutions for $q(\theta)$ and θ^*, one has to specify the cost structure $C(q,\theta)$ and the distribution of types $F(\theta)$.

2.6 QUADRATIC COST FUNCTION

In their model of optimal resource royalties, Gaudet, Lasserre and Long [1991] use a cost function with the specific form

(2.59) $$C(q,\theta)=\theta q+\frac{b}{2}q^2, \quad b\geq 0.$$

I will in this section show that the model of Gaudet et al. [1991] is obtained as an application of the general model developed in this chapter. It will be made clear that the choice of a quadratic cost function is convenient, since it in this special case is possible to find an explicit solution for quantity as a function of the partnership's type.

As a start I will have to check whether the cost function (2.59) satisfies assumptions A1-A4 in section 2.3. It is easy to verify that A1 and A2 are satisfied. A3 is also satisfied, by the restriction $b \geq 0$. Since the third-derivatives of a quadratic cost function are zero, A4 is trivially satisfied.

Proposition 2.4

For a quadratic cost function, there exists a θ^* such that

(2.60)
$$q(\theta) = K, \quad \frac{dq(\theta)}{d\theta} = 0, \quad \text{for } \underline{\theta} \leq \theta \leq \theta^*$$
$$q(\theta) = \frac{1}{b}\left[p - \theta - \frac{\lambda + \mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\right], \quad \frac{dq(\theta)}{d\theta} < 0, \quad \text{for } \theta^* \leq \theta \leq \overline{\theta},$$

This solution of q, as a function of the distribution of types, is analogous to equation (38) in Gaudet et al. [1991]. To solve for this special case, I insert for a quadratic cost function in the solution of the general model. I start by solving for the interior solution for extraction level q. Inserting for a quadratic cost function in equation (2.54), yields

(2.61)
$$\gamma(\theta) = (p - \theta - bq)(1+\lambda)f(\theta) - (\lambda + \mu)F(\theta) = 0, \qquad \theta^* \leq \theta \leq \overline{\theta}.$$

Solving with respect to q, gives

(2.62)
$$q = \frac{1}{b}\left[p - \theta - \frac{\lambda + \mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\right] \leq K, \quad \theta^* \leq \theta \leq \overline{\theta},$$

I continue with a characterisation of θ^*. Parallel to the approach in the case of a general cost function, I make use of the fact that $\gamma(\theta)$ is decreasing in θ for $\underline{\theta} \leq \theta \leq \theta^*$.[12] This is satisfied by assumption A(2.17) in appendix 2.4. I insert for the quadratic cost function in equation (2.58):

$$\text{(2.63)} \qquad \frac{1}{b}\left[p - \theta^* - \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta^*)}{f(\theta^*)}\right] = K.$$

The critical type θ^* is implicitly determined by equation (2.63), and this is analogous to equation (36) in Gaudet et al. [1991].

To obtain an explicit solution, I proceed by assuming a uniform distribution of types. The hazard rate is now equal to[13]

$$\text{(2.64)} \qquad \frac{F(\theta)}{f(\theta)} = \frac{(\theta-\underline{\theta})/(\overline{\theta}-\underline{\theta})}{1/(\overline{\theta}-\underline{\theta})} = \theta - \underline{\theta}.$$

Hence, the optimal extraction level (interior solution) and the critical type are given by

$$\text{(2.65)} \qquad q(\theta) = \frac{1}{b}\left[p - \frac{1+2\lambda+\mu}{1+\lambda}\theta + \frac{\lambda+\mu}{1+\lambda}\underline{\theta}\right],$$

$$\text{(2.66)} \qquad \theta^* = \frac{(1+\lambda)(p-bK)+(\lambda+\mu)\underline{\theta}}{1+2\lambda+\mu}.$$

To illustrate the effect of introducing a binding resource constraint, I draw the optimal quantity as a function of type.

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12 This assumption, not mentioned in Gaudet et al. [1991], is necessary to characterise θ^*.

13 The uniform distribution satisfies the monotone hazard rate assumption A5, as $\frac{d}{d\theta}\left(\frac{F(\theta)}{f(\theta)}\right) = 1$.

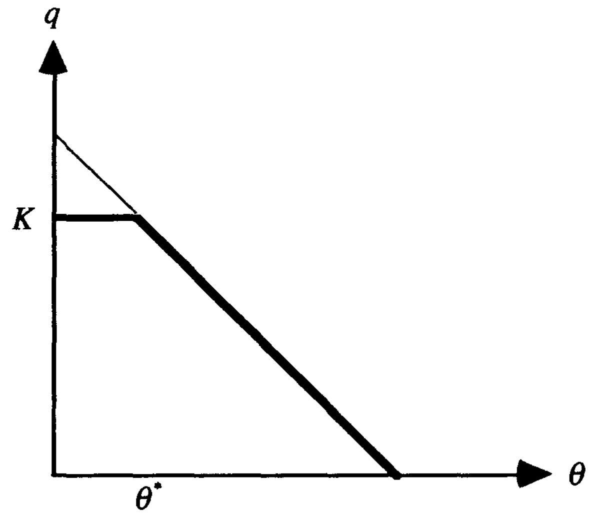

Figure 2.3: Optimal production schedule for manufacturing and petroleum extraction, under assumptions of quadratic cost function and uniform distribution of types.

In figure 2.3 optimal quantity is drawn with a bold line for the case with a binding resource constraint (the petroleum sector) and with a thin line for cases of absence of binding resource constraints (e.g., the manufacturing sector). The two lines coincide for the inefficient types $\theta^* \leq \theta \leq \overline{\theta}$, whereas the line for manufacturing quantity lies above the petroleum line for the more efficient types $\underline{\theta} \leq \theta < \theta^*$. The optimal regulatory solution in the case with a binding resource constraint implies bunching (partial pooling) for an interval of efficient types. Compared with a situation without a binding resource constraint (a fully separating equilibrium), the quantity is lower for those types.

For the case of quadratic cost function, figure 2.4 below illustrates the optimal extraction path for symmetric and asymmetric information about costs. The optimal extraction level under symmetric information, $\theta^* = (p - bK)$, is obtained by inserting for a quadratic cost function in equation (2.11). Similarly, by inserting for a quadratic cost function in equation (2.18), I obtain the critical type with symmetric information; $\theta_S^* = (p - bK)$.

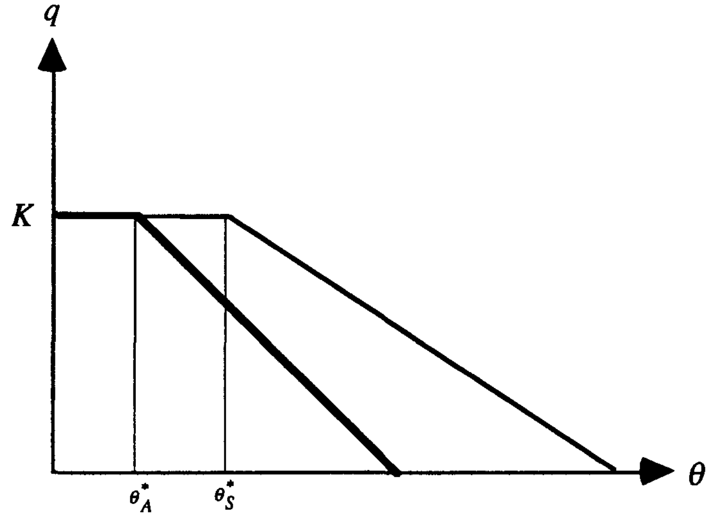

Figure 2.4: Optimal production schedule with symmetric (thin line) and asymmetric information (bold line), under assumptions of quadratic cost function and uniform distribution of types.

We see that the two curves coincide for the types $\theta \leq \theta_A^*$, whereas, for the less efficient types, the optimal production schedule for asymmetric information is below the schedule for symmetric information.

2.7 COMPARATIVE STATICS

I will try to keep the analyses at the highest possible level of generality, and will therefore return to the original model with a general cost function and a general distribution of types. Since in this model it is not possible to find an explicit solution for $q(\theta)$, I will instead characterise the solution by comparative statics analysis. These analyses will also be of help in providing more intuition for the economic results.

I will start by determining the relations between the critical type θ^* and the parameters p, λ and μ.

Corollary 2.1

The critical type is increasing in the petroleum price, and decreasing in the net cost of public funds and the foreign equity share.

These comparative statics results can be shown by implicit derivation of (2.58'). Equation (2.58') defines θ^* as an implicit function of p, λ and μ:

$$(2.67) \qquad G = p - \frac{\partial C(K,\theta^*)}{\partial q(\theta^*)} - \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta^*)}{f(\theta^*)}\frac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*},$$

as we from the assumptions A2, A4, and A5, have that

$$(2.68) \quad G_{\theta^*} = -\frac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*} - \frac{\lambda+\mu}{1+\lambda}\frac{d}{d\theta^*}\left(\frac{F(\theta^*)}{f(\theta^*)}\right)\frac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*} - \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta^*)}{f(\theta^*)}\frac{\partial^3 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^{*2}} \neq 0.$$

Hence, corollary 2.1 is verified by the following derivations:

(2.69)

$$\frac{d\theta^*}{dp} = -\frac{G_p}{G_{\theta^*}} = \frac{1}{\frac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*} + \frac{\lambda+\mu}{1+\lambda}\frac{d}{d\theta^*}\left(\frac{F(\theta^*)}{f(\theta^*)}\right)\frac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*} + \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta^*)}{f(\theta^*)}\frac{\partial^3 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^{*2}}} > 0.$$

(2.70)

$$\frac{d\theta^*}{d\lambda}=-\frac{G_\lambda}{G_{\theta^*}}=-\frac{\dfrac{1+2\lambda+\mu}{(1+\lambda)^2}\dfrac{F(\theta^*)}{f(\theta^*)}\dfrac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*}}{\dfrac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*}+\dfrac{\lambda+\mu}{1+\lambda}\dfrac{d}{d\theta^*}\left(\dfrac{F(\theta^*)}{f(\theta^*)}\right)\dfrac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*}+\dfrac{\lambda+\mu}{1+\lambda}\dfrac{F(\theta^*)}{f(\theta^*)}\dfrac{\partial^3 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^{*2}}}<0$$

(2.71)

$$\frac{d\theta^*}{d\mu}=-\frac{G_\mu}{G_{\theta^*}}=-\frac{\dfrac{1}{1+\lambda}\dfrac{F(\theta^*)}{f(\theta^*)}\dfrac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*}}{\dfrac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*}+\dfrac{\lambda+\mu}{1+\lambda}\dfrac{d}{d\theta^*}\left(\dfrac{F(\theta^*)}{f(\theta^*)}\right)\dfrac{\partial^2 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^*}+\dfrac{\lambda+\mu}{1+\lambda}\dfrac{F(\theta^*)}{f(\theta^*)}\dfrac{\partial^3 C(K,\theta^*)}{\partial q(\theta^*)\partial\theta^{*2}}}<0$$

The economic interpretation is that a higher petroleum price, ceteris paribus, increases the marginal value of petroleum. It will therefore be optimal to empty the reservoir also for producer groups with lower efficiency. An increase in the net cost of public funds and the foreign equity share, on the other hand, will increase the value of transferring funds from private petroleum companies to the state; $\lambda+\mu$. Ceteris paribus, this will call for increased rent extraction. More rent is extracted by reducing the interval of types for which the resource constraint is binding, $\underline{\theta}\le\theta\le\theta^*$, i.e., by reducing θ^*.

For a very high petroleum price and very low levels of the net cost of public funds and the foreign equity share, we may have $\theta^*\ge\overline{\theta}$, i.e., it will be optimal to empty the reservoir irrespective of the efficiency of the petroleum companies (pooling). Conversely, for low petroleum prices and a high value of transferring funds from private petroleum companies to the state, it may be optimal to leave petroleum in the reservoir for all producer types .

Corollary 2.2

For a non-binding resource constraint the optimal extraction level is increasing in the product price and decreasing in the foreign equity share and the net cost of public funds.

These results of how the optimal extraction level $q(\theta)$ depends on the parameters p, μ and λ when the resource constraint is non-binding ($\gamma(\theta)=0$), can be verified by comparative statics analysis. Equation (2.46) defines $q(\theta)$ as an implicit function of p, μ and λ:

$$G = p - \frac{\partial C(q(\theta),\theta)}{\partial q(\theta)} - \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta} = 0, \tag{2.72}$$

since we from assumptions A3 and A4 have that

$$G_q = -\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)^2} - \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^3 C(q(\theta),\theta)}{\partial q(\theta)^2\partial\theta} \neq 0, \tag{2.73}$$

Hence, the relationship between optimal extraction level $q(\theta)$ and the product price p is derived by implicit derivation in equation (2.46):

$$\frac{dq(\theta)}{dp} = -\frac{G_p}{G_q} = \frac{1}{\dfrac{\partial^2 C(q(\theta),\lambda)}{\partial q(\theta)^2} + \dfrac{\lambda+\mu}{1+\lambda}\dfrac{F(\theta)}{f(\theta)}\dfrac{\partial^3 C(q(\theta),\theta)}{\partial q(\theta)^2\partial\theta}} > 0. \tag{2.74}$$

The positive sign is due to assumptions A3 and A4. The economic interpretation is that an increase in product price implies, ceteris paribus, an increase in the expected ex post extraction inefficiency for a given distortion (reduction) of $q(\theta)$. Hence, the balance between rent extraction and ex post efficiency is tilted, and the optimal extraction level is increased.

To establish the relationship between the production level $q(\theta)$ and the foreign equity share μ, I proceed in the same manner:

$$(2.75) \qquad \frac{dq(\theta)}{d\mu} = -\frac{G_\mu}{G_q} = -\frac{\dfrac{1}{1+\lambda}\dfrac{F(\theta)}{f(\theta)}\dfrac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}}{\dfrac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)^2} + \dfrac{\lambda+\mu}{1+\lambda}\dfrac{F(\theta)}{f(\theta)}\dfrac{\partial^3 C(q(\theta),\theta)}{\partial q(\theta)^2\partial\theta}} < 0$$

The sign is determined by assumptions A2, A3 and A4. The economic intuition of the result is that an increase of foreign ownership decreases the welfare weight to the partnership profit, $1-\mu$, since income accruing to foreign investors is not seen as contributing to the welfare in Norway. As a consequence, the welfare gain from transferring one unit of income from the partnership to the government, $\lambda+\mu$, is increasing in the foreign equity share. The motive for rent extraction is reinforced, and, ceteris paribus, the extraction level should therefore be reduced as this is a means for rent extraction.

The effect on optimal extraction level of a change in the net cost of public funds is given by

$$(2.76) \qquad \frac{dq(\theta)}{d\lambda} = -\frac{G_\lambda}{G_q} = -\frac{\dfrac{1-\mu}{(1+\lambda)^2}\dfrac{F(\theta)}{f(\theta)}\dfrac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}}{\dfrac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)^2} + \dfrac{\lambda+\mu}{1+\lambda}\dfrac{F(\theta)}{f(\theta)}\dfrac{\partial^3 C(q(\theta),\theta)}{\partial q(\theta)^2\partial\theta}} < 0.$$

Again the sign is determined by assumptions A2, A3 and A4. The economic rationale is similar as for the change in the foreign equity share: The welfare gain from transferring one unit of income from the partnership to the government, $\lambda+\mu$, is increasing in the net cost of public funds. The motive for rent extraction is reinforced, and, ceteris paribus, the extraction level should therefore be reduced as this is a means for rent extraction. An increase of λ reflects an increase of tax-induced distortions in other sectors of the economy. Optimal taxation in the petroleum sector implies balancing the deadweight loss of petroleum taxes against deadweight losses elsewhere in the economy. When the latter are increasing, ceteris paribus, second best taxation optimum calls for higher taxes (more distortions) in the petroleum sector. Reduction in the level of petroleum production introduces an ex post extraction inefficiency. Hence, by reducing the production level we get a higher expected ex post deadweight loss in the petroleum sector.

Corollary 2.3

Compared with a situation without a resource constraint, the partnership gets a lower information rent if it is of type $\underline{\theta} \leq \theta < \theta^*$. For the other types the rent is equal.

The economic rationale for the reduction of rent is that the resource constraint is binding for the types $\underline{\theta} \leq \theta \leq \theta^*$. The optimal regulatory solution in the case with a binding resource constraint implies bunching. Compared with a situation without a binding resource constraint (a fully separating equilibrium, see the thin line in figure 2.3), the extraction level is lower for those types. From (2.35) we get that

$$\frac{d\Pi(\theta)}{dq(\theta)} = \int_{\theta}^{\bar{\theta}} \frac{\partial^2 C(q(\tilde{\theta}),\tilde{\theta})}{\partial q(\tilde{\theta})\partial\tilde{\theta}} d\tilde{\theta} > 0, \tag{2.77}$$

i.e., a lower quantity implies lower rent. The expression in (2.77) is positive due to the single crossing property (assumption A2). Due to bunching (partial pooling), the types that are more efficient than θ^* are not able to obtain higher quantity and rent through self selection.

In interpretation of figure 2.3, I used manufacturing as an example of an industry with absence of binding resource constraints. For this example an economic implication of corollary 2.3, *ceteris paribus*, is that efficient producers in the manufacturing industry enjoy higher rents than efficient petroleum companies. Since the information rent of the producer is derived from private information, it is important to note that this comparison presupposes the same degree of private information in the two industries. As I argue in section 1.2, however, in Norway the presence of asymmetric information is more likely offshore than onshore.

2.8 OPTIMAL CUTOFF TYPE

I will now discuss the principal's strategy option of denying extraction rights if the reported cost parameter is above some critical level θ_c, a cutoff level. I make use of the approaches in Baron [1989] and Laffont and Tirole [1993], section 1.4.5. Let $r(\theta)$=1 indicate that the partnership is allowed to produce and let $r(\theta)$=0 indicate denial of extraction rights.

Proposition 2.5

The partnership will be awarded a production right if $\theta \le \theta_c$, i.e.,

(2.78) $$r(\theta) = \begin{cases} 1, & \text{if } \theta \in [\underline{\theta}, \theta_c] \\ 0, & \text{if } \theta \in (\theta_c, \overline{\theta}] \end{cases}$$

To start with symmetric information, it was made clear in section 2.4 that the government in this case was able to capture all the economic rent, i.e., $\Pi = 0$. The welfare function in equation (2.2) is now equal to

$$W = (1+\lambda)(pq(\theta) - C(q(\theta),\theta)). \tag{2.79}$$

It will be optimal for MIE to deny extraction, i.e., to set $q(\theta) = 0$, for $\theta \in (\theta_c, \overline{\theta}]$, where θ_c is implicitly given by

$$W(\theta_c) = (1+\lambda)(pq(\theta_c) - C(q(\theta_c),\theta_c)) = 0. \tag{2.80}$$

This is self-explanatory; MIE denies extraction rights for types that would generate a negative net production value. We have not gained any new insights, however, since this result is already contained in the participation constraints (2.4).

By introducing asymmetric information, the ex ante optimal contract may imply denial of extraction for some interval of types even though it is ex post efficient for them to produce. The rationale for this ex post inefficiency is the same as for the distortion of production levels: It reduces the rent of the more efficient types. This is clear from the expression of the partnership's rent:

$$\Pi(\theta) = \int_{\theta}^{\overline{\theta}} \frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial \tilde{\theta}} d\tilde{\theta}. \tag{2.35}$$

The incentive compatible rent difference between two types θ and $\theta + d\theta$ is equal to relative cost advantage of type θ, $C(q(\theta+d\theta),\theta+d\theta) - C(q(\theta+d\theta),\theta)$. For a type θ, therefore, the total information rent is equal to cumulative cost differences given by equation (2.35). By introducing a cutoff rate $\theta_c < \overline{\theta}$, the least efficient company gets more efficient. Hence, the cumulative cost advantage for a type θ, i.e., the profit, is reduced.

In determining θ_c, I assume that there is an interior solution to the cutoff rate problem, in which the resource constraint is non-binding. To solve, I make use of the fact that the rent function (2.35) combines the participation and the incentive constraints. Inserting for this rent in the objective function (2.37), the expected welfare is given by:

$$(2.81) \qquad EW = \int_{\underline{\theta}}^{\bar{\theta}} [(1+\lambda)(pq(\theta) - C(q(\theta),\theta)) - (\lambda+\mu)\int_{\theta}^{\bar{\theta}} \frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial \tilde{\theta}} d\tilde{\theta}] dF(\theta).$$

By integrating by parts in the last term, (2.81) can be rewritten as

$$(2.82) \qquad EW = \int_{\underline{\theta}}^{\bar{\theta}} [(1+\lambda)(pq(\theta) - C(q(\theta),\theta)) - (\lambda+\mu)\frac{\partial C(q(\theta),\theta)}{\partial \theta}\frac{F(\theta)}{f(\theta)}] dF(\theta).$$

An implicit expression for the optimal production schedule $q^*(\theta)$, is found by pointwise differentiation of the expected welfare, equation (2.82), with respect to $q(\theta)$:

$$(2.83) \qquad p - \frac{\partial C(q(\theta),\theta)}{\partial q(\theta)} = \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial \theta}.$$

We see that (2.83) is the same as equation (2.46), for $\gamma(\theta) = 0$. Since I have not used the optimal control theory approach of section 2.5, this represents an alternative derivation of the optimal production schedule, $q^*(\theta)$. The production levels are distorted in order to extract more rent from the partnership.

By making extraction contingent on the reported $\hat{\theta}$ belonging to a certain interval, the government has an additional means for rent extraction. This is clear from the rent function, given by equation (2.35). With a cutoff rate θ_c, the rent of a partnership of type θ is given by

$$(2.84) \qquad \Pi(\theta) = \int_{\theta}^{\theta_c} \frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial \tilde{\theta}} d\tilde{\theta}.$$

The change in rent with respect to a change in cutoff rate is

(2.85) $$\frac{d\Pi(\theta)}{d\theta_c} = \frac{\partial C(q(\theta_c),\theta_c)}{\partial \theta_c} > 0.$$

The rent is increasing in the cutoff rate, due to the monotonicity assumption A1. It is, therefore, clear that MIE can reduce the information rent by denying production for some of the least efficient producer groups, i.e., by reducing the support of the distribution function $F(\theta)$ from $[\underline{\theta},\overline{\theta}]$ to $[\underline{\theta},\theta^c]$. By denial of production rights for reports $\hat{\theta} \in (\theta_c,\overline{\theta}]$, MIE strengthens its negotiating power (by reducing the partnership's strategy space, given by the support for $\hat{\theta}$), and is hereby able to capture more of the rent if $\theta \in [\underline{\theta},\theta_c]$. If $\theta \in (\theta_c,\overline{\theta}]$, however, this strategy may give a welfare loss if extraction for those types would give positive welfare ex post.

The partnership now faces a contract involving a positive production schedule $q^*(\theta)$ for the types $\theta \in [\underline{\theta},\theta_c]$ and zero production for the types $\theta \in (\theta_c,\overline{\theta}]$. The right-hand tail of the distribution of types, i.e., the types to the right of θ_c, is cut off. Note that the hazard rate is invariant to an upward truncation of the distribution: For $\theta \le \theta_c, [f(\theta)/F(\theta_c)]/[F(\theta)/F(\theta_c)] = f(\theta)/F(\theta)$. The optimal production schedule at $\theta < \theta_c$ is therefore still given by (2.46), i.e., it is independent of the truncation point θ_c. The economic intuition of this result is clear from the interpretation of (2.46): $q(\theta)$ is distorted from the symmetric information level until the gain from a marginal increase in rent extraction (the right hand side) is equal to the marginal reduction in production value (the left hand side). These are local effects that are not affected by an upward truncation of the probability distribution.

Hence, the expected social welfare is given by

(2.86) $$EW(\theta_c) = \int_{\underline{\theta}}^{\theta_c} [(1+\lambda)(pq^*(\theta) - C(q^*(\theta),\theta)) - (\lambda+\mu)\frac{\partial C(q^*(\theta),\theta)}{\partial \theta}\frac{F(\theta)}{f(\theta)}]dF(\theta).$$

The optimal cutoff rate is found by maximising (2.86) with respect to θ_c (i.e., with respect to the upper integral limit):

(2.87) $$(1+\lambda)(pq^*(\theta_c) - C(q^*(\theta_c),\theta_c)) = (\lambda+\mu)\frac{\partial C(q^*(\theta_c),\theta_c)}{\partial \theta}F(\theta_c).$$

An interpretation of this condition is that in choosing the truncation point θ_c, MIE will trade off the net value of keeping type θ_c (the left hand side) against the cost of extra rent to the more efficient types (the right hand side). Compared with the case of symmetric information, equation (2.80), we see that asymmetric information generates the additional right hand side of equation (2.87). To extract more rent, the government is willing to accept some ex post inefficiency in production.

Corollary 2.4

The cutoff rate is non-increasing in the foreign equity share and the net cost of public funds, and it is non-decreasing in the petroleum price.

These results of how the optimal cutoff rate θ_c depends on the parameters μ, λ and p, can be verified by comparative statics analysis. To start with the cutoff rate's dependence on the foreign equity share in the license, let θ_c^0 and θ_c^1 denote the optimal cutoff rates for the owner shares μ^0 and μ^1, respectively. By applying revealed preference, we have

(2.88) $$EW(\theta_c^0, \mu^0) \geq EW(\theta_c^1, \mu^0),$$

(2.89) $$EW(\theta_c^1,\mu^1) \geq EW(\theta_c^0,\mu^1).$$

Adding up (2.88) and (2.89) gives

(2.90) $$EW(\theta_c^0,\mu^0) - EW(\theta_c^0,\mu^1) - EW(\theta_c^1,\mu^0) + EW(\theta_c^1,\mu^1) \geq 0,$$

or

(2.91) $$\int_{\theta_c^0}^{\theta_c^1}\int_{\mu^0}^{\mu^1} \frac{\partial^2 EW}{\partial\mu\partial\theta_c} d\mu d\theta_c \geq 0.$$

From (2.86) I get

(2.92) $$\frac{\partial^2 EW}{\partial\mu\partial\theta_c} = -\frac{\partial C(q^*(\theta_c),\theta_c)}{\partial\theta} F(\theta_c) < 0,$$

where the sign is determined by assumption A1. Since the intregrand in equation (2.91) is negative, the integration limits, θ and μ, must be non-positively related for the double integral to be non-negative. Hence, equation (2.91) implies the following: $\mu^1 > \mu^0 \Rightarrow \theta_c^1 \leq \theta_c^0$, i.e., the cutoff rate is non-increasing in the foreign equity share. Put differently, higher foreign participation in a license leads to lower probability for production rights to be granted; $F(\theta_c)$ is non-increasing in μ . The economic intuition of the result is parallel to the comparative statics analysis of optimal extraction level: The welfare gain from transferring one unit of income from the partnership to the government, $\lambda + \mu$, is increasing in the foreign equity share. The motive for rent extraction is reinforced, and, ceteris paribus, the cutoff rate should therefore be reduced since this is a means for rent extraction.

To establish the functional relationship between the cutoff rate θ_c and the net cost of public funds λ, I proceed in the same manner as above. From (2.86) I get

(2.93)
$$\frac{\partial^2 EW}{\partial\lambda\partial\theta_c} = f(\theta_c)(pq^*(\theta_c) - C(q^*(\theta_c),\theta_c)) - \frac{\partial C(q^*(\theta_c),\theta_c)}{\partial\theta}F(\theta_c)$$
$$= -\frac{1-\mu}{1+\lambda}\frac{\partial C(q^*(\theta_c),\theta_c)}{\partial\theta}F(\theta_c) < 0,$$

where the second equality is obtained by using (2.87). Hence, we have that the cutoff rate is non-increasing in the net cost of public funds. The economic rationale is similar as for the change in the foreign equity share: The welfare gain from transferring one unit of income from the partnership to the government, $\lambda + \mu$, is increasing in the net cost of public funds. The motive for rent extraction is reinforced, and the cutoff rate should therefore be reduced since this is a means for rent extraction. An increase of λ reflects an increase of tax-induced distortions in other sectors of the economy. Optimal taxation in the petroleum sector implies balancing the deadweight loss of petroleum taxes against deadweight losses elsewhere in the economy. When the latter are increasing, ceteris paribus, second best taxation optimum calls for higher taxes (more distortions) in the petroleum sector. Introducing a cutoff rate introduces an ex post extraction inefficiency, since the field is not developed if $\theta \in (\theta_c, \overline{\theta}]$. Hence, by reducing the cutoff rate we get a higher expected ex post deadweight loss.

From (2.86) we get

(2.94)
$$\frac{\partial^2 EW}{\partial p\partial\theta_c} = f(\theta_c)(1+\lambda)q^*(\theta_c) > 0.$$

The sign is positive since $q^*(\theta_c)$, determined by (2.46), is assumed to be positive. Consequently, the cutoff rate is non-decreasing in the petroleum price. The economic interpretation is that an increase in product price implies, ceteris paribus, an increase in the expected ex post extraction inefficiency for a given cutoff rate. Hence, the balance between rent extraction and ex post efficiency is tilted, and the optimal cutoff rate is increased. If p is sufficiently large, the reservoir is developed for all types, i.e., $\theta_c = \overline{\theta}$.

2.9 MARKET POWER

In the preceding analysis I have made the simplifying assumption that Norway is a price taker in the petroleum market. With the increasing pace of extraction in the North Sea, this is at present probably not a reasonable assumption. Norway probably has market power both in the oil and the gas market. According to BP Statistical Review of World Energy, in 1992 the Norwegian shares of total world production of oil and natural gas are 3.4 and 1.4 per cent, respectively. Gas and oil have different market characteristics, mainly due to different means of transportation. Whereas the oil market is global, the gas market is segmented into regional markets due to higher transport costs. Norwegian petroleum companies export oil to the world market, whereas the gas sales are restricted to the European market. Norwegian share of European gas production is 3 per cent. Since there are only a small number of companies supplying gas to Europe, and since Norway is perceived as a more reliable supplier than its main competitor, Russia, Norway probably has more market power for gas than for oil.

It is important to note that the principal (MIE) and the agent (the partnership) in the regulatory model of this chapter, may have different degrees of market power. Since there are several gas fields on stream in the Norwegian sector, and since the partnerships vary among the licenses, the total Norwegian gas sales (q_N) are higher than the sales of a particular partnership (q_P). Hence, Norway has higher market power and a lower marginal revenue than that of a particular partnership:

(2.95) $$p + \frac{dp}{dq} q_N < p + \frac{dp}{dq} q_P.$$

In addition to the problem of achieving truthful cost reporting, MIE will in this situation face a problem of pricing. In calculating the marginal revenue, a partnership will not take into account that selling one additional gas unit will reduce the incomes of the other Norwegian partnerships (a pecuniary external effect). Consequently, from a domestic welfare perspective, total Norwegian gas sales may bee too high and the price too low. To exploit the Norwegian market power, it may therefore be optimal to restrict competition among Norwegian partnerships selling gas to Europe. Since 1986 such cartelisation has been in effect, all negotiations on sales of Norwegian gas are taken care of by the Gas Negotiating Committee (GFU).

To avoid the problems related to pricing issues, I have in this chapter made the assumption that Norway is a price taker in the petroleum market. I will now try to indicate the effects of relaxing this assumption. I will focus on gas, since the presence of Norwegian market power for petroleum is most relevant in this market.

Proposition 2.6

Introducing a downward-sloping demand curve does not affect the qualitative conclusions as to asymmetric information.

Up to now I have assumed that the welfare generated from a petroleum license can be expressed as a weighted sum of the partnership's profit and the net total government take; with the objective function

(1.3) $$W = (1+\lambda)R + (1-\mu)\Pi.$$

If Norway faces a downward sloping demand curve for gas, our decisions on gas extraction and marketing will affect the European gas price. Hereby will also the Norwegian consumer surplus of gas be affected. The *change* in domestic consumer surplus caused by Norwegian gas supply is thus a third welfare effect, and should be included in the welfare function (1.3). Introducing this new effect, ceteris paribus, will call for a higher gas quantity q for all types

θ, but will not change the qualitative results of the analysis above. Due to our hydroelectric power, the domestic consumption of natural gas is small, and practically all the production volume is exported. Hence, the change in consumer surplus of natural gas is probably negligible compared with the effects on revenue and production inefficiency. Since inclusion of consumer surplus considerations in the model will also cause technical complexities, it will be abstracted from in the analysis to follow.

To illustrate that the presence of market power does not change the qualitative conclusions of the analysis, I will make a stylised model of a partnership facing a downward sloping demand curve. To abstract from problems of pecuniary external effects, I will assume that there is only one gas license on the Norwegian continental shelf. Alternatively, there are several gas licenses, but they are all awarded to the same partnership group. In order to avoid complexities of strategic interaction among petroleum producers, I will furthermore assume that the partnership is a monopolist on the European market. In the following I will examine whether the results of sections 2.4 and 2.5 are modified under these altered assumptions.

To start with symmetric information, the only change in the model of section 2.4 is that the partnership no longer considers the product price to be a parameter p, but rather a function $p(q)$, where $dp(q)/dq < 0$. Analogous to equation (2.6), the regulatory problem now generates the Lagrangian

(2.96) $$L = (1+\lambda)(p(q)q - C(q,\theta)) + \gamma(K - q),$$

and the first-order condition is[14]

(2.97) $$p(1+\frac{1}{\varepsilon(q)}) - \frac{\partial C(q,\theta)}{\partial q} = \frac{\gamma}{1+\lambda},$$

[14] Sufficient conditions for the second-order condition to be satisfied, are assumption A3 and $d^2p(q)/dq^2 \le 0$, i.e., a convex cost function and a concave inverse demand function, respectively.

where $\varepsilon(q)$ is the elasticity of demand, given by

$$(2.98) \qquad \varepsilon(q) = \frac{dq(p)}{dp}\frac{p}{q(p)} < 0.$$

Comparing with condition (2.7), we see that the only difference is the replacement of the price p with the marginal revenue $p(1+1/\varepsilon)$. Since the cost function is assumed convex (assumption A3), comparison of (2.7) and (2.97) shows that, with the resource constraint non-binding, the quantity extracted is lower when the partnership faces a downward-sloping demand curve. This is due to traditional monopolist behaviour; increasing the profit by limiting the supply.

Turning to the case of asymmetric information; repeating the procedure of section 2.5 will make clear that the regulatory problem now will generate the Lagrangian[15]

$$(2.99) \qquad L = [(1+\lambda)(p(q(\theta))q(\theta) - C(q(\theta),\theta)) - (\lambda+\mu)\Pi(\theta)]f(\theta)$$

$$-\eta(\theta)\frac{\partial C(q(\theta),\theta)}{\partial\theta} + \gamma(\theta)(K - q(\theta)).$$

The second-best optimum is given by[16]

$$(2.100) \qquad p(1+\frac{1}{\varepsilon}) - \frac{\partial C(q(\theta),\theta)}{\partial q(\theta)} = \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta} + \frac{\gamma(\theta)}{(1+\lambda)f(\theta)},$$

and is identical to condition (2.46), except that the price p is replaced with the marginal revenue $p(1+1/\varepsilon)$. For a non-binding resource constraint, the quantity extracted is thereby

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[15] The reason why the Lagrangians in (2.41) and (2.99) are almost identical, is that equation (2.34) still applies. This can be verified by noting that in this case we have $\Pi(\theta) = p(q(\theta))q(\theta) - C(q(\theta),\theta) - R(\theta)$. Condition (2.35) for the price taker case, that encompasses the incentive and the participation constraints, therefore generalises to this context.

[16] The sufficient conditions for optimum are the ones listed in appendix 2.2, with the addition of $d^2p(q)/dq^2 \le 0$ (concave inverse demand function).

lower when the partnership faces a downward-sloping demand curve. This is similar to the case with symmetric information.

With the same reasoning it is also clear that the critical type (the type for which the resource constraint is exactly binding, θ^*) is lower when the partnership faces a downward-sloping instead of a horizontal demand curve. This result is valid for both symmetric and asymmetric information, and can be shown by replacing the price p with the marginal revenue $p(1+1/\varepsilon)p$ in equations (2.18) and (2.58'), respectively. The economic interpretation is straight forward; as the marginal revenue is reduced, it takes a more efficient producer group to make the resource constraint binding.

Introducing a negative-sloped demand curve, therefore, has the same effect in the symmetric and the asymmetric case: It reduces the critical type θ^*, and for a non-binding resource constraint, it reduces the optimal extraction level for all types. However, the marginal information cost, $\frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}$, is unaffected. The qualitative conclusions with respect to asymmetric information are therefore unaffected by the change in slope of the demand curve. The economic explanation is that the model is based on private information about the cost parameter θ, whereas there is assumed to be symmetric information about the demand function.

2.10 IMPLEMENTATION

In developing an optimal contract for petroleum regulation, I have used the revelation approach, i.e., the Ministry of Industry and Energy is assumed to offer the petroleum companies a revelation mechanism $M=\{(q(\theta),R(\theta),\theta\in[\underline{\theta},\overline{\theta}]\}$. Since the optimal mechanism satisfies incentive compatibility, the partnership will report their true cost parameter θ, in response to which they will be instructed to extract

$$(2.101) \qquad \begin{array}{lll} q(\theta)=K, & \text{if } \underline{\theta}\le\theta\le\theta^{*} & \\ q(\theta)<K, & \text{given by (2.46)}, & \text{if } \theta^{*}\le\theta\le\overline{\theta}, \end{array}$$

and to pay the net taxes

$$(2.102) \qquad R(\theta)=pq(\theta)-C(q(\theta),\theta)-\Pi(\theta).$$

Comparing this contract with present systems for petroleum taxation is difficult, since direct revelation mechanisms are rarely used. Under certain conditions, however, the optimal contract can be given an alternative implementation that is similar to present petroleum tax schemes; net taxes as a function of the production level. This is termed the delegation approach, since the level of extraction is left for the partnership to decide.

The following is an analogous application of the approach in Laffont and Tirole [1993], section 1.4. As shown in appendix 2.3, $q(\theta)$ is strictly decreasing for the types $\theta^{*}\le\theta\le\overline{\theta}$, and can thus, for this interval of types, be inverted; $\theta(q)$. I substitute for this function in (2.36):

$$(2.103) \qquad T(q)\equiv R(\theta(q))=pq-C(q(\theta),\theta(q))-\Pi(\theta(q)).$$

The optimal net tax $T(q)$ for the types $\theta^{*}\le\theta\le\overline{\theta}$, is now a function of the extraction level. I examine the properties of this function:

$$(2.104) \qquad \begin{aligned} \frac{dT(q)}{dq}&=p-\frac{\partial C(q(\theta),\theta(q))}{\partial q}-\frac{\partial C(q(\theta),\theta(q))}{\partial\theta(q)}\frac{d\theta(q)}{dq}-\frac{d\Pi(\theta(q))}{d\theta(q)}\frac{d\theta(q)}{dq}\\ &=p-\frac{\partial C(q(\theta),\theta(q))}{\partial q} \end{aligned}$$

The second equality in equation (2.104) is obtained by using condition (2.39). Since price exceeds marginal extraction costs for all types $\theta>\underline{\theta}$, the net tax function is upward-sloping.

The optimal allocation solving the regulatory problem can thus be implemented by offering a menu of tax-production bundles, forming an increasing net tax function $T(q)$:

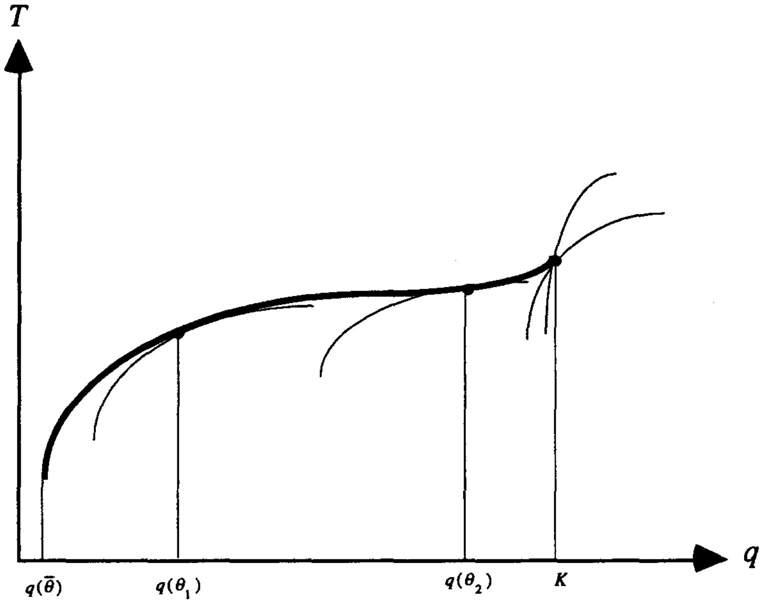

Figure 2.5: Implementation by a net tax function.

The partnership types $\theta > \theta^*$ choose the tax-production bundle where their isoprofit curves are tangent to the net tax schedule (self selection), whereas the types $\theta \leq \theta^*$ bunch at the boundary point $q = K$, i.e., $q(\theta)|_{\theta\in[\underline{\theta},\theta^*]} = K$.

I have established that the net tax function is increasing in the extraction level. Without more information it is not possible to be more exact about the functional form. As shown in appendix 2.5, $T(q)$ is likely to be a strictly concave function either if the cost function exhibits a strong degree of convexity or if the marginal extraction costs do not differ much among different producer types. As was made clear in the discussion of assumption A3 in section 2.3, it is reasonable to expect convex costs in petroleum extraction, due to reservoir pressure considerations. As I argued in sections 1.2 and 1.11, however, there is a severe problem of asymmetric information in petroleum regulation and taxation. This is formalised in assumption A1 (total costs increase with the producer type) and assumption A2 (the marginal extraction costs increases with the producer type). If the major part of the private information is related to fixed costs, the marginal extraction costs will not differ much among different producer types, and $T(q)$ is a strictly concave function. If there is much asymmetry with relation to the marginal extraction costs, the curvature of the net tax function is ambiguous.

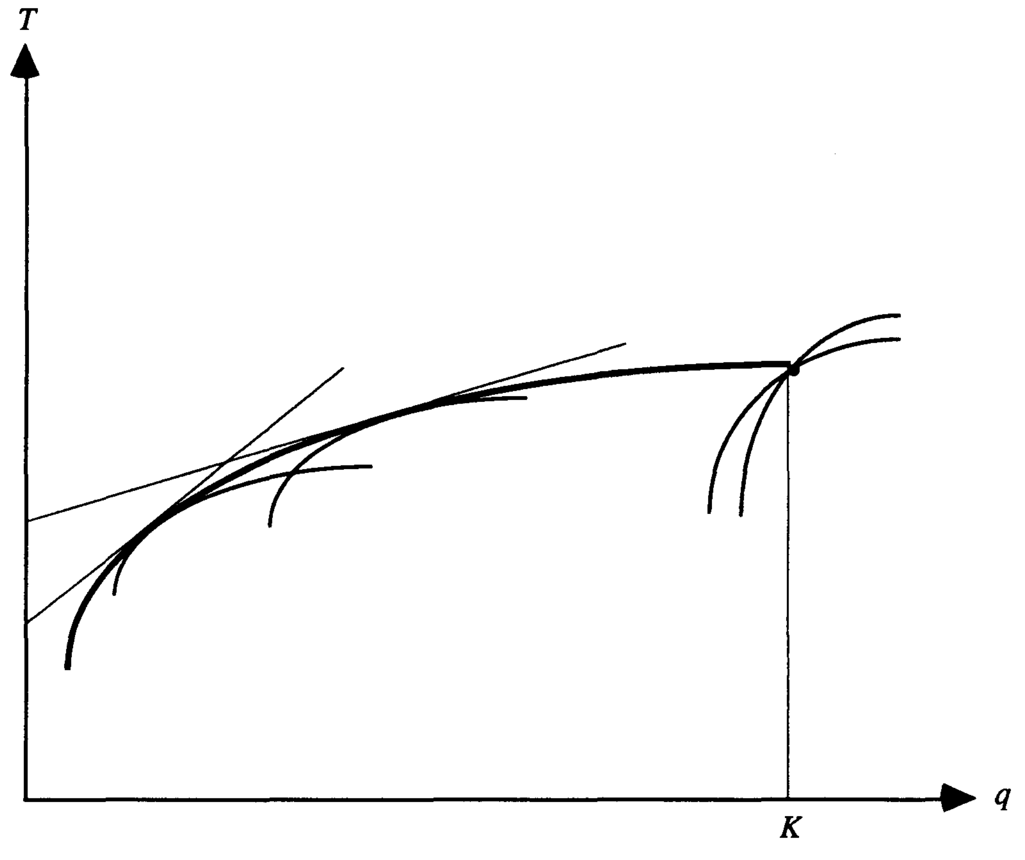

Figure 2.6: Implementation of a concave net tax function by a menu of linear contracts.

As illustrated in figure 2.6, the concave net tax function can be replaced by the family of its tangents.[17] The partnership's choice of extraction-tax bundle is the same whether it is offered

[17] This is an analogous application of Laffont and Tirole [1993], section 1.4.

a concave net tax schedule (bold curve) or its set of tangents (depicted by light linear lines). The optimal regulatory policy, therefore, can be implemented by a menu of contracts that are linear in the realised extraction level:

$$(2.105) \qquad R(\hat{\theta},q)=R^*(\hat{\theta})+(p-\frac{\partial C(q^*(\hat{\theta}),\theta)}{\partial q^*})(q-q^*(\hat{\theta})),$$

where $q^*(\hat{\theta})$ and $R^*(\hat{\theta})$ are, respectively, the extraction level and the net government take determined by the optimal mechanism (equations (2.46) and (2.36), respectively). To verify that (2.105) induces revelation ($\hat{\theta}=\theta$) and the appropriate extraction level $(q=q^*(\theta))$, I will analyse the partnership's optimisation program when facing this menu of linear contracts:

$$(2.106) \qquad \underset{\hat{\theta},q}{Max}\left\{pq(\theta)-C(q(\theta),\theta)-R^*(\hat{\theta})-(p-\frac{\partial C(q^*(\hat{\theta}),\theta)}{\partial q^*})(q-q^*(\hat{\theta}))\right\}.$$

The first-order conditions are

$$(2.107) \qquad (p-\frac{\partial C(q(\theta),\theta)}{\partial q})-(p-\frac{\partial C(q^*(\hat{\theta}),\theta)}{\partial q^*})=0,$$

$$(2.108) \qquad -(p-\frac{\partial C(q^*(\hat{\theta}),\hat{\theta})}{\partial q^*})\frac{dq^*(\hat{\theta})}{d\hat{\theta}}+(p-\frac{\partial C(q^*(\hat{\theta}),\theta)}{\partial q^*})\frac{dq^*(\hat{\theta})}{d\hat{\theta}} + \frac{\partial^2 C(q^*(\hat{\theta}),\theta)}{\partial q^{*2}}\frac{dq^*(\hat{\theta})}{d\hat{\theta}}(q-q^*(\hat{\theta}))=0.$$

The first term in condition (2.108), $-dR^*(\hat{\theta})/d\hat{\theta}$, is calculated from equation (2.36). Equation (2.107) gives $q=q^*(\hat{\theta})$, and (2.108) implies that $\hat{\theta}=\theta$.

Implementation by a menu of linear contracts is more easily compared with existing systems for petroleum taxation. Each of the linear contracts described above is composed of a fixed amount and a proportional tax, or in the language of petroleum taxation, a mixture of a license fee and a royalty. The most striking difference between the optimal contracts generated from the model of this chapter and those commonly observed in real petroleum tax systems, is that the petroleum companies in the model are not offered a single contract, but a set of contracts. The purpose is screening of the firms' technology. Through its choice of tax-extraction bundle, the partnership reveals its true efficiency parameter (self selection). This is illustrated in figure 2.6: Due to lower extraction costs, an efficient producer group will select a higher extraction level than an inefficient producer, and thereby pay a higher license fee and a lower royalty.

Contrary to most petroleum tax schemes, it is also worth noting that the suggested menu of contracts does not involve a profits tax. The explanation is evident; since there is assumed to be asymmetric information as to costs, MIE is not able to observe true profits. The net tax is instead made contingent on an observable variable, namely the extraction level chosen by the partnership.

2.11 COMPETITION

Up to now I have assumed that the production right is awarded by discretionary licensing. The production license gives the selected partnership group a monopoly in extraction from the petroleum field. The regulatory problem is to tax the monopoly under asymmetric information, by design of an optimal incentive contract. As shown in section 2.10, the optimal regulation is a menu of linear contracts, composed of a license fee and a royalty.

If there exist several companies with adequate resources and competence to exploit the reservoir, the regulatory agency may be able to improve the outcome by utilising competition ex ante or ex post, i.e., before or after awarding the production license. Conventional ex post competition would be the threat of entry, or threatening to award the production right to another partnership group. Models for ex post competition, by means of *repeated* auctions, are provided in chapter 4.

Ex ante competition, by the auctioning of production rights, may improve rent extraction, provided it is possible to avoid collusion. This follows analogously from Laffont and Tirole [1993], chapter 7. A number of m producer groups, drawn independently from a distribution $F(\theta)$, with support $[\underline{\theta},\overline{\theta}]$, bid simultaneously by announcing efficiency parameters. The optimal auction awards the production license to the partnership with the lowest efficiency parameter, and the winner is given an incentive contract similar to the monopoly case. The only difference induced by the auction is a truncation of the interval $[\underline{\theta},\overline{\theta}]$ to $[\underline{\theta},\theta^j]$, where θ^j is the second-lowest bid. The negotiating power of MIE is increased, as it can threaten to replace the winner with the second-lowest bidder. The information rent, the rent necessary to induce truthful report, is now reduced to

$$(2.109)\qquad \Pi(\theta)=\int_{\theta}^{\theta^j}\frac{\partial C(q(\tilde{\theta}),\tilde{\theta})}{\partial\tilde{\theta}}d\tilde{\theta},$$

i.e., the rent of the most efficient partnership if it instead were to mimic the second-lowest bidder.

The optimal contract exhibits a separation property; the optimal extraction level is the same as if there had been no bidding competition. This is clear as the hazard rate is invariant to an upward truncation of the distribution: For $\theta\le\theta^j$, $[f(\theta)/F(\theta^j)]/[F(\theta)/F(\theta^j)]$ $=f(\theta)/F(\theta)$. The optimal production schedule, therefore, is still determined by equation (2.46). As before, the optimal regulatory policy can be implemented by a menu of contracts that are linear in the realised extraction level. The effect of competitive bidding is to increase the license fee, whereas the level of the royalty is left unchanged.

APPENDIXES

Appendix 2.1

In proving that the policies $q(\hat{\theta})$ and $\theta \in [\underline{\theta},\overline{\theta}]$ are differentiable, I will follow the approach in Laffont and Tirole [1993], section 1.4. The profit of the partnership is given by

A(2.1) $$\Pi(\hat{\theta},\theta) = pq(\hat{\theta}) - C(q(\hat{\theta}),\theta) - R(\hat{\theta}).$$

The truth-telling requirement implies that for any pair of values θ' and θ in $[\underline{\theta},\overline{\theta}]$,

A(2.2) $$pq(\theta) - C(q(\theta),\theta) - R(\theta) \geq pq(\theta') - C(q(\theta'),\theta) - R(\theta'),$$

A(2.3) $$pq(\theta') - C(q(\theta'),\theta') - R(\theta') \geq pq(\theta) - C(q(\theta),\theta') - R(\theta).$$

Adding up A(2.2) and A(2.3) gives

A(2.4) $$-C(q(\theta),\theta) + C(q(\theta),\theta') \geq -C(q(\theta'),\theta) + C(q(\theta'),\theta'),$$

or

A(2.5) $$\int_{\theta}^{\theta'}\int_{q(\theta)}^{q(\theta')} \frac{\partial^2 C(q(\theta),\theta)}{\partial\tilde{\theta}\partial\tilde{q}(\theta)} d\tilde{q}(\theta)d\tilde{\theta} \leq 0.$$

Therefore, if $\theta' > \theta$, then $q(\theta') < q(\theta)$, i.e., incentive compatibility implies that $q(\theta)$ is a non- increasing function. Hence $q(\theta)$ is differentiable almost everywhere.

I will now prove that at a point of differentiability for $q(\theta)$, A(2.2) and A(2.3) imply that $R(\theta)$ is also differentiable. Let θ be a point of differentiability of $q(\theta)$. From A(2.2) and A(2.3), and for $\theta' > \theta$,

A(2.6) $$-\frac{(C(q(\theta'),\theta') - C(q(\theta),\theta'))}{\theta' - \theta} \geq \frac{R(\theta') - R(\theta)}{\theta' - \theta} \geq -\frac{(C(q(\theta'),\theta) - C(q(\theta),\theta))}{\theta' - \theta}.$$

Since $\theta' \to \theta$, the left-hand and right-hand sides converge to $-\frac{\partial C(q(\theta),\theta)}{\partial q(\theta)}\frac{dq(\theta)}{d\theta}$, i.e.,

A(2.7) $$\left.\frac{dR(\theta)}{d\theta}\right|_{+} = -\frac{\partial C(q(\theta),\theta)}{\partial q(\theta)}\frac{dq(\theta)}{d\theta}.$$

Similarly, taking $\theta' < \theta$, I get

A(2.8) $$\left.\frac{dR(\theta)}{d\theta}\right|_{-} = -\frac{\partial C(q(\theta),\theta)}{\partial q(\theta)}\frac{dq(\theta)}{d\theta}.$$

Therefore, at any point where $q(\theta)$ is differentiable, $R(\theta)$ is differentiable.

■

Appendix 2.2

I will check the sufficient condition for the regulatory problem. The sufficient condition is that the Lagrangian (2.41) shall be concave in $(q(\theta), \Pi(\theta))$ for all θ, or expressed with the principal minors of the Hessian matrix:

A(2.9) $$L_{qq} \leq 0,$$

A(2.10) $L_{\Pi\Pi} \leq 0, \quad \begin{vmatrix} L_{qq} & L_{q\Pi} \\ L_{\Pi q} & L_{\Pi\Pi} \end{vmatrix} \geq 0.$

As the Lagrangian is linear in Π, A(2.10) is trivially satisfied. A(2.9) can be written as

A(2.11) $$\frac{\partial^2 L}{\partial q(\theta)^2} = -(1+\lambda)\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)^2} f(\theta) - \eta(\theta)\frac{\partial^3 C(q(\theta),\theta)}{\partial\theta\partial q(\theta)^2} \leq 0,$$

and is satisfied by the assumptions A3 and A4.

■

Appendix 2.3

By applying the implicit function theorem, I will now show that the solution to the regulatory problem satisfies the monotonicity condition

(2.24) $$\frac{dq(\theta)}{d\theta} \leq 0.$$

For $\underline{\theta} \leq \theta \leq \theta^*$ the resource constraint is binding $(q(\theta) = K)$; the monotonicity condition is therefore trivially satisfied for these types. In case of an interior solution, i.e., for $\theta^* < \theta \leq \overline{\theta}$ $(\gamma(\theta) = 0)$, equation (2.46) defines $q(\theta)$ as an implicit function of θ:

A(2.12) $$F(\theta, q(\theta)) = p - \frac{\partial C(q(\theta),\theta)}{\partial q(\theta)} - \frac{\lambda + \mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta} = 0,$$

since we from assumptions A3 and A4 have

A(2.13) $$F_q = -\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)^2} - \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^3 C(q(\theta),\theta)}{\partial q(\theta)^2 \partial\theta} \neq 0.$$

Hence, the derivative is given by

A(2.14) $$\frac{dq(\theta)}{d\theta} = -\frac{F_\theta}{F_q} =$$

$$-\frac{\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta} + \frac{\lambda+\mu}{1+\lambda}\frac{d}{d\theta}\left(\frac{F(\theta)}{f(\theta)}\right)\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta} + \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^3 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta^2}}{\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)^2} + \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^3 C(q(\theta),\theta)}{\partial q(\theta)^2\partial\theta}},$$

which is strictly negative due to assumptions A2, A3, A4, and A5.

■

Appendix 2.4

Iwill examine under what conditions $\gamma(\theta)$ is decreasing in θ for $\underline{\theta} \le \theta \le \theta^*$. The Lagrange multiplier for the resource constraint is given by

(2.56)
$$\gamma(\theta) = (p - \frac{\partial C(q(\theta),\theta)}{\partial q(\theta)})(1+\lambda)f(\theta) - (\lambda+\mu)F(\theta)\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta} \ge 0, \quad \underline{\theta} \le \theta \le \theta^*.$$

I want to show that

A(2.15) $$\frac{d\gamma(\theta)}{d\theta} = -\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}(1+\lambda)f(\theta) + (p - \frac{\partial C(q(\theta),\theta)}{\partial q(\theta)})(1+\lambda)\frac{df(\theta)}{d\theta}$$

$$-(\lambda+\mu)f(\theta)\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}-(\lambda+\mu)F(\theta)\frac{\partial^3 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta^2}<0, \quad \underline{\theta}\leq\theta\leq\theta^*.$$

In the derivation of $\gamma(\theta)$ I have made use of the fact that in the optimal mechanism we have bunching (i.e., $dq(\theta)/d\theta=0$) for $\underline{\theta}\leq\theta\leq\theta^*$. By inserting for $(p-\partial C(q(\theta),\theta))/\partial q(\theta)$ from equation (2.46), and solving with respect to $df(\theta)/d\theta$, yields

A(2.16) $$\frac{df(\theta)}{d\theta}<\frac{\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}(1+2\lambda+\mu)f(\theta)^2+(\lambda+\mu)F(\theta)f(\theta)\frac{\partial^3 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta^2}}{(\lambda+\mu)F(\theta)\frac{\partial^2 C(q(\theta),\theta)}{\partial q(\theta)\partial\theta}+\gamma(\theta)}.$$

For a quadratic cost function $C(q,\theta)=\theta q+(b/2)q^2, \quad b\geq 0$, this condition is equal to

A(2.17) $$\frac{df(\theta)}{d\theta}<\frac{(1+2\lambda+\mu)f(\theta)^2+(\lambda+\mu)F(\theta)f(\theta)}{(\lambda+\mu)F(\theta)+\gamma(\theta)}.$$

It is therefore clear that to secure that the shadow price for petroleum is decreasing in θ (i.e., is increasing in the efficiency parameter of the partnership), one has to introduce a restriction on the distribution of possible types. The restrictions on the slope of the density function, for a general cost function in A(2.16) and for a quadratic cost function in A(2.17), however, may already be contained in the assumption of a monotone hazard rate:

A5: $$\frac{d}{d\theta}\left(\frac{F(\theta)}{f(\theta)}\right)\geq 0.$$

Taking the derivative in A5, and solving for $df(\theta)/d\theta$, yields

A(2.18) $$\frac{df(\theta)}{d\theta}\leq\frac{f(\theta)^2}{F(\theta)}.$$

For certain values of λ, μ and $\gamma(\theta)$, the conditions A(2.16) and A(2.17) may be contained in condition A(2.18). In this case the requirement of $\gamma(\theta)$ to be decreasing in θ will not imply additional restrictions on the density function.

■

Appendix 2.5

I will examine under what conditions the net tax function $T(q)$, for the types $\theta^* \leq \theta \leq \overline{\theta}$, is a strictly concave function. From (2.104), we get

A(2.19)
$$\frac{d^2T(q)}{dq^2} = -\frac{\partial^2 C(q,\theta(q))}{\partial q^2} - \frac{\partial^2 C(q,\theta(q))}{\partial q \partial \theta(q)} \frac{1}{\frac{dq}{d\theta(q)}}.$$

By rearranging A(2.19) we get that the net tax function is strictly concave if

A(2.20)
$$\frac{dq}{d\theta(q)} < -\frac{\frac{\partial^2 C(q,\theta(q))}{\partial q \partial \theta(q)}}{\frac{\partial^2 C(q,\theta(q))}{\partial q^2}}.$$

Since the right hand side of condition A(2.20) is strictly negative, due to assumptions A2 and A3, condition A(2.20) is stronger than the monotonicity condition ($dq / d\theta(q) \leq 0$). Inserting for A(2.14), i.e., the expression for $dq / d\theta(q)$ developed in appendix 2.3, condition A(2.20) can be written as

A(2.21)

$$\frac{\dfrac{\partial^2 C(q,\theta(q))}{\partial q \partial \theta(q)} + \dfrac{\lambda+\mu}{1+\lambda}\dfrac{d}{d\theta}\left(\dfrac{F(\theta)}{f(\theta)}\right)\dfrac{\partial^2 C(q,\theta(q))}{\partial q \partial \theta(q)} + \dfrac{\lambda+\mu}{1+\lambda}\dfrac{F(\theta)}{f(\theta)}\dfrac{\partial^3 C(q,\theta(q))}{\partial q \partial \theta(q)^2}}{\dfrac{\partial^2 C(q,\theta(q))}{\partial q^2} + \dfrac{\lambda+\mu}{1+\lambda}\dfrac{F(\theta)}{f(\theta)}\dfrac{\partial^3 C(q,\theta(q))}{\partial q^2 \partial \theta(q)}} > \frac{\dfrac{\partial^2 C(q,\theta(q))}{\partial q \partial \theta(q)}}{\dfrac{\partial^2 C(q,\theta(q))}{\partial q^2}}$$

The quadratic cost function used by Gaudet et al. [1991], is one example of a cost function that satisfies the conditions for concavity of $T(q)$, provided the hazard rate is strictly monotone. This is simply shown by inserting for $C(q,\theta) = \theta q + (b/2)q^2$, $b \geq 0$, in condition A(2.21) :

A(2.22) $$\frac{1+\dfrac{\lambda+\mu}{1+\lambda}\dfrac{d}{d\theta}\left(\dfrac{F(\theta)}{f(\theta)}\right)}{b} > \frac{1}{b}.$$

For general cost functions I will show that $T(q)$ is more likely to be a strictly concave function ($d^2T(q)/dq^2 < 0$), either if the cost function exhibits a strong degree of convexity ($\partial^2 C(q,\theta(q))/\partial q^2$ is high), or if the marginal extraction costs do not differ much among different producer types ($\partial^2 C(q,\theta(q))/\partial q \partial \theta(q)$ is low). These comparative statics results are obtained by differentiating equation A(2.19), taking into account the expression for $dq/d\theta(q)$ in equation A(2.14):

A(2.23) $$d\left(\frac{d^2T(q)}{dq^2}\right) / d\left(\frac{\partial^2 C(q,\theta(q))}{\partial q^2}\right) =$$

$$-1 + \frac{\dfrac{\partial^2 C(q,\theta(q))}{\partial q \partial \theta(q)}}{\dfrac{\partial^2 C(q,\theta(q))}{\partial q \partial \theta(q)} + \dfrac{\lambda+\mu}{1+\lambda}\dfrac{d}{d\theta}\left(\dfrac{F(\theta)}{f(\theta)}\right)\dfrac{\partial^2 C(q,\theta(q))}{\partial q \partial \theta(q)} + \dfrac{\lambda+\mu}{1+\lambda}\dfrac{F(\theta)}{f(\theta)}\dfrac{\partial^3 C(q,\theta(q))}{\partial q \partial \theta(q)^2}} < 0$$

A(2.24) $$d\left(\frac{d^2T(q)}{dq^2}\right) / d\left(\frac{\partial^2 C(q,\theta(q))}{\partial q \partial \theta(q)}\right) =$$

$$-\frac{1}{\frac{dq}{d\theta(q)}}\left[1-\frac{\frac{\partial^2 C(q,\theta(q))}{\partial q\partial\theta(q)}+\frac{\lambda+\mu}{1+\lambda}\frac{d}{d\theta}\left(\frac{F(\theta)}{f(\theta)}\right)\frac{\partial^2 C(q,\theta(q))}{\partial q\partial\theta(q)}}{\frac{\partial^2 C(q,\theta(q))}{\partial q\partial\theta(q)}+\frac{\lambda+\mu}{1+\lambda}\frac{d}{d\theta}\left(\frac{F(\theta)}{f(\theta)}\right)\frac{\partial^2 C(q,\theta(q))}{\partial q\partial\theta(q)}+\frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^3 C(q,\theta(q))}{\partial q\partial\theta(q)^2}}\right]>0$$

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Chapter 3

Petroleum taxation with adverse selection.
Interactions of dynamics in costs and information*

3.1 A DYNAMIC ADVERSE SELECTION MODEL OF PETROLEUM REGULATION

This chapter examines how real economic intertemporal dependence in extraction costs interacts with informational dynamics, in design of optimal intertemporal taxation of the petroleum companies. It is a well known result that optimal dynamic regulation under full commitment is to repeat the optimal static scheme in each period. Due to the non-stationarity imposed by inter-period link in extraction costs, the optimal contracts for the petroleum industry will differ between periods. Assuming symmetric information, tax theory has prescribed a neutral petroleum taxation, e.g. the resource rent tax. Asymmetric information brings us in a second best situation, calling for a non-neutral petroleum tax system. The

* I would like to thank Kåre P. Hagen and Diderik Lund for useful comments. This chapter has also benefited from comments at Nordic Workshop on Applied Game Theory and Industrial Organisation , May 1994, and the 1994 EARIE conference.

implementation mechanism of chapter 2 is generalised; the optimal allocation can be implemented by menus of tangent planes.

Dynamics are important in the petroleum industry, due to a long planning horizon in petroleum investments. Exploration is time consuming and it takes several years to develop a field, which thereafter may produce in thirty years. In the static model the focus was on the extent of extraction. In a dynamic resource-constrained context, the regulator will also have to make decisions about the rate of extraction, i.e., select a depletion path.

Generally, going from a static to a dynamic regulatory problem adds well-known complexities of renegotiation and lack of credible commitment.[1] The regulatory agency, the Ministry of Industry and Energy (MIE), will in this chapter be assumed to be able to credibly commit to a regulatory contract for the entire period of exploration, development and extraction. This assumption considerably simplifies the model: Under full commitment all decisions are taken in period one, and a binding contract is drawn for the entire horizon. The parties commit not to bilaterally renegotiate or unilaterally revise this long term contract. From a decision making point of view, therefore, this is a static problem, and parallel to the static model in chapter 2, the relevant equilibrium concept is static Bayesian equilibrium.

Due to the long planning horizon in petroleum extraction, however, the assumption of full commitment is far from innocuous. As I argued in section 1.7, two additional characteristics of petroleum regulation make credible commitments especially hard to achieve in the relationship between petroleum companies and the government: 1) Irreversible investments; it is tempting for the government to increase the net take from the petroleum sector once large investments are sunk, as this causes no (static) deadweight loss, and 2) Institutional restrictions; the present government cannot commit future governments. It can be argued, however, that a confiscatory tax policy after sinking of irreversible investments, can not be expected until there are only a few petroleum fields left for extraction. Before that time,

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1 See section 1.7 for a discussion of dynamic petroleum regulation.

since the government realises that it depends on private participation in petroleum extraction, taxation will probably be reasonable so as to encourage private companies to apply for blocks in future licensing rounds. Put differently, to keep down the dynamic deadweight loss, the government will not opt for ex post confiscatory taxation.[2] Although MIE is generally believed not to choose the drastic means of nationalisation, and therefore has more credibility than politically unstable and less internationally integrated countries, it will still have to build reputation for not choosing less dramatic means like heavy ex post taxation of irreversible investments. The present discretionary tax regime is probably not effective for building such a reputation.

As for the inability to commit future governments, this problem is somewhat modified by the fact that for many years there has been a consensus among the largest Norwegian political parties about the major questions of petroleum regulation. The arguments of political consensus and dynamic deadweight loss, can to some extent give the government credibility for not unilaterally deviating from long term contracts. It is difficult, however, to find arguments of why MIE and the partnership should not amend (renegotiate) the initial contract if both parties agree to do so. On the basis of this discussion, clearly the assumption of full commitment, made in this chapter, is not reasonable. The full commitment model, nevertheless, is useful as a reference case.

In the specific adverse selection model of this chapter, a two-period version of the model in chapter 2, the investment decision is suppressed. The action taken by the partnership is to report an efficiency parameter θ, or, equivalently, select an extraction path. Full commitment in this context implies that the government, at the initial time of contracting, can credibly commit to how to use information about the true θ revealed in future periods. If there is a separating equilibrium in period 1, there will be symmetric information at the beginning of period 2. Reoptimising the contract, taking into account the new information

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[2] The Norwegian government is not expected to impose confiscatory taxation. It may, however, be suspected to impose less dramatic tax increases. In the case of an unexpected high return for the petroleum companies, the government may ex post choose to capture more of the resource rent than prescribed by the initial contract. Some examples of such practise are mentioned in chapter 1.

available, will typically yield a revision of the ex ante optimal contract. Full commitment means that the government is credible when it asserts that it will not choose the revised ex post contract, but will stick to the committed ex ante contract; i.e., the government is credible in its claim of not making use of the new information available. When possible, it will always be optimal for the principal at the initial contracting date to commit to a policy for the entire horizon.[3]

Dynamic analyses of the petroleum industry are interesting from the perspective of regulation theory. Two-period models of manufacturing industry have dynamics in information; the asymmetric information may be resolved over time, and the principal updates his expectations. In addition, being an exhaustible resource, petroleum also has an intertemporal dependence in production. The higher is the present extraction level, the less is left for future production. Equivalently, the more petroleum is extracted in this period, the more costly is future production. The main objective of chapter 3 is to examine how the real economic intertemporal dependence in extraction costs interacts with the informational dynamics, in design of optimal intertemporal taxation of the petroleum companies.

This chapter is inspired by an article on regulation of the mining industry by Gaudet, Lasserre and Long [1991]; "Optimal resource royalties under asymmetric information".[4] The structure of their two-period model is similar to that of Baron and Besanko [1984], with an added resource constraint. I make the same changes in the model of Gaudet et al. [1991] as in chapter 2.[5] Additional changes made in this chapter are introducing an asymptotic cost function, redefining the resource stock, and allowing for the private information (given by a parameter θ in the cost function) to be correlated over time.[6] Whereas Gaudet et al. assume that θ is temporally independent, I choose the other polar case, assuming θ to be perfectly

[3] By entering into a binding long-term contract, the parties can always duplicate a sequence of short term contracts, and generally they will be able to improve the outcome of short term contracting.

[4] I also benefit from Baron and Besanko [1984], Baron [1989], and Laffont and Tirole [1993], chapters 8 and 10.

[5] The changes are a) The introduction of a general cost function, b) The elimination of one constraint, and c) Some minor changes in the government's objective function.

[6] The asymtotic cost function (assumption A6) and the resource base will be explained in section 3.2.

correlated over time, i.e., $\theta_1 = \theta_2 = \theta$. I will analyse the perfect correlation case because I find this more descriptive of the information structure over time, and because this case yields more interesting economic interpretations.

The assumption of a time invariant θ is best explained by remembering the interpretation of θ as an intrinsic cost parameter. As discussed in chapter 2, in this context the private information underlying the intrinsic cost parameter θ, is either the partnership's efficiency level or the quality of the reservoir (the geological structure). It is reasonable to assume that the private information about efficiency or reservoir characteristics affects costs in a related manner in the two periods, i.e., θ_1 and θ_2 are likely to be correlated. (The case of independent cost parameters would be descriptive of a regulatory situation where the private information is factor prices, and where these prices are statistically independent over time.) By choosing the polar case of perfect correlation, I implicitly assume that the efficiency level or the reservoir characteristics persist through time. Hence, the partnership has the same advantage of private information in both periods. It may be that the partnership in observing θ_1 obtains only imperfect information about θ_2, i.e., θ_1 and θ_2 are imperfectly correlated: Observing the intrinsic cost parameter in period one gives some indication of the extraction costs in period two, but not exact knowledge as reservoir characteristics and efficiency may change over time. I make the assumption of perfect correlation for tractability reasons.[7]

If θ_1 and θ_2 were assumed to be independent, it implies that the partnership at the contracting date knows its first period costs, but has no private information about its intrinsic cost parameter in the second period. In other words, at the time of contracting there is symmetric information about costs in period two. In this case, assuming full intertemporal commitment, there is no informational dynamics. The optimal dynamic regulation, therefore, is straight forward, and can be deduced from the static model in chapter two: Due to symmetric information, the first best static contract of section 2.4 is chosen for the second period: For a

[7] When $\theta_1 = \theta_2$, MIE needs to ask for a report of intrinsic cost parameter in period one only. Hence, there is only one incentive constraint to consider.

non-binding resource constraint the price is set equal to marginal extraction costs, and MIE sets net takes so as to capture all of the resource rent. In the first period the information advantage of the partnership is the same as in the static model in section 2.5: Price is set equal to marginal extraction costs plus marginal information costs, and the partnership obtains an information rent. Introducing informational dynamics by allowing for a correlated cost parameter, gives a more complex model, but yields interesting economic interpretations.[8]

3.2 ASSUMPTIONS

There are two basic approaches for modelling the inter-period link arising from the resource constraint: 1) Imposing a resource constraint that may bind for some parameter values, or 2) Reserve-based cost functions.[9] By introducing a general cost function $C(q_t,\theta,S_t)$, where S_t is the remaining petroleum stock at the beginning of period t, I choose the latter approach in this chapter. In a two-period model we have

(3.1) $$S_1 = K$$

(3.2) $$S_2 = K - q_1(\theta),$$

where the initial petroleum deposit, K, taken as exogenously given, is defined as the total amount of petroleum in the reservoir (the resource base). As in chapter 2, the initial petroleum deposit is assumed to have a deterministic size that is known to both parties. In Gaudet et al. [1991], and in the static model in chapter 2 of this monograph, the first approach is chosen. K is still exogenous, but is now defined as the amount of recoverable reserves.[10]

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[8] By making the simplifying assumption of independent cost parametes, however, Gaudet et al. [1991] are able to analyse the non-commitment situation.

[9] For a review of strategies for modeling exhaustible resources, see Epple and Londregan [1993] and Sweeney [1993].

[10] Gaudet et al. do not give a precise definition of the resource stock, but by allowing the resource constraint to be binding, they implicitly treat the resource stock as recoverable reserves.

I will argue that this definition of K, although common, may be questionable in the present context. The size of recoverable reserves depends on economics and technology. It is, therefore, endogenously determined in the model, and should not be treated as exogenously given.

For the single period cost function $C(q_t(\theta),\theta,S_t)$ and the distribution of efficiency types, $F(\theta)$, I make the following assumptions ($t=1,2$):

A1: $\frac{\partial C(q_t,\theta,S_t)}{\partial\theta}>0$ Monotonicity

A2: $\frac{\partial^2 C(q_t,\theta,S_t)}{\partial\theta\partial q_t}>0$ Static single crossing

A3: $\frac{\partial^2 C(q_t,\theta,S_t)}{\partial q_t^2}>0$ Convexity

A4: $\lim_{\sum_t q\to K}\sum_t C(q_t,\theta,S_t)=\infty$ Asymptote

A5: $\frac{\partial C(q_2,\theta,S_2)}{\partial S_2}<0$ Stock effect

A6: $\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial S_2^2}>0$ Decreasing return in remaining stock

A7: $\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial S_2\partial\theta}<0$ Dynamic single crossing

A8: $\frac{\partial^3 C(q_t,\theta,S_t)}{\partial\theta\partial q_t^2}\geq 0$, $\frac{\partial^3 C(q_t,\theta,S_t)}{\partial\theta^2\partial q_t}\geq 0$, $\frac{\partial^3 C(q_2,\theta,S_2)}{\partial\theta\partial S_2^2}\geq 0$, $\frac{\partial^3 C(q_2,\theta,S_2)}{\partial\theta^2\partial S_2}\leq 0$

A9: $\frac{d}{d\theta}\left(\frac{F(\theta)}{f(\theta)}\right) \geq 0$ Monotone hazard rate

We recognise assumptions A1 and A2 from chapter 2. They merely state that the intrinsic cost parameter is defined so as the total and the marginal extraction costs are increasing in θ. As explained in section 2.3, convex extraction costs, are explained by reservoir physics: Petroleum production is dependent on a certain level of driving pressure in the reservoir to pump up oil and gas. As production proceeds the reservoir pressure, therefore, must be maintained, e.g., by pumping water or associated gas into the reservoir. These activities are costly. The injection level needed to compensate for the loss of reservoir pressure from one unit of petroleum production, is increasing with the extraction level. Another reason for convexity is that it typically will be optimal to start extracting the high-quality (low-cost) portions of the deposit. The smaller the remaining stock, the lower is the quality of the remaining reserves, and the more expensive is additional extraction. These are arguments for the extraction costs to be convex in cumulative extraction level. Assumption A4 goes one step further, claiming that the cumulative extraction costs approach infinity when the remaining resource base approaches zero. The asymptotic costs assumption implies an interior solution, i.e., a non-binding resource constraint. This is in accordance with geological observations; the amount of petroleum extracted from a reservoir is usually in the range of 20 to 60 per cent of the resource base. It is technically feasible to increase the extraction further, but only at prohibitive costs.

The convexity of the single period costs $C(q_t(\theta),\theta,S_t)$, assumption A3, makes it profitable to spread production over both periods. This assumption coincides with geological experience of a more rapid decline of the driving reservoir pressure the more rapid is the pace of extraction.

Assumption A5 takes care of the inter-period link arising from the non-renewability constraint: The costs are lower the larger is the remaining reservoir (stock effect). The geological explanation is the same as for convexity; reservoir pressure. This assumption implies dynamics in extraction costs: The extraction level chosen in the first period will affect the size of the resource base remaining at the beginning of period two, and, consequently, the second period extraction costs.

Assumption A6 says that the rate of cost reductions, caused by a larger residual deposit, is declining (decreasing return in stock). The dynamic single crossing property, assumption A7, says that the rate of reduction in extraction costs caused by an increase in remaining reservoir, is higher for inefficient than for efficient partnerships. The interpretation in terms of production technology is straight forward: Inefficient producers, by having a larger stock of petroleum available, are to some extent able to compensate for their intrinsic cost disadvantage, i.e., stock is relatively more important for inefficient producers (intrinsic efficiency level and remaining stock are substitutes).[11]

As in the static model, I need restrictions on the third derivatives of the cost function (assumption A8, having no clear economic interpretations), to secure the sufficient conditions for the principal's regulation problem. An interpretation of the monotone hazard rate, assumption A9, is provided in section 2.3.

Summing up, as is common for regulation theory, a number of assumptions are needed to secure concavity of the problem, etc. In the case of petroleum regulation most of these assumptions are reasonable, as they have economic and reservoir physical justifications.

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[11] Single crossing property in the two-period model is explained in more detail in section 3.4 below.

3.3 SYMMETRIC INFORMATION

Under symmetric information, MIE knows the cost parameter θ. The regulatory problem is to maximise an intertemporal welfare function[12]

$$(3.3) \qquad \underset{q_1(\theta),q_2(\theta),R_1(\theta),R_2(\theta)}{Max} \{(1+\lambda)[p_1q_1(\theta) - C(q_1(\theta),\theta,S_1) + \delta(p_2q_2(\theta) - C(q_2(\theta),\theta,S_2))] - (\lambda+\mu)\Pi(\theta)\},$$

subject to a set of intertemporal participation constraints and a resource constraint:

$$(3.4) \qquad \Pi(\theta) \geq 0, \quad \forall \theta \in [\underline{\theta}, \overline{\theta}]$$

$$(3.5) \qquad q_1 + q_2 \leq K,$$

where $\Pi(\theta) \equiv \Pi_1(\theta) + \delta\Pi_2(\theta)$. Due to assumption A4 of asymptotic cumulative costs, it will never be optimal to empty the reservoir. The model is thus simplified, since I can abstract from the resource constraint in the mathematical analysis.

Under symmetric information MIE is able to capture all of the resource rent, i.e., the rent, in net present value terms, of the partnership is equal to zero (the intertemporal participation constraint will be binding for all types in optimum). By inserting for $\Pi(\theta) = 0$ in (3.3), we see that the regulator's problem is reduced to maximising the net present value of the resource rent:

[12] This is a two-period version of the function in equation (2.2), where δ is the discount factor. In the analysis to follow, δ is assumed to be the same for MIE and the partnership. This might be justified by referring to Diamond and Mirrlees' [1971] result that social prices should be based on market prices. In deriving this conclusion, however, Diamond and Mirrlees assume lump sum taxation and constant returns to scale. Clearly, these assumptions are violated in my model. Still, from reasons of tractability, the assumptions of a common δ will be maintained.

(3.6) $$\underset{q_1(\theta),q_2(\theta)}{Max} \{(1+\lambda)[p_1q_1(\theta)-C(q_1(\theta),\theta,S_1)+\delta[p_2q_2(\theta)-C(q_2(\theta),\theta,S_2)]]\}$$

The first order conditions are

(3.7) $$p_1-\frac{\partial C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)}+\delta\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial S_2}=0$$

(3.8) $$p_2-\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)}=0.$$

In calculating (3.7), I have made use of (3.2). The second order conditions are given in appendix 3.1.

Optimal regulation of a manufacturing industry would imply repetition of the static contract. Due to exhaustibility of the resource, this is not the case for petroleum extraction. We recognise the expression for the second period extraction level, equation (3.8), as the solution to the static problem.[13] In the first period, optimum is still given by price equal to marginal extraction costs. The marginal costs, however, have an additional component, $\delta\partial C(q_2(\theta),\theta,S_2)/\partial S_2$; the present value of incremental costs in period two, caused by extracting an additional unit in period one. This is an opportunity cost, accounting for the inter-period link in extraction costs (the stock effect).

Parallel to the static model, the optimum of this primal regulatory problem can be implemented by instructing the partnership to choose the extraction levels determined by equations (3.7) and (3.8), and to pay a lump sum tax equal to the resulting resource rent.[14] Net present value of the net tax is equal to the resource rent, but its distribution is arbitrary. The license fees may be set so as the participation constraint is binding in each period, i.e., $R_t = p_tq_t(\theta)-C(q_t(\theta),\theta,S_t)$, $t=1,2$.

[13] For a non-binding resource constraint, it is equivalent to equation (2.9).

[14] This lump sum tax is equal to $R(\theta)=p_1q_1(\theta)-C(q_1(\theta),\theta,S_1)+\delta[p_2q_2(\theta)-C(q_2(\theta),\theta,S_2)]$.

Alternatively, from the dual problem, the regulatory agency can delegate the decision of extraction path to the partnership, and levy a neutral tax of 100 per cent of the rent. The tax can be levied on reported profits or cash flow. The latter could be a tax on non-financial cash flow, proposed by Brown [1948], or, as proposed by Garnaut and Ross [1975], a resource rent tax. The regulatory agency is able to reach the first best outcome, since it under symmetric information is equipped with a wide range of tax measures. In real life, however, a rent tax of 100 per cent is not considered feasible, or, put differently, the assumption of symmetric information is unrealistic.

Note that under symmetric information, royalties are not among the optimal tax instruments. This is because a tax on gross income, with extraction costs not being deductible, implies a disincentive for extraction.

3.4 ASYMMETRIC INFORMATION WITH FULL COMMITMENT

Under full commitment, we assume that the government has the ability to credibly commit to a two-period contract specifying how the regulatory instruments available (extraction path and net taxes) will be set in each of the two periods.

The partnership is assumed to know its own type, θ, whereas the regulator only knows the distribution, given by the probability density function $f(\theta)$, $\theta \in [\underline{\theta}, \overline{\theta}]$. In this case, the regulator will recognise that if he tried to implement the first best solution of section 3.3, the companies would have incentives to overstate their costs to obtain higher profits. The analysis to follow is facilitated by the revelation principle, stating that the principal can restrict his attention to the class of mechanisms in response to which the firms report their types truthfully. The revelation principle is valid for static games. As argued in section 3.1, under full intertemporal commitment, all decisions are taken in period one. The relevant equilibrium concept, therefore, is a static Bayesian equilibrium. Hence, the revelation principle applies.

The regulatory agency, the Ministry of Industry and Energy (MIE), offers the self-selection mechanism $M=\{[(q_1(\theta),R_1(\theta)],[(q_2(\theta),R_2(\theta)],\theta\in[\underline{\theta},\overline{\theta}]\}$, i.e., a menu of type-revealing two-period contracts in q and R that the partnership can choose among.

The regulatory problem is now to maximise the expected intertemporal welfare

$$(3.9)\qquad \underset{q_1(\theta),q_2(\theta),R_1(\theta),R_2(\theta)}{Max}\int_{\underline{\theta}}^{\overline{\theta}}\{(1+\lambda)[p_1q_1(\theta)-C(q_1(\theta),\theta,S_1)+\delta(p_2q_2(\theta)-C(q_2(\theta),\theta,S_2))]$$
$$-(\lambda+\mu)\Pi(\theta)\}f(\theta)d\theta,$$

subject to

$$(3.4)\qquad \Pi(\theta)\equiv\Pi(\theta,\theta)\geq 0,\qquad \forall\theta\in[\underline{\theta},\overline{\theta}]$$

$$(3.10)\qquad \Pi(\theta)\geq\Pi(\hat{\theta},\theta),\qquad \forall\hat{\theta},\theta\in[\underline{\theta},\overline{\theta}]$$

$$(3.5)\qquad q_1+q_2\leq K$$

We recognise the set of intertemporal participation constraints (3.4) and the resource constraint (3.5) from the symmetric information case. As in the static model, asymmetric information generates an additional set of constraints; incentive constraints, given by equation (3.10).

In solving this program, I proceed in the same manner as in chapter 2. Net present value of the partnership's rent, as a function of reported efficiency $\hat{\theta}$ and true efficiency θ, is given by

$$(3.11) \qquad \Pi(\hat{\theta},\theta) \equiv \Pi_1(\hat{\theta},\theta) + \delta\Pi_2(\hat{\theta},\theta) = p_1 q_1(\hat{\theta}) - C(q_1(\hat{\theta}),\theta,S_1) - R_1(\hat{\theta}) + \delta[p_2 q_2(\hat{\theta}) - C(q_2(\hat{\theta}),\theta,S_2) - R_2(\hat{\theta})].$$

From the envelope theorem, i.e., by using the first order condition for incentive compatibility, we get

$$(3.12) \qquad \frac{d\Pi(\theta)}{d\theta} = \left.\frac{\partial\Pi(\hat{\theta})}{\partial\hat{\theta}}\right|_{\hat{\theta}=\theta} = -\frac{\partial C(q_1(\theta),\theta,S_1)}{\partial\theta} - \delta\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial\theta}.$$

We see that the rent, due to assumption A1, is decreasing in θ, i.e., to be willing to reveal their true type, efficient partnerships must be rewarded with a higher rent than inefficient partnerships. The economic interpretation is parallel to the static model; instead of revealing its true efficiency θ and produce accordingly, the partnership may choose to camouflage as a marginally less efficient producer group $\theta + d\theta$. The mimicking is done by selecting the combination of production levels and net taxes intended for this type; $\{[q_1(\theta+d\theta), R_1(\theta+d\theta)], [q_2(\theta+d\theta), R_2(\theta+d\theta)]\}$. From the monotonicity condition (3.19) below, this implies a lower level of extraction, i.e., installation of a smaller capacity (smaller or fewer platforms) or a less extensive use of extraction enhancing techniques in the production phase (e.g., injections). An interpretation of the rent expression, equation (3.16) below, therefore, is that to get incentive compatibility, the partnership group, when they reveal their true type, is rewarded with the rent they would get if they instead were to mimic a marginally less efficient type. It therefore follows that for the two types θ and $\theta + d\theta$, the difference in rent is equal to the cost advantage (in net present value terms) of type θ relative to type $\theta + d\theta$. Type θ can masquerade as type $\theta + d\theta$ by producing $q_t(\theta + d\theta)$ at cost $C(q_t(\theta + d\theta), \theta), t = 1,2$. By inserting into the profit function (3.11), we see that relative to type $\theta + d\theta$, this strategy yields a rent equal to

(3.13) $$\Pi(\theta)-\Pi(\theta+d\theta)=[C(q_1(\theta+d\theta),\theta+d\theta,S_1)-C(q_1(\theta+d\theta),\theta,S_1)]+ \delta[C(q_2(\theta+d\theta),\theta+d\theta,S_2)-C(q_2(\theta+d\theta),\theta,S_2)].$$

Taking the limit of (3.13), letting $d\theta$ approach zero, we get the incentive constraint (3.12). As this local incentive constraint is binding, i.e. type θ is indifferent between announcing θ and $\theta+d\theta$, the same rent difference will appear when the partnership announces its true type (a separating equilibrium). From this it follows that the total rent of a producer of type θ must be given by a cumulation of cost differences, as is clear from equation (3.16) below.

Integrating both sides of equation (3.12), yields

(3.14) $$\int_{\theta}^{\bar{\theta}}\frac{d\Pi(\tilde{\theta})}{d\tilde{\theta}}d\tilde{\theta}=-\int_{\theta}^{\bar{\theta}}\left\{\frac{\partial C(q_1(\tilde{\theta}),\tilde{\theta},S_1)}{\partial\tilde{\theta}}+\delta\frac{\partial C(q_2(\tilde{\theta}),\tilde{\theta},S_2)}{\partial\tilde{\theta}}\right\}d\tilde{\theta},$$

or

(3.15) $$\Pi(\theta)=\Pi(\bar{\theta})+\int_{\theta}^{\bar{\theta}}\left\{\frac{\partial C(q_1(\tilde{\theta}),\tilde{\theta},S_1)}{\partial\tilde{\theta}}+\delta\frac{\partial C(q_2(\tilde{\theta}),\tilde{\theta},S_2)}{\partial\tilde{\theta}}\right\}d\tilde{\theta}.$$

By assumption A1, $C(q_t,\theta,S_t)$ is increasing in θ. If the participation constraint, equation (3.4), is satisfied for type $\theta=\bar{\theta}$, it is therefore satisfied for all $\theta\in[\underline{\theta},\bar{\theta}]$. Since MIE wants to extract rent, the participation constraint will be binding for type $\theta=\bar{\theta}$. Hence, the set of participation constraints in equation (3.4) is reduced to the single constraint $\Pi(\bar{\theta})=0$. By combining the first order condition for incentive compatibility, equation (3.15), and the participation constraint, we get

(3.16) $$\Pi(\theta)=\int_{\theta}^{\bar{\theta}}\left\{\frac{\partial C(q_1(\tilde{\theta}),\tilde{\theta},S_1)}{\partial\tilde{\theta}}+\delta\frac{\partial C(q_2(\tilde{\theta}),\tilde{\theta},S_2)}{\partial\tilde{\theta}}\right\}d\tilde{\theta}.$$

Defining $R(\theta)\equiv R_1(\theta)+\delta R_2(\theta)$, we have

(3.17) $$\Pi(\theta)=p_1q_1(\theta)-C(q_1(\theta),\theta,S_1)\ +\delta[p_2q_2(\theta)-C(q_2(\theta),\theta,S_2)]-R(\theta).$$

By combining (3.16) and (3.17), I get

(3.18) $$R(\theta)=p_1q_1(\theta)-C(q_1(\theta),\theta,S_1)+\delta[p_2q_2(\theta)-C(q_2(\theta),\theta,S_2)]$$

$$-\int_{\theta}^{\bar{\theta}}\left\{\frac{\partial C(q_1(\tilde{\theta}),\tilde{\theta},S_1)}{\partial\tilde{\theta}}+\delta\frac{\partial C(q_2(\tilde{\theta}),\tilde{\theta},S_2)}{\partial\tilde{\theta}}\right\}d\tilde{\theta}.$$

Following the same procedure as in section 2.5 for the static case, we find that the second-order condition for incentive compatibility implies a dynamic monotonicity constraint:

(3.19) $$\frac{d}{d\theta}\{q_1(\theta)+\delta q_2(\theta)\}\leq 0$$

I have shown that the class of mechanisms satisfying the incentive and the participation constraints, is composed of those policies in which the quantities of extraction are non-increasing in type, and where the fixed government charge $R(\theta)$ satisfies (3.18).

As shown, the rent function (3.16) combines the participation constraint and the first order condition for incentive compatibility. Inserting for this rent expression in the objective function (3.9), the expected welfare is given by

$$EW = \int_{\underline{\theta}}^{\bar{\theta}} \{(1+\lambda)[p_1 q_1(\theta) - C(q_1(\theta),\theta,S_1) + \delta(p_2 q_2(\theta) - C(q_2(\theta),\theta,S_2))] \tag{3.20}$$

$$-(\lambda+\mu)\int_{\theta}^{\bar{\theta}} \left\{\frac{\partial C(q_1(\tilde{\theta}),\tilde{\theta},S_1)}{\partial\tilde{\theta}} + \delta\frac{\partial C(q_2(\tilde{\theta}),\tilde{\theta},S_2)}{\partial\tilde{\theta}}\right\} d\tilde{\theta}\Bigg\} f(\theta)d\theta.$$

By integrating by parts in the last term, (3.20) can be rewritten as

$$EW = \int_{\underline{\theta}}^{\bar{\theta}} \{(1+\lambda)[p_1 q_1(\theta) - C(q_1(\theta),\theta,S_1) + \delta(p_2 q_2(\theta) - C(q_2(\theta),\theta,S_2))] \tag{3.21}$$

$$-(\lambda+\mu)\left[\frac{\partial C(q_1(\theta),\theta,S_1)}{\partial\theta} + \delta\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial\theta}\right]\frac{F(\theta)}{f(\theta)}\Bigg\} f(\theta)d\theta$$

The regulatory problem is now reduced to maximising the expected welfare, equation (3.21), subject to the dynamic monotonicity constraint (3.19) and the resource constraint (3.5). As in the symmetric information case, the resource constraint will be non-binding for all producer types, due to assumption A4 of asymptotic costs. I will ignore the dynamic monotonicity constraint at first, and later, in appendix 3.2, show that the solution to the less constrained problem satisfies this condition. I am now left with an unconstrained optimisation problem. An implicit expression for the optimal exploration path $\{q_1^*(\theta), q_2^*(\theta)\}$, is found by pointwise differentiation of the expected welfare, equation (3.21), with respect to $q_1(\theta)$ and $q_2(\theta)$:

(3.22)

$$p_1 - \frac{\partial C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)} + \delta\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial S_2} = \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\left(\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial\theta\partial q_1(\theta)} - \delta\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial S_2}\right)$$

$$p_2 - \frac{\partial C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)} = \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial q_2(\theta)} \tag{3.23}$$

Second order conditions are given in appendix 3.3.

We recognise condition (3.23) from the static model of chapter 2. For a non-binding resource constraint, condition (3.23) is equal to condition (2.46). There is a wedge between price and marginal extraction costs, equal to the marginal information costs. As a means of enhanced rent extraction, for all types $\theta > \underline{\theta}$ extraction is reduced relative to the first best (symmetric information case).[15] The extraction level is distorted to the point where the expected value-weighted marginal deadweight loss in production equals the expected marginal reduction in deadweight loss in other sectors of the economy, made possible by the increase in government take from the petroleum sector. This is more thoroughly discussed in section 2.5.

Proposition 3.1
It is not optimal to repeat the static contract. Optimal petroleum regulation will involve distortions of both the extent and the pace of depletion.

The first order condition determining $q_1(\theta)$ has a structure similar to (3.23), but contains two additional terms. Optimal dynamic regulation of the manufacturing industry under full commitment, is to repeat the optimal static scheme in each period; see Baron and Besanko [1984] and Laffont and Tirole [1993], section 1.10. Due to the inter-period link in extraction costs derived from changes in the reservoir pressure, the optimal contracts for the petroleum industry will differ in the two periods. This is clear from comparison of conditions (3.22) and (3.23). As a special case, by ignoring the intertemporal cost dependency from the model of this chapter, we get results analogously to Baron and Besanko [1984] and Laffont and Tirole [1993]. This is done by eliminating the stock effect, i.e., by letting $\partial C(q_2(\theta),\theta,S_2) / \partial S_2$ $= \partial^2 C(q_2(\theta),\theta,S_2) / \partial\theta\partial S_2 = 0$. Condition (3.22), the first period optimum, will now be reduced to the static contract, parallel to equation (3.23).

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15 This is clear by comparing conditions (3.8) and (3.23).

To give a more detailed interpretation of the first order conditions of the regulatory problem, I need to define the single crossing property for a dynamic model. In a two-period model, for the net present cost $\mathrm{C}(q,\theta,S) \equiv C(q_1(\theta),\theta,S_1) + \delta C(q_2(\theta),\theta,S_2)$, the single crossing property can be stated as

$$(3.24) \qquad \frac{\partial}{\partial\theta}\frac{d\mathrm{C}(q,\theta,S)}{dq_t} > 0, \quad t = 1,2.$$ [16]

The distortion of the second period extraction level is due to the fact that the partnership's rent is increasing in $q_2(\theta)$, as is clear from the rent expression (3.16):

$$(3.25) \qquad \frac{d\Pi(\theta)}{dq_2(\theta)} = \int_{\theta}^{\bar{\theta}} \frac{\partial^2 C(q_2(\tilde{\theta}),\tilde{\theta},S_2)}{\partial q_2(\tilde{\theta})\partial\tilde{\theta}} d\tilde{\theta} > 0.$$

We recognise the integrand in (3.25) from the marginal information cost (the right hand side of condition (3.23)). In the same manner as in the static model, the sign is determined by the single crossing property (3.24), which for $t = 2$ reduces to

$$(3.26) \qquad \frac{\partial^2 C(q_2(\tilde{\theta}),\tilde{\theta},S_2)}{\partial q_2(\tilde{\theta})\partial\tilde{\theta}} > 0,$$

see assumption A2.

For the first period, we get

$$(3.27) \qquad \frac{d\Pi(\theta)}{dq_1(\theta)} = \int_{\theta}^{\bar{\theta}} \left[\frac{\partial^2 C(q_1(\tilde{\theta}),\tilde{\theta},S_1)}{\partial q_1(\tilde{\theta})\partial\tilde{\theta}} - \delta \frac{C(q_2(\tilde{\theta}),\tilde{\theta},S_2)}{\partial S_2 \partial\tilde{\theta}} \right] d\tilde{\theta} > 0.$$

[16] This is a sufficient condition for the iso-NPV curves for different partnership types to cross only once.

The sign is again determined by (3.24), the single crossing property, which in this case ($t = 1$) contains two terms:

(3.28) $$\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)\partial\theta} - \delta\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial S_2\partial\theta} > 0$$

Assuming the static condition, $\partial^2 C(q_1(\theta),\theta,S_1) / \partial q_1(\theta)\partial\theta > 0$, is satisfied (assumption A2), a sufficient (but not necessary) additional condition for the dynamic single crossing property (3.28) to hold, is $\partial^2 C(q_2(\theta),\theta,S_2) / \partial S_2\partial\theta < 0$ (assumption A7). As explained in section 3.2, assumptions A2 and A7 have plausible economic explanations. Again, the integrand, equation (3.27), is part of the marginal information cost at the right hand side of condition (3.22). Comparing with the symmetric information case (condition (3.7)), $q_1(\theta)$ is reduced to enhance rent extraction. As for $q_2(\theta)$, the economic explanation for this distortion in $q_1(\theta)$ is that it makes it less favourable for efficient companies to mimic inefficient companies, made clear by equation (3.27). The economic interpretation is that the dynamic single crossing property, condition (3.24), implies that the marginal extraction costs (direct costs and indirect costs caused by the stock effect) are increasing in θ. Hence, a producer of type θ has lower marginal costs than a type $\theta + d\theta$. Therefore, the relative cost advantage of type θ (in net present value),

(3.29)
$$[C(q_1(\theta+d\theta),\theta+d\theta)+\delta C(q_2(\theta+d\theta),\theta+d\theta)]-[C(q_1(\theta+d\theta),\theta)+\delta C(q_2(\theta+d\theta),\theta)],$$

i.e., the difference in information rent, is increasing in $q_1(\theta)$.

Comparing with the symmetric information case of section three, we see that asymmetric information causes the production levels to be reduced in both periods. Due to assumption A7 that marginal indirect costs caused by the stock effect are increasing in θ, however, first period production is likely to suffer the biggest reduction. Asymmetric information, therefore, not only reduces the extent of extraction, but also slows down the pace of depletion.

3.5 IMPLEMENTATION

In developing an optimal contract for petroleum regulation, I have used the revelation approach, i.e., the Ministry of Industry and Energy is assumed to offer the petroleum companies a revelation mechanism $M=\{[(q_1(\theta),R_1(\theta)],[(q_2(\theta),R_2(\theta)],\theta\in[\underline{\theta},\overline{\theta}]\}$. Since the optimal mechanism satisfies incentive compatibility, the partnership will report their true cost parameter θ, in response to which they will be instructed to follow an extraction path determined by equations (3.22) and (3.23), and pay net taxes according to equation (3.18). Comparing this contract with present systems for petroleum taxation is difficult, since direct revelation mechanisms are rarely used. The optimal contract, however, can be given an alternative implementation that is similar to present petroleum tax schemes; net taxes as a function of the selected production levels. The implementation of this dual regulatory problem is termed the delegation approach, since the pace of extraction is left for the partnership to decide. As shown in appendix 3.2, $q_1(\theta)$ and $q_2(\theta)$ are strictly decreasing for all types (monotonicity), and can thus be inverted; $\theta(q_1)$ and $\theta(q_2)$. I substitute for these functions in (3.18):

$$(3.30)\qquad \begin{aligned} T(q_1,q_2)\equiv R(\theta(q_1),\theta(q_2)) = p_1q_1 - C(q_1,\theta(q_1),S_1) \\ + \delta[p_2q_2 - C(q_2,\theta(q_2),S_2)] - \Pi(\theta(q_1),\theta(q_2)) \end{aligned}$$

The optimal net tax is now a function of the extraction levels; $T(q_1,q_2)$. The second best allocation of this chapter, given by conditions (3.22) and (3.23), therefore, can be implemented by designing a tax system that generates the functional form for intertemporal net taxes given by equation (3.30).

Dasgupta, Heal and Stiglitz [1980] show that petroleum taxation can be used to realise all types of extraction paths. The only tax instruments required is a tax on profits and a depletion allowance. In formulating their model, however, they make the restrictive assumption that costs are independent of the rate of extraction. Their results, therefore, do not directly apply to my model, as it contains a stock effect. By adding some instruments, I find it reasonable to assume that the optimal contract derived in this chapter can be implemented by means of taxation policy, i.e., the government should be able to replicate the net tax function (3.30).

In the static model of chapter 2, by an analogous application of Laffont and Tirole [1993], section 1.4, I showed that the optimal regulatory outcome can be implemented by a simple menu of linear contracts, composed of royalties and license fees. In a two-period model of procurement under asymmetric information, Laffont and Tirole [1993], appendix 8.2, it is shown that the optimal allocation can be implemented by two separate menus of linear incentive schemes, one for each period. In the dynamic model of petroleum taxation, this implementation is not possible, due to the non-stationarity imposed by the intertemporal link in extraction costs (stock effect). I will show, however, that optimal tax policy may still consist of royalties and license fees. By a generalisation of Laffont and Tirole [1993], appendix 8.2, I obtain the following result:

Proposition 3.2

The optimal contract can be implemented by a menu of tangent planes, generated by license fees and royalties in each period. To account for the dynamics in extraction costs, the partnership must be presented the tax scheme for the entire horizon at the beginning of period one. It cannot sequentially be offered separate single period contracts.

As shown in appendix 3.4, the net tax function $T(q_1,q_2)$ is strictly concave if either the single period cost functions are strongly convex or if there is a rapidly decreasing return in remaining stock. These are the same type of requirements securing sufficient conditions for the primal regulatory problem, see appendix 3.3. As argued in section 3.2, the convexity of the single period costs $C(q_t(\theta),\theta,S_t)$, assumption A3, coincides with geological experience of a more rapid decline of the driving reservoir pressure the more rapid is the pace of extraction. In the following, therefore, I will assume that $T(q_1,q_2)$ is a strictly concave function.

As illustrated in figure 3.1 below, the net tax function can in this case be replaced by the family of its tangent planes.[17] The partnerships choose the tax-production bundles where their iso-NPV curves are tangent to the net tax plane (self selection). The partnerships' selection is the same whether it is offered the concave net tax function or its set of tangent planes.

The optimal regulatory policy, therefore, can be implemented by a menu of tangent planes, written in vector notation:

$$R(\hat{\theta},\mathbf{q}) - R^*(\hat{\theta}) = \nabla T(\mathbf{q}^*)(\mathbf{q}-\mathbf{q}^*), \tag{3.31}$$

where $\mathbf{q}^*$ and $R^*(\hat{\theta})$ are the extraction levels and the net total government take, determined by the optimal mechanism (equations (3.22), (3.23) and (3.18), respectively). Inserting for the gradient

$$\begin{aligned}\nabla T(\mathbf{q}^*) &= \left(\frac{\partial T(\mathbf{q}^*)}{\partial q_1^*},\frac{\partial T(\mathbf{q}^*)}{\partial q_2^*}\right)\\ &= \left(p_1 - \frac{\partial C(q_1^*(\hat{\theta}),\theta,S_1)}{\partial q_1^*} + \delta\frac{\partial C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial S_2^*},\delta(p_2 - \frac{\partial C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial q_2^*})\right),\end{aligned} \tag{3.32}$$

[17] I am thankful to Lars Håkonsen for diagram design.

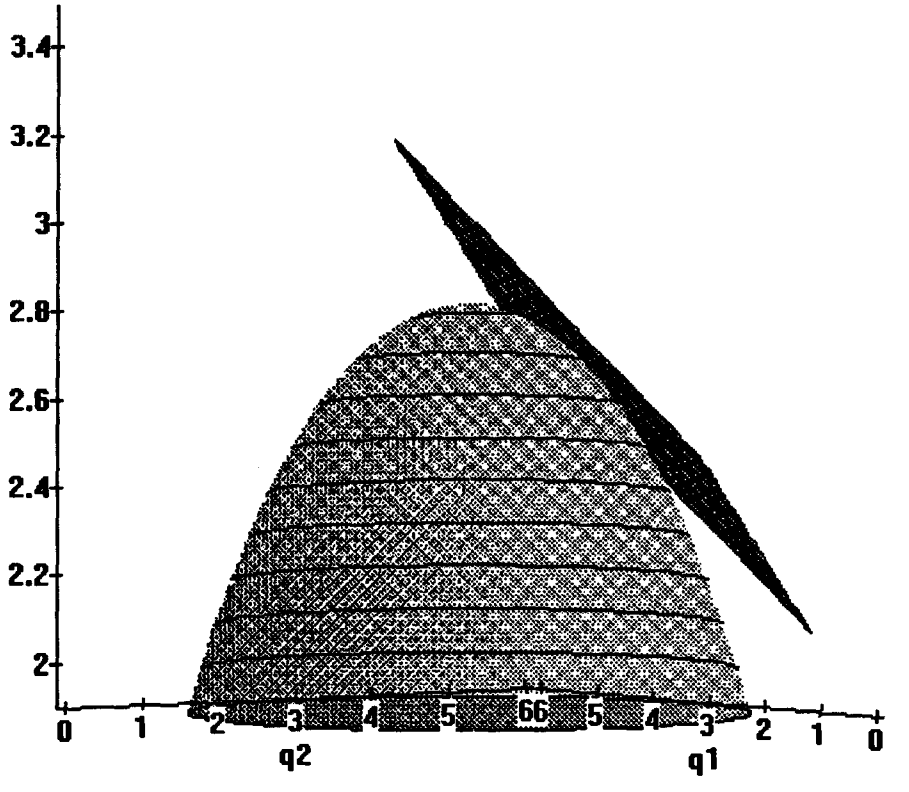

Figure 3.1: Implementation of a concave net tax function by a menu of tangent planes.

the menu of tangent planes can be written out as

$$(3.33)\quad \begin{aligned} R(\hat{\theta},q_1,q_2) &= R^*(\hat{\theta})+[p_1-\frac{\partial C(q_1^*(\hat{\theta}),\theta,S_1)}{\partial q_1^*}+\delta\frac{\partial C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial S_2^*}](q_1-q_1^*(\hat{\theta})) \\ &+\delta[p_2-\frac{\partial C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial q_2^*}](q_2-q_2^*(\hat{\theta})) \end{aligned}$$

In the language of petroleum taxation, we have

$$(3.34)\quad Net\ tax = License\ Fee + Royalty_1\times q_1 + Royalty_2\times q_2,$$

where

$$(3.35)\quad \begin{aligned} License\ Fee &= R^*(\hat{\theta})-[p_1-\frac{\partial C(q_1^*(\hat{\theta}),\theta,S_1)}{\partial q_1^*}+\delta\frac{\partial C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial S_2^*}]q_1^*(\hat{\theta}) \\ &-\delta[p_2-\frac{\partial C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial q_2^*}]q_2^*(\hat{\theta}) \end{aligned}$$

$$(3.36)\quad Royalty_1 = p_1-\frac{\partial C(q_1^*(\hat{\theta}),\theta,S_1)}{\partial q_1^*}+\delta\frac{\partial C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial S_2^*}$$

$$(3.37)\quad Royalty_2 = \delta(p_2-\frac{\partial C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial q_2^*})$$

From (3.36) we see that $Royalty_1$ depends on the optimal extraction level in period two, i.e., the optimal depletion path cannot be implemented by a sequence of static contracts. To account for the intertemporal link in extraction costs, extraction levels for both periods must be set simultaneously at the beginning of period one. Equation (3.35) specifies a license fee at the beginning of the first period. Alternatively, we may have a license fee in each period, where their discounted sum satisfies (3.35).

Using the conditions for the optimal allocation, equations (3.22) and (3.23), the royalties can be rewritten as

$$(3.38) \qquad Royalty_1 = \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\left(\frac{\partial^2 C(q_1^*(\hat{\theta}),\theta,S_1)}{\partial\theta\partial q_1^*} - \delta\frac{\partial^2 C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial\theta\partial S_2^*}\right)$$

$$(3.39) \qquad Royalty_2 = \delta\left(\frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q_2^*(\hat{\theta}),\theta,S_2^*)}{\partial\theta\partial q_2^*}\right)$$

In the symmetric information case, as shown in section 3.3, first best optimal regulation implies neutral taxation. As made clear in section 3.4, the optimal regulatory response to asymmetric cost information is to distort (reduce) the production levels for all types $\theta > \underline{\theta}$, in order to enhance rent extraction. This second best allocation is implemented by levying royalties for all types but the most efficient. The most efficient producer is only faced with a license fee, and will therefore choose the first best extraction level (no distortion on the top).

The regulatory agency is not able to reach the first best for the types $\theta > \underline{\theta}$, since it has no taxes that are both neutral and revenue effective at its disposal. The explanation is evident; with asymmetric information about costs, the regulatory agency is not able to observe true profits or the true cash flow. By strategic reporting of costs the partnership is able to manipulate the tax base, i.e., these taxes are non-neutral.[18] The net tax of the asymmetric information model is instead made contingent on observable variables, namely the extraction levels chosen by the partnership.

As is clear from (3.38) and (3.39), the royalties are equal to the marginal information costs in optimum. In this sence they are similar to Pigouvian taxes. Comparing $Royalty_1$ and $Royalty_2$, we see that they differ. This is due to the assumption that the intertemporal link in extraction costs is systematically type-dependent, see assumption A7 and the discussion of dynamic single crossing in section 3.4. Hence, it is optimal to distort both the extent and the

18 In the discussion of the resource rent tax proposed by Garnaut and Ross [1975], it has been pointed out that the neutrality rests on the government being able to observe the company's cost of capital. Clearly, symmetric information about operating costs is also required.

pace of extraction. The first is achieved by imposing royalties, and the latter is secured by letting the royalties differ among the periods. Comparing (3.38) and (3.39) we see that the first period royalty is likely to be higher than the royalty in the second period, i.e. the rate of depletion is reduced. The economic explanation was given in section 3.4: The rent of an efficient producer group is derived from its cost advantage, in net present value terms. From the single crossing assumptions, this cost advantage is increasing in the extraction levels. To capture more of the rent, therefore, it is optimal (by means of distortive royalties) to reduce extraction. It is relatively more important to reduce the first period extraction level (implemented by setting $Royalty_1 > Royalty_2$), since it through the stock effect affects extraction costs in both periods.

To verify that (3.33) induces revelation ($\hat{\theta} = \theta$) and the appropriate extraction path $\{q_1^*, q_2^*\}$, I will analyse the partnership's optimisation program when facing this menu of hyperplanes:

(3.40)
$$\begin{aligned} &\underset{q_1, q_2, \hat{\theta}}{Max}\{p_1 q_1(\theta) - C(q_1(\theta), \theta, S_1) + \delta[p_2 q_2(\theta) - C(q_2(\theta), \theta, S_2)] \\ &-R^*(\hat{\theta}) - [p_1 - \frac{\partial C(q_1^*(\hat{\theta}), \theta, S_1)}{\partial q_1^*} + \delta \frac{\partial C(q_2^*(\hat{\theta}), \theta, S_2^*)}{\partial S_2^*}](q_1 - q_1^*(\hat{\theta})) \\ &-\delta[p_2 - \frac{\partial C(q_2^*(\hat{\theta}), \theta, S_2^*)}{\partial q_2^*}](q_2 - q_2^*(\hat{\theta}))\} \end{aligned}$$

The first-order conditions are

(3.41)
$$[p_1 - \frac{\partial C(q_1(\theta), \theta, S_1)}{\partial q_1} + \delta \frac{\partial C(q_2(\theta), \theta, S_2)}{\partial S_2}] - [p_1 - \frac{\partial C(q_1^*(\hat{\theta}), \theta, S_1)}{\partial q_1^*} + \delta \frac{\partial C(q_2^*(\hat{\theta}), \theta, S_2^*)}{\partial S_2^*}] = 0$$

(3.42)
$$\delta[p_2 - \frac{\partial C(q_2(\theta), \theta, S_2)}{\partial q_2}] - \delta[p_2 - \frac{\partial C(q_2^*(\hat{\theta}), \theta, S_2^*)}{\partial q_2^*}] = 0$$

$$
\begin{aligned}
(3.43)\qquad & -\frac{dR^*(\hat\theta)}{d\hat\theta}+[p_1-\frac{\partial C(q_1^*(\hat\theta),\theta,S_1)}{\partial q_1^*}+\delta\frac{\partial C(q_2^*(\hat\theta),\theta,S_2^*)}{\partial S_2^*}]\frac{dq_1^*(\hat\theta)}{d\hat\theta} \\
& +[\frac{\partial^2 C(q_1^*(\hat\theta),\theta,S_1^*)}{\partial q_1^{*2}}+\delta\frac{\partial^2 C(q_2^*(\hat\theta),\theta,S_2^*)}{\partial S_2^{*2}}]\frac{dq_1^*(\hat\theta)}{d\hat\theta}(q_1-q_1^*(\hat\theta)) \\
& +\delta[p_2-\frac{\partial C(q_2^*(\hat\theta),\theta,S_2^*)}{\partial q_2^*}]\frac{dq_2^*(\hat\theta)}{d\hat\theta} \\
& +\delta[\frac{\partial^2 C(q_2^*(\hat\theta),\theta,S_2^*)}{\partial q_2^{*2}}\frac{dq_2^*(\hat\theta)}{d\hat\theta}-\frac{\partial^2 C(q_2^*(\hat\theta),\theta,S_2^*)}{\partial q_2^*\partial S_2^*}\frac{dq_1^*(\hat\theta)}{d\hat\theta}](q_2-q_2^*(\hat\theta))=0
\end{aligned}
$$

The first term in condition (3.43), can be calculated from equation (3.18):

(3.44)

$$
\frac{dR^*(\hat\theta)}{d\hat\theta}=[p_1-\frac{\partial C(q_1^*(\hat\theta),\theta,S_1)}{\partial q_1^*}+\delta\frac{\partial C(q_2^*(\hat\theta),\theta,S_2^*)}{\partial S_2^*}]\frac{dq_1^*(\hat\theta)}{d\hat\theta}+\delta[p_2-\frac{\partial C(q_2^*(\hat\theta),\theta,S_2^*)}{\partial q_2^*}]\frac{dq_2^*(\hat\theta)}{d\hat\theta}
$$

After inserting equation (3.44) into condition (3.43), it is easy to check by substitution that $\{q_1^*,q_2^*,\theta\}$ solves the equation system (3.41)-(3.43).

APPENDIXES

Appendix 3.1

The second-order conditions of the symmetric information case are:

A(3.1) $$\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)^2} > -\delta \frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial S_2{}^2}$$

A(3.2) $$\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)^2} > 0$$

Condition A(3.2) is satisfied by assumption A3 of convex extraction costs. Condition A(3.1) requires the additional assumption that extraction costs, in present value terms, is more convex in first period extraction level than in the consequent declining stock (or, put differently, net present costs are more convex in the direct than in the indirect effect).

■

Appendix 3.2

By applying the implicit function theorem, I will show that the solution to the regulatory problem under full commitment satisfies the dynamic monotonicity condition

A(3.3) $$\frac{d}{d\theta}\{q_1(\theta)+\delta q_2(\theta)\} \le 0.$$

A sufficient condition for this constraint to be satisfied is

A(3.4) $$\frac{dq_1(\theta)}{d\theta} \le 0 \text{ and } \frac{dq_2(\theta)}{d\theta} \le 0$$

As explained, the second period decision problem is equivalent to the static problem. Hence, we already know that $dq_2(\theta)/d\theta \le 0$ is satisfied, see appendix 2.3.

By applying the implicit function theorem I will now show that the solution to the regulatory problem also satisfies the first period monotonicity condition, $dq_1(\theta)/d\theta \le 0$. Equation (3.22) defines q_1 as an implicit function of θ:

A(3.5) $$G(\theta, q_1) = p_1 - \frac{\partial C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)} + \delta \frac{\partial C(q_2(\theta),\theta,S_2)}{\partial S_2} - \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\left(\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial\theta\partial q_1(\theta)} - \delta\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial S_2}\right) = 0,$$

since we from assumptions A3 and A8 have

A(3.6) $$G_{q_1} = -\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)^2} - \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^3 C(q_1(\theta),\theta,S_1)}{\partial\theta\partial q_1(\theta)^2} < 0.$$

Hence, the derivative is given by

A(3.7) $$\frac{dq_1(\theta)}{d\theta} = -\frac{G_\theta}{G_{q_1}} = -\left\{\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial\theta\partial q_1(\theta)} - \delta\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial S_2} + \frac{\lambda+\mu}{1+\lambda}\frac{d}{d\theta}\left(\frac{F(\theta)}{f(\theta)}\right)\left[\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial\theta\partial q_1(\theta)} - \delta\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial S_2\partial\theta}\right] + \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\left[\frac{\partial^3 C(q_1(\theta),\theta,S_1)}{\partial\theta^2\partial q_1(\theta)} - \delta\frac{\partial^3 C(q_2(\theta),\theta,S_2)}{\partial S_2\partial\theta^2}\right]\right\} / \left\{\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)^2} + \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^3 C(q_1(\theta),\theta,S_1)}{\partial\theta\partial q_1(\theta)^2}\right\},$$

which is strictly negative due to assumptions A2, A3, A7, A8 and A9.

■

Appendix 3.3

I will check the sufficient conditions for a unique solution to the regulatory problem. The sufficient condition is that the welfare function (3.21) is strictly concave in $(q_1(\theta), q_2(\theta))$ for all θ, or, expressed with the principal minors of the Hessian matrix:

A(3.8) $$W_{q_1 q_1} < 0$$

A(3.9) $$W_{q_2 q_2} < 0$$

A(3.10) $$\begin{vmatrix} W_{q_1 q_1} & W_{q_1 q_2} \\ W_{q_2 q_1} & W_{q_2 q_2} \end{vmatrix} > 0.$$

Derivating the first order conditions, (3.22) and (3.23), yields

A(3.11) $$W_{q_1 q_1} = -(1+\lambda)\left\{ \frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)^2} + \frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial S_2{}^2} \right\} - (\lambda+\mu)\left\{ \frac{\partial^3 C(q_1(\theta),\theta,S_1)}{\partial\theta\partial q_1(\theta)^2} + \delta \frac{\partial^3 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial S_2{}^2} \right\} < 0$$

A(3.12) $$W_{q_2 q_2} = -(1+\lambda)\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)^2} - (\lambda+\mu)\frac{\partial^3 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial q_2(\theta)^2}\frac{F(\theta)}{f(\theta)} < 0$$

A(3.13) $$\begin{vmatrix} W_{q_1 q_1} & W_{q_1 q_2} \\ W_{q_2 q_1} & W_{q_2 q_2} \end{vmatrix} = W_{q_1 q_1} W_{q_2 q_2} - \left(W_{q_2 q_1}\right)^2 > 0$$

A(3.11) is satisfied by assumptions A3, A6 and A8, and A(3.12) is satisfied by assumptions A3 and A8. Condition A(3.13), however, is not so obvious. Written in its complete form, it requires

A(3.14)

$$(1+\lambda)^2\delta\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)^2}\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)^2}+(1+\lambda)\delta^2\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial S_2{}^2}\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)^2}>$$

$$(1+\lambda)^2\delta^2\left(\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)\partial S_2}\right)^2+2(1+\lambda)(\lambda+\mu)\delta^2\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)\partial S_2}\frac{\partial^3 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial q_2(\theta)\partial S_2}\frac{F(\theta)}{f(\theta)}$$

$$+(\lambda+\mu)^2\delta^2\left(\frac{F(\theta)}{f(\theta)}\right)^2\frac{\partial^3 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial q_2(\theta)\partial S_2}$$

From the left hand side of A(3.14) we see that the condition is likely to be satisfied if either the single period cost functions are strongly convex or if there is a rapidly decreasing return in stock. As argued in section 3.2, the convexity of the single period costs $C(q_t(\theta),\theta,S_t)$, assumption A3, coincides with geological experience of a more rapid decline of the driving reservoir pressure the more rapid is the pace of extraction.

■

Appendix 3.4

I will check the sufficient conditions for strict concavity of the net tax function $T(q_1,q_2)$, expressed with the principal minors of the Hessian matrix:

A(3.15) $$T_{q_1q_1}=-\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)^2}-\delta\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial S_2{}^2}<0$$

A(3.16) $$T_{q_2q_2} = -\delta \frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)^2} < 0$$

A(3.17) $$\begin{vmatrix} T_{q_1q_1} & T_{q_1q_2} \\ T_{q_2q_1} & T_{q_2q_2} \end{vmatrix} > 0,$$

In calculating $T_{q_1q_1}$ and $T_{q_2q_2}$, I make use of equation (3.30). A(3.15) is satisfied by assumptions A3 and A6, and A(3.16) is satisfied by assumption A3. Condition A(3.17) is more complex. Written in its complete form, it requires

A(3.18)

$$\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)^2}\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)^2} + \delta\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial S_2{}^2}\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial q_2{}^2} > \delta\left(\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)\partial S_2}\right)^2$$

Condition A(3.18) resembles one of the conditions for a unique solution to the regulatory problem; condition A(3.14). From the left hand side of A(3.18) we see that the condition is likely to be satisfied if either the single period cost functions are strongly convex or if there is a rapidly decreasing return in stock. These are the same requirements securing sufficient conditions for the primal regulatory problem, see appendix 3.3.

■

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Chapter 4

Adverse selection and moral hazard in the petroleum industry, repeated auctions of incentive contracts*

4.1 INTRODUCTION

In section 2.11 I discuss how the government can improve the regulatory outcome in the petroleum sector by utilising competition ex ante or ex post, i.e., before or after awarding the production license. In this chapter of repeated auctions, I provide models of ex post competition.

Laffont and Tirole [1993], chapter 8, analyse repeated auctions in procurement; a regulated monopolist may be replaced if performance is poor. The Chicago school (e.g., Demsetz [1968]) suggests repeated bidding, and at any point in time awarding the monopoly franchise

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to the bidder with the best terms (bidding parity). Inspired by Williamson [1976], Laffont and Tirole [1993] show that in case of transferable and unobservable investment, bidding parity does not apply; the second-sourcing auction should to some extent be biased in favour of the incumbent. By raising the incumbent's probability of keeping the franchise in the second period, the problem of underinvestment is mitigated.

The topic of this chapter is interactions between incentive schemes and optimal policy of replacing license groups with low efficiency or low production. By introducing non-verifiable investment (moral hazard) in a repeated game version of the dynamic model of petroleum regulation in chapter 3, I show that the biased auction result of Laffont and Tirole [1993] carries over to petroleum regulation. In addition, the model of Laffont and Tirole [1993] is generalised, from a fixed size to a variable size project, and with a slightly more general cost function. Thereafter, in an adverse selection model with asymmetric information about extraction levels, I show that it may be optimal to deviate from bidding parity even in the absence of moral hazard. If a producer group has some positive probability of being replaced in the second period, it will not fully internalise the stock effect. Again, it will be optimal to mitigate this effect by introducing a bias in the second period auction.

Once a petroleum license is awarded, the license group has an exclusive right to exploit the tract. Petroleum regulation, therefore, has some resemblance with regulation of natural monopolists in manufacturing. The monopoly position, along with a predictable and reasonable tax system, guarantees the partnership to reap some of the possible future profits. This is vital as to provide incentives for the partnership to sink large irreversible investments in extraction and transport facilities. If the performance is not adequate, however, the monopoly position will represent an obstacle for the regulatory agency, since the license cannot be transferred to a more efficient company. A problem of the monopoly position, particularly relevant to the petroleum industry, is that potential entrants may implement technological progress. Mismanagement can to some extent be avoided by contract design, e.g., letting the petroleum license contain clauses regulating the number of exploration wells.

As previously discussed in this monograph, however, due to asymmetric information, several vital factors contributing to the costs and the volume of petroleum production are non-contractible.[1] Examples are the inherent efficiency level, effort, non-monetary investments, and monetary investments that can be manipulated.

The problem of inadequate performance may be reduced by holding repeated auctions. The winner of the first auction is awarded the license for a limited number of years, after which a new auction is held. Thus, a poor performing license group may be replaced. A complicating element, pointed out by Williamson [1976], is that capital may be hard to transfer and measure. Physical capital, platforms and transport systems, are likely to be transferable, but human capital may not be so easy to transfer from one license group to another. Measurability is difficult for non-monetary investments, e.g. the quality of capital investments. As discussed in the previous chapters, by strategic reporting of costs, the petroleum companies are also able to conceal the true amount of monetary investments. This problem is particularly severe in the petroleum industry, due to its multinational nature (use of inputs from many countries makes it hard to check true costs) and due to the high degree of vertical integration (giving opportunities for transfer pricing).

In designing an optimal system for repeated auctions, therefore, the Ministry of Industry and Energy (MIE) must take into account that changing the license group may cause a loss of non-transferableinvestments. Furthermore, due to measurement problems, capital cannot be transferred at correct price. This will affect the willingness to invest.

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[1] I.e., they are non-observable to one of the contracting parties or non-verifiable by the courts.

4.2 THE MODEL

The model has two periods. In the first period an incentive contract is offered to a single license group; the incumbent. A possible justification is that initially only one license group possesses the adequate technology, competence, or resources to exploit the reservoir.[2] In the second period an auction is held, where the incumbent and another license group (the potential entrant) participates. The partnerships bid simultaneously by announcing efficiency parameters $\hat{\theta}$ and $\hat{\theta}'$, and the selected partnership is given an incentive contract similar to the monopoly case. MIE designs a breakout rule $\theta^*(\theta)$, where the potential entrant is awarded the license if $\theta' < \theta^*$. It is assumed that the government can avoid collusion. Investments are only made in the first period. The cost function is assumed to be additively separable in capital and extraction costs. The first and second period costs of the incumbent and the costs of the entrant, respectively, are given by

(4.1) $$C_1 = C(q_1(\theta), \theta, S_1) + d(i)$$

(4.2) $$C_2 = C(q_2(\theta), \theta, S_2) - i$$

(4.3) $$C' = C(q'(\theta), \theta, S_2) - ki,$$

where $d(i)$ $(d' > 0, d'' > 0)$ is first-period investment costs that reduces the incumbent's second period costs by i, and the entrant's costs by $ki (k \in [0,1]$, with $k = 0$ being a non-transferable (specific) and $k = 1$ being a fully transferable (general) capital). The extraction costs for the incumbent and the entrant have the same functional form $C(q, \theta, S)$, but differ

[2] Alternatively, the model can be generalised to allow for several companies competing in period one, where they are defeated due to inferior technology. In the second period, the competitors may have improved their technology.

with respect to the efficiency parameters; θ and θ' respectively. The investment level is not observable for the regulatory agency. The inherent efficiency parameters are private information for the incumbent and the entrant, and they are independently drawn from the same distribution $f(\theta)$. The assumptions of section 3.2 and the objective function of chapter 3 are maintained. MIE is assumed to be able to credibly commit to a regulatory contract for the entire horizon of exploration, development and extraction.

4.3 SYMMETRIC INFORMATION

The regulatory problem is to maximise an intertemporal welfare function [3]

(4.4)

$$\underset{q_1(\theta),q_2(\theta),q'(\theta'),i,\theta^*}{Max} \Big\{(1+\lambda)[p_1q_1(\theta)-C(q_1(\theta),\theta,S_1)-d(i)]-(\lambda+\mu)\Pi(\theta)$$
$$+\delta(1-F(\theta^*))(1+\lambda)[p_2q_2(\theta)-C(q_2(\theta),\theta,S_2)+i]$$
$$+\delta\int_{\underline{\theta}}^{\theta^*}\{(1+\lambda)[p_2q'(\theta')-C(q'(\theta'),\theta',S_2)+ki]-(\lambda+\mu)\Pi(\theta')\}f(\theta')d\theta'\Big\},$$

subject to a resource constraint and two sets of participation constraints:

(4.5) $$q_1+q_2+q'\leq K$$

(4.6) $$\Pi(\theta)\equiv\Pi(\theta,\theta)\geq 0, \quad \forall\theta\in[\underline{\theta},\overline{\theta}]$$

[3] The probability that the incumbent wins the second period auction is $(1-F(\theta^*))$.

(4.7) $$\Pi(\theta') \equiv \Pi(\theta',\theta') \geq 0, \qquad \forall \theta' \in [\underline{\theta},\overline{\theta}]$$

In the case of symmetric information, the instruments available to MIE are the extraction levels, the level of investment, and the breakout rule. Analogous to chapter 3, the participation constraints will bind, whereas the resource constraint is non-binding. Inserting for $\Pi(\theta) = \Pi(\theta') = 0$ in the objective function, and differentiating, the first order conditions are given by

(4.8)
$$p_1 - \frac{\partial C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)} + \delta(1-F(\theta^*))\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial S_2} + \delta\int_{\underline{\theta}}^{\theta^*}\frac{\partial C(q'(\theta'),\theta',S_2)}{\partial S_2}f(\theta')d\theta' = 0$$

(4.9) $$p_2 - \frac{\partial C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)} = 0$$

(4.10) $$p_2 - \frac{\partial C(q'(\theta'),\theta',S_2)}{\partial q'(\theta')} = 0$$

(4.11) $$d'(i) = \delta(1-F(\theta^*)) + \delta k F(\theta^*)$$

(4.12) $$p_2 q_2(\theta) - C(q_2(\theta),\theta,S_2) + i = p_2 q'(\theta^*) - C(q'(\theta^*),\theta^*,S_2) + ki$$

Condition (4.8) is analogous to conditions (3.7) and (4.9) and (4.10) are analogous to (3.8); price is equal to marginal extraction costs. The only difference is that that the opportunity cost (stock effect) in condition (4.8) now is given as an expected value. From condition (4.11) we see that the optimal investment level is where the marginal cost is equal to the expected benefit. From (4.12) we see that the critical breakout level θ^* is where the period two net total government take (i.e., the resource rent) is equalised for the two license groups, or, generally, the breakout level θ^* is determined by equality of net social value from the two bidders. This is a variable quantity generalisation of bidding parity. In the fixed size project model of Laffont and Tirole [1993], bidding parity is defined as a regulatory policy where the government selects the entrant if and only if the entrant's second-period efficiency exceeds the incumbent's. For general investments ($k=1$), this definition of bidding parity implies $\theta^* = \theta$. We would get the same result in this model, by setting $q_2 = q' = \bar{q}$. In a variable size model of petroleum regulation, however, condition (4.12) may be satisfied for constellations of cost parameters and extraction levels where $\theta^* \neq \theta$ and $q^* \neq q$.

As one may expect, non-transferability of investments works in favour of the incumbent. This can be shown by implicit derivation of condition (4.12):

$$\text{(4.13)} \qquad \frac{d\theta^*}{dk} = -\frac{i}{p_2 \dfrac{dq'(\theta^*)}{d\theta^*} - \dfrac{\partial C(q'(\theta^*),\theta^*,S_2)}{\partial \theta^*}},$$

which is positive due to the monotonicity constraint (see appendix 3.2) and assumption A1.

4.4 ASYMMETRIC INFORMATION ABOUT COSTS

The regulatory problem is now to maximise the expected intertemporal welfare

$$\text{(4.14)} \qquad \begin{aligned} EW = \int_{\underline{\theta}}^{\bar{\theta}} \{ & (1+\lambda)[p_1 q_1(\theta) - C(q_1(\theta),\theta,S_1) - d(i)] - (\lambda+\mu)\Pi(\theta) \\ & + \delta(1-F(\theta^*))(1+\lambda)[p_2 q_2(\theta) - C(q_2(\theta),\theta,S_2) + i] \\ & + \int_{\underline{\theta}}^{\theta^*} \{(1+\lambda)[p_2 q'(\theta') - C(q'(\theta'),\theta',S_2) + ki] \\ & - (\lambda+\mu)\Pi(\theta')\} f(\theta')d\theta' \} f(\theta)d\theta, \end{aligned}$$

subject to

(4.6) $$\Pi(\theta) \equiv \Pi(\theta, \theta) \geq 0, \qquad \forall \theta \in [\underline{\theta}, \overline{\theta}]$$

(4.7) $$\Pi(\theta') \equiv \Pi(\theta', \theta') \geq 0, \qquad \forall \theta' \in [\underline{\theta}, \overline{\theta}]$$

(4.15) $$\Pi(\theta) \geq \Pi(\hat{\theta}, \theta), \qquad \forall \hat{\theta}, \theta \in [\underline{\theta}, \overline{\theta}]$$

(4.16) $$\Pi(\theta') \geq \Pi(\hat{\theta}', \theta'), \qquad \forall \hat{\theta}', \theta' \in [\underline{\theta}, \overline{\theta}]$$

(4.5) $$q_1 + q_2 + q' \leq K$$

(4.17) $$-d'(i) + \delta(1 - F(\theta^*)) = 0$$

Asymmetric information concerning the intrinsic cost parameter generates an additional set of constraints; incentive constraints, given by equations (4.15) and (4.16). Non-observable investment imposes the moral hazard constraint (4.17). This constraint is the first order condition of the incumbent's investment problem:

(4.18) $$\underset{i}{Max}\left\{-d(i) + \delta(1 - F(\theta^*))i\right\}$$

In solving this program, I proceed in the same manner as in chapters 2 and 3. By combining the first order conditions for incentive compatibility and the participation constraints, for the incumbent and the entrant, respectively, we get the information rents :

(4.19)
$$\Pi(\theta)=\int_{\theta}^{\bar{\theta}}\left\{\frac{\partial C(q_1(\tilde{\theta}),\tilde{\theta},S_1)}{\partial\tilde{\theta}}+\delta(1-F(\theta^*))\frac{\partial C(q_2(\tilde{\theta}),\tilde{\theta},S_2)}{\partial\tilde{\theta}}\right\}d\tilde{\theta}$$

(4.20)
$$\Pi'(\theta')=\int_{\theta'}^{\theta^*}\frac{\partial C(q'(\tilde{\theta}'),\tilde{\theta}',S_2)}{\partial\tilde{\theta}'}d\tilde{\theta}'$$

Inserting for these rent expressions in the objective function (4.14), and integrating by parts, the expected welfare is given by

(4.21)
$$\begin{aligned}EW=\int_{\underline{\theta}}^{\bar{\theta}}\Big\{&(1+\lambda)[p_1q_1(\theta)-C(q_1(\theta),\theta,S_1)-d(i)]\\&-(\lambda+\mu)\left[\frac{\partial C(q_1(\theta),\theta,S_1)}{\partial\theta}+\delta(1-F(\theta^*))\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial\theta}\right]\frac{F(\theta)}{f(\theta)}\\&+\delta(1-F(\theta^*))(1+\lambda)[p_2q_2(\theta)-C(q_2(\theta),\theta,S_2)+i]\\&+\delta\int_{\underline{\theta}}^{\theta^*}\Big\{(1+\lambda)[p_2q'(\theta')-C(q'(\theta'),\theta',S_2)+ki]\\&-(\lambda+\mu)\frac{\partial C(q'(\theta'),\theta',S_2)}{\partial\theta'}\frac{F(\theta')}{f(\theta')}\Big\}f(\theta')d\theta'\Big\}f(\theta)d\theta\end{aligned}$$

The regulatory problem is now reduced to maximising the expected welfare, equation (4.21), subject to the resource constraint (4.5), and the moral hazard constraint (4.17). As in the symmetric information case, the resource constraint will be non-binding for all producer types, due to the assumption of asymptotic costs. Optimal regulatory policy is found by maximising the Lagrangian

$$
\begin{aligned}
L = \Big\{&(1+\lambda)[p_1 q_1(\theta) - C(q_1(\theta),\theta,S_1) - d(i)] \\
&-(\lambda+\mu)\left[\frac{\partial C(q_1(\theta),\theta,S_1)}{\partial\theta} + \delta(1-F(\theta^*))\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial\theta}\right]\frac{F(\theta)}{f(\theta)} \\
&+\delta(1-F(\theta^*))(1+\lambda)[p_2 q_2(\theta) - C(q_2(\theta),\theta,S_2) + i] \\
&+\delta\int_{\underline{\theta}}^{\theta^*}\Big\{(1+\lambda)[p_2 q'(\theta') - C(q'(\theta'),\theta',S_2) + ki] \\
&-(\lambda+\mu)\frac{\partial C(q'(\theta'),\theta',S_2)}{\partial\theta'}\frac{F(\theta')}{f(\theta')}\Big\} f(\theta')d\theta'\Big\} f(\theta) \\
&-\nu(\theta)[d'(i) - \delta(1-F(\theta^*))]
\end{aligned}
\tag{4.22}
$$

with respect to $q_1(\theta)$, $q_2(\theta)$, $q'(\theta')$, i, and θ^*:

$$
\begin{aligned}
&p_1 - \frac{\partial C(q_1(\theta),\theta,S_1)}{\partial q_1(\theta)} + \delta(1-F(\theta^*))\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial S_2} + \delta\int_{\underline{\theta}}^{\theta^*}\frac{\partial C(q'(\theta'),\theta',S_2)}{\partial S_2} f(\theta')d\theta' \\
&= \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\left(\frac{\partial^2 C(q_1(\theta),\theta,S_1)}{\partial\theta\partial q_1(\theta)} - \delta(1-F(\theta^*))\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial S_2}\right) \\
&-\delta\frac{\lambda+\mu}{1+\lambda}\int_{\underline{\theta}}^{\theta^*}\left(\frac{\partial^2 C(q'(\theta'),\theta',S_2)}{\partial\theta'\partial S_2}\frac{F(\theta')}{f(\theta')}\right) f(\theta')d\theta'
\end{aligned}
\tag{4.23}
$$

$$
p_2 - \frac{\partial C(q_2(\theta),\theta,S_2)}{\partial q_2(\theta)} = \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta)}{f(\theta)}\frac{\partial^2 C(q_2(\theta),\theta,S_2)}{\partial\theta\partial q_2(\theta)}
\tag{4.24}
$$

$$
p_2 - \frac{\partial C(q'(\theta'),\theta',S_2)}{\partial q'(\theta')} = \frac{\lambda+\mu}{1+\lambda}\frac{F(\theta')}{f(\theta')}\frac{\partial^2 C(q'(\theta'),\theta',S_2)}{\partial\theta'\partial q'(\theta')}
\tag{4.25}
$$

$$
\nu(\theta) = \frac{(1+\lambda)f(\theta)[-d'(i) + \delta(1-F(\theta^*)) + \delta k F(\theta^*)]}{d''(i)}
\tag{4.26}
$$

$$(1+\lambda)[p_2q_2(\theta)-C(q_2(\theta),\theta,S_2)+i]-(\lambda+\mu)\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial\theta}\frac{F(\theta)}{f(\theta)}+\frac{v(\theta)}{f(\theta)}$$
$$=(1+\lambda)[p_2q'(\theta^*)-C(q'(\theta^*),\theta^*,S_2)+ki]-(\lambda+\mu)\frac{\partial C(q'(\theta^*),\theta^*,S_2)}{\partial\theta^*}\frac{F(\theta^*)}{f(\theta^*)} \quad (4.27)$$

Equations (4.24) and (4.25) are directly analogous to equation (3.23). Condition (4.23) follows the same pattern as condition (3.22), except that the stock effect and the dynamic single crossing are now in expected value terms. Abstracting from the moral hazard constraint (i.e., setting $v(\theta)=0$), condition (4.27) says that the breakout level θ^* is determined by equality of net social value from the two bidders; bidding parity.[4] Compared with the symmetric information case, condition (4.27) corrects for the fact that the partnerships are to keep some of the resource rent, due to private information about intrinsic efficiency. The additional term, $v(\theta)/f(\theta)$, indicates that the moral hazard constraint, if it is binding ($v(\theta)>0$), will affect the breakout rule.

Proposition 4.1

The qualitative results of Laffont and Tirole [1993], chapter 8, carry over to a variable size model of petroleum regulation

Lemma $v(\theta)=0$ iff $k=0$ or $\theta=\underline{\theta}$, $v(\theta)>0$ otherwise.

Proof This is shown by substituting the moral hazard constraint (4.17) into (4.26), yielding

---

[4] The net social value is the value of the license if MIE were able to capture all the resource rent, $(1+\lambda)[p_2q_2(\theta)-C(q_2,\theta,S_2)+i]$, corrected for the loss of welfare caused by the partnership's information rent, $(\lambda+\mu)\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial\theta}\frac{F(\theta)}{f(\theta)}$.

(4.28) $$v(\theta)=\frac{(1+\lambda)f(\theta)\delta kF(\theta^*)}{d''(i)}.$$

■

If the moral hazard constraint is binding ($v(\theta)>0$), there will be a discrimination in favour of the incumbent. This can be seen directly from condition (4.27); θ^* will be negatively correlated with $v(\theta)$ under the assumption that the net social value of a petroleum deposit is higher the more efficient is the partnership.[5] This seems to be a reasonable assumption; a more favourable intrinsic cost parameter implies a higher resource rent. Due to asymmetric information, the increase in rent is likely to be split between the partnership and the government, and social welfare is increased. The assumed relationship between θ^* and $v(\theta)$ can be verified by implicit derivation of (4.27):

(4.29) $$\frac{d\theta^*}{dv(\theta)}=-(1+\lambda)f(\theta)/\left(-p_2\frac{dq'(\theta^*)}{d\theta^*}+\frac{\partial C(q'(\theta^*),\theta^*,S_2)}{\partial\theta^*}\right.$$
$$\left.+\frac{\lambda+\mu}{1+\lambda}\frac{\partial C(q'(\theta^*),\theta^*,S_2)}{\partial\theta^*}\frac{d}{d\theta^*}\left(\frac{F(\theta^*)}{f(\theta^*)}\right)+\frac{\lambda+\mu}{1+\lambda}\frac{\partial^2 C(q'(\theta^*),\theta^*,S_2)}{\partial\theta^{*2}}\frac{F(\theta^*)}{f(\theta^*)}\right).$$

A sufficient but not necessary condition for this expression to be negative is that the problem of private information, at the margin, is not too severe, i.e., $\partial^2 C(q'(\theta^*),\theta^*,S_2)/\partial\theta^{*2}$ is not too high.

The economic interpretation of the biased auction result is that the incumbent, not knowing whether he will be allowed to produce in period two, will not internalise all the benefits of his investments. More specifically, he will not take into account the positive (investment-

---

[5] I.e., $pq(\theta)-C(q(\theta),\theta,S)-\frac{\lambda+\mu}{1+\lambda}\frac{\partial C(q(\theta),\theta,S)}{\partial\theta}\frac{F(\theta)}{f(\theta)}$ is decreasing in θ.

induced) externality on the entrant's costs. This was not a problem in the symmetric information case, as full internalisation could be secured by the contract. With unobservable investments, however, there will be a welfare loss from underinvestment. Optimal regulatory response for the types $\theta \in (\underline{\theta}, \overline{\theta}]$ is to discriminate against the potential entrant in the second period auction (i.e., reduce θ^*); the underinvestment problem is then mitigated, as it raises the incumbent's probability of a prolonged license period. An incumbent of type $\underline{\theta}$ does not run the risk of being replaced.[6] Accordingly, the investments will be socially optimal, and there is no need for discrimination. Nor is it necessary to bias the selection rule when the investments are non-transferable $(k = 0)$, as there in this case is no externality.

By reducing θ^* the underinvestment problem is mitigated, or, put differently, the moral hazard constraint (condition (4.17)) is relaxed. This is achieved by sacrificing optimal selection; the incumbent may get a prolonged license period even if the potential entrant is more efficient. The optimal breakout rule $\theta^*(\theta)$, therefore, is a trade-off between optimal selection and reduction of moral hazard. This is illustrated by rearranging equation (4.27):

$$\nu(\theta)d\theta =$$

$$(4.30)\quad \left[(1+\lambda)[p_2 q'(\theta^*) - C(q'(\theta^*),\theta^*,S_2) + ki] - (\lambda+\mu)\frac{\partial C(q'(\theta^*),\theta^*,S_2)}{\partial \theta^*}\frac{F(\theta^*)}{f(\theta^*)}\right] f(\theta)d\theta$$

$$-\left[(1+\lambda)[p_2 q_2(\theta) - C(q_2(\theta),\theta,S_2) + i] - (\lambda+\mu)\frac{\partial C(q_2(\theta),\theta,S_2)}{\partial \theta}\frac{F(\theta)}{f(\theta)}\right] f(\theta)d\theta$$

The critical intrinsic cost parameter θ^* is determined by equality of the welfare gain of the relaxation of moral hazard, the left hand side of (4.27) [7], and the expected welfare loss of inefficient selection; the right hand side.

---

[6] Technically, from equation (4.27) we get $\theta^*(\underline{\theta}) = \underline{\theta}$, i.e., the probability of prolonged license for the incumbent is $(1 - F(\underline{\theta})) = 1$.

[7] The welfare gain of a marginal relaxation of the moral hazard constraint is expressed by the Lagrange multiplier $\nu(\theta)$.

4.5 ASYMMETRIC INFORMATION ABOUT EXTRACTION LEVELS

The results of the analysis above are similar to Laffont and Tirole [1993]. The specific cost structure in petroleum production (i.e., stock effect) does not qualitatively affect the results. From a practical point of view, however, one might suspect that an incumbent facing a positive probability of losing the production license in period two, will, compared to a situation without repeated bidding, change his period one behaviour. Due to the stock effect, present production will increase the costs of future extraction. With some probability of losing the period two auction, the incumbent may not fully internalise this stock effect. This problem was easily solved in the model above. Since extraction levels were assumed to be observable to both parties, MIE could secure full internalisation through the incentive contracts offered. In a repeated auction model with asymmetric information about extraction levels, I will now show that it may be optimal to deviate from bidding parity even in absence of moral hazard (I assume that the principal and the agents are symmetrically informed about investments).

Due to private information about internal resources and reservoir characteristics, each agent is assumed to possess private information concerning the amount of petroleum it can extract from a given tract. In some cases the regulatory agency will be able to control the extraction level ex post, by inspection of sales contracts. Due to the high degree of vertical integration in the petroleum industry, however, oil and gas are often sold on an internal market, e.g., petroleum is shipped to a petrochemical plant owned by the same corporation. In addition, the shipment is often carried out by subsidiaries, and the internal purchasers are often located in other countries. This distribution structure may give some leeway for strategic reporting of extraction levels.

The problem of asymmetric information about extraction capacities, as for other types of private information, can be met by three basic approaches by the regulatory agency: 1)

Offering the petroleum companies incentive contracts to induce truthful reports, 2) Imposing control measures, and 3) A combination of 1) and 2). For petroleum production there exist instruments, installed at the well head, that can give fairly accurate measurement of production levels. These control measures, however, are costly. High precision measurement devices may have an investment cost close to ten million US dollars, and, in addition, these high tech instruments are costly to operate. For large wells, investments in advanced measurement technology may be justified. For smaller wells, however, the optimal regulatory response may be incentive contracts, or a combination of incentive contracts and a less expensive measurement device.[8] Less sophisticated measurement technology has lower precision; it will reduce but not eliminate the uncertainty concerning extraction capacity. Examples of small wells are the on shore tracts in the United States. There is also a trend toward smaller wells on the Norwegian continental shelf.

Specifically, the partnerships' types are in this adverse selection model given by extraction levels q and q', with support $q \in [\underline{q}, \overline{q}]$, independently drawn from a common knowledge distribution $F(q)$. The extraction capacities q and q' are private information for the partnerships, but from experience and comparisons with other tracts, the regulatory agency knows the support and the distribution. Alternatively, the support and the distribution are generated by an inexpensive and inaccurate measurement technology.[9]

It is unconventional in economic models to treat production as an exogenous variable. The parallel variable in the previous models was the intrinsic cost parameter θ. In reality, both q and θ are subject to optimisation; the assumptions of exogenity are made to facilitate the analyses.

Furthermore, the adverse selection parameter will be assumed to be perfect correlated over time, i.e., $q_1 = q_2 = q$. Since the model also contains a stock effect, $\partial C(q, i_2, S_2) / \partial S_2 < 0$,

---

[8] For other types of exhaustible resources the available measurement technology may not be so effective as in the petroleum industry. In this case incentive contracts may be the optimal regulatory response even for large deposits.

[9] To keep the model tractable, the choice of measurement technology is not endogenised.

this assumption may seem restrictive. To maintain the reservoir pressure, petroleum extraction usually starts off at a moderate pace, gradually increasing to the plateau level. A possible generalisation would be to apply the framework of Baron and Besanko [1984], assuming the extraction levels to be imperfectly correlated over time. This would, however, not change the qualitative conclusions. As it would also add complexity, I will stick to the assumption of perfect correlation. I will argue that the stock effect can be accounted for in the present model, by allowing the period lengths to vary.

Costs and extraction levels are unobservable to the regulatory agency. Investments are assumed to be observable and verifiable. Total costs are given by the sum of extraction costs and investments:

(4.31) $C = C(q,i_t,S_t) + i_t$

The total costs of the incumbent and the entrant have the same functional form, but differ with respect to the extraction capacity parameters; q and q', respectively. Investment, or effort, lowers the extraction costs; $\partial C(q,i,S)/\partial i < 0$. Investments are assumed fully transferable. MIE, assumed to be able to credibly commit for the entire regulatory horizon, offers in period one the incumbent a self-selection mechanism $\{[i_1(q),R_1(q)],[i_2(q),R_2(q),q^*(q)]\}$, i.e., a menu of type-revealing two-period contracts in investment i and tax R. In period two, the potential entrant is offered the contract $\{i'(q'),R'(q'),q^*(q')\}$. An auction is held in period two, where the entrant takes over the license if it announces $q' > q^*$. The critical extraction level q^* is determined by a breakout rule.

The expected rent, in net present value, of an incumbent of type q announcing $\hat{q}$, is given by

(4.32)
$$\begin{aligned}\Pi(\hat{q},q) \equiv \Pi_1(\hat{q},q) + \delta\Pi_2(\hat{q},q) = p_1 q - C(q,i_1(\hat{q}),S_1) - i_1(\hat{q}) - R_1(\hat{q}) \\ + \delta F(q^*)[p_2 q - C(q,i_2(\hat{q}),S_2) - i_2(\hat{q}) - R_2(\hat{q})]\end{aligned}$$

For an entrant of type q' announcing $\hat{q}'$, the rent is given by

$$\text{(4.33)}\quad \Pi'(\hat{q}',q') = p_2 q' - C(q',i'(\hat{q}'),S_2) - i'(\hat{q}') - R_2(\hat{q}')$$

By combining the participation constraints and the first order incentive constraints (the derivative of equations (4.32) and (4.33) with respect to q and q'), and by integrating, we obtain the expected information rents for the incumbent and the entrant, respectively:

$$\text{(4.34)}\quad \Pi(q) = \int_{\underline{q}}^{q} \left\{ p_1 - \frac{\partial C(\tilde{q},i_1,S_1)}{\partial \tilde{q}} + \delta F(q^*) \frac{\partial C(\tilde{q},i_2,S_2)}{\partial S_2} + \delta F(q^*)(p_2 - \frac{\partial C(\tilde{q},i_2,S_2)}{\partial \tilde{q}}) \right\} d\tilde{q}$$

$$\text{(4.35)}\qquad \Pi'(q') = \int_{q^*}^{q'} \left\{ p_2 - \frac{\partial C(\tilde{q}',i'(\tilde{q}'),S_2)}{\partial \tilde{q}'} \right\} d\tilde{q}'$$

By construction, I will now give an economic explanation of the information rent of the entrant; equation (4.35). Instead of revealing its true extraction capacity q', the partnership may choose to masquerade as a marginally lower producer $q'-dq'$, where dq' is a small and positive number. The mimicking is done by selecting the bundle $\{i'(q'-dq'),R'(q'-dq')\}$ intended for type $q'-dq'$. By inserting in the profit function (4.33), we see that relative to type $q'-dq'$ this strategy yields a rent equal to

$$\text{(4.36)}\qquad \begin{aligned} &\Pi'(q') - \Pi'(q'-dq') \\ &= p_2 q' - C(q',i'(q'-dq'),S_2) - [p_2(q'-dq') - C(q'-dq',i'(q'-dq'),S_2)] \end{aligned}$$

It is clear from equation (4.36) that the payoff to this strategy is equal to the difference in resource rent for the two producer types. Taking the limit of (4.36), letting dq' approach zero, we get the incentive constraint

(4.37) $$\frac{d\Pi'(q')}{dq'} = p_2 - \frac{\partial C(q',i'(q'),S_2)}{\partial q'}$$

Hence, an interpretation of (4.37) is that to get incentive compatibility, the partnership group, when they reveal their true type, is rewarded with the rent they would get if they instead were to mimic a marginally lower producer. From this it follows that the total rent of a partnership of type q is given by a cumulation of differences in resource rent. This rent, equation (4.35), is obtained by integrating (4.37) and applying the participation constraint.

Similarly, the rent of the incumbent, equation (4.34), can be derived from equation (4.32). To be willing to reveal its true extraction capacity, the incumbent must be given a rent equal to the net present value of cumulated resource rent differences over two periods. Due to an intertemporal dependence in extraction costs, the first period marginal extraction costs includes ad additional term; the stock effect.

The regulatory agency seeks to maximise the expected value of the intertemporal welfare function

(4.38) $$W = (1+\lambda)\left[p_1 q - C(q,i_1,S_1) - i_1 + \delta(p_2 q - C(q,i_2,S_2) - i_2)\right] - (\lambda+\mu)\Pi(q),$$

with respect to the investment levels i_1, i_2, i', and the breakout level q^*. Inserting for the rent functions (4.34) and (4.35), i.e., incorporating the incentive and the participation constraints, the expected welfare is given by

$$EW = \int_{\underline{q}}^{\bar{q}} \{(1+\lambda)[p_1 q - C(q,i_1(q),S_1) - i_1(q)]$$

$$-(\lambda+\mu)\left[p_1 - \frac{\partial C(q,i_1(q),S_1)}{\partial q} + \delta F(q^*)\frac{\partial C(q,i_2(q),S_2)}{\partial S_2}\right]\frac{1-F(q)}{f(q)}$$

$$+\delta F(q^*)\left[(1+\lambda)[p_2 q - C(q,i_2(q),S_2) - i_2(q)] - (\lambda+\mu)(p_2 - \frac{\partial C(q,i_2(q),S_2)}{\partial q})\frac{1-F(q)}{f(q)}\right]$$

$$+\delta \int_{q^*}^{\bar{q}} \{(1+\lambda)[p_2 q' - C(q',i'(q'),S_2) - i'(q')] \tag{4.39}$$

$$-(\lambda+\mu)(p_2 - \frac{\partial C(q',i'(q'),S_2)}{\partial q'})\frac{1-F(q')}{f(q')}\Big\} f(q')dq' \Big\} f(q)dq$$

Maximisation with respect to i_1, i', i_2, and q^*, yields the first order conditions

$$-\frac{\partial C(q,i_1,S_1)}{\partial i_1} - 1 = -\frac{\lambda+\mu}{1+\lambda}\frac{\partial^2 C(q,i_1,S_1)}{\partial q \partial i_1}\frac{1-F(q)}{f(q)} \tag{4.40}$$

$$-\frac{\partial C(q',i',S_1)}{\partial i'} - 1 = -\frac{\lambda+\mu}{1+\lambda}\frac{\partial^2 C(q',i',S_1)}{\partial q' \partial i'}\frac{1-F(q')}{f(q')} \tag{4.41}$$

$$-\frac{\partial C(q,i_2,S_2)}{\partial i_2} - 1 = \frac{\lambda+\mu}{1+\lambda}\left[\frac{\partial^2 C(q,i_2,S_2)}{\partial S_2 \partial i_2} - \frac{\partial^2 C(q,i_2,S_2)}{\partial q \partial i_2}\right]\frac{1-F(q)}{f(q)} \tag{4.42}$$

$$p_2 q - C(q,i_2(q),S_2) - i_2(q) - \frac{\lambda+\mu}{1+\lambda}(p_2 - \frac{\partial C(q,i_2(q),S_2)}{\partial q})\frac{1-F(q)}{f(q)}$$

$$-\frac{\lambda+\mu}{1+\lambda}\frac{\partial C(q,i_2(q),S_2)}{\partial S_2}\frac{1-F(q)}{f(q)} \tag{4.43}$$

$$= p_2 q^* - C(q^*,i'(q^*),S_2) - i'(q^*) - \frac{\lambda+\mu}{1+\lambda}(p_2 - \frac{\partial C(q^*,i'(q^*),S_2)}{\partial q^*})\frac{1-F(q^*)}{f(q^*)}$$

Proposition 4.2
In a repeated auctions model of the petroleum industry, with private information about extraction levels, deviation from bidding parity is obtained without the introduction of moral hazard.

Analogous to section 3.2, I have made the following assumptions

(A2 ')	$\frac{\partial^2 C(q,i_t,S_t)}{\partial q \partial i_t} < 0$	Static single crossing
(A7 ')	$\frac{\partial^2 C(q,i_2,S_2)}{\partial S_2 \partial i_2} > 0$	Dynamic single crossing
(A3 ')	$\frac{\partial^2 C(q,i_t,S_t)}{\partial i^2} > 0$	Convexity

These assumptions have plausible economic explanations. Assumption (A2 '), static single crossing, states that the rate of cost reductions from investments is higher for high volume than for low volume producers, i.e., investments are more effective at a high than a low extraction level. The dynamic single crossing property, assumption (A7 '), states that the rate of reduction in extraction costs caused by investments, is decreasing in the remaining petroleum stock, i.e., investments and remaining petroleum reserves are assumed to be substitutes. The convexity assumption, (A3 '), implies diminishing returns of investments.

Parallel to the previous models, I also assume a monotone hazard rate:

(A9 ') $$\frac{d}{dq}\left(\frac{f(q)}{1-F(q)}\right)\geq 0$$

The first best investment level is where the marginal investment-induced cost reduction is equal to the marginal investment cost:

(4.44) $$-\frac{\partial C(q,i_t,S_t)}{\partial i_t}-1=0$$

This solution will be obtained in a situation of symmetric information about extraction levels. Under asymmetric information, optimal regulation will imply a wedge between marginal costs and benefits of investment. As is clear from the conditions (4.40), (4.41), and (4.42), the wedge is equal to the marginal information cost.[10] Due to the convexity assumption (A7 ') we get the conventional underinvestment result; to enhance rent extraction, investments are reduced from their first best levels. Underinvestment applies for all types $q<\bar{q}$, i.e., we have no distortion at the top.

Abstracting from the stock effect, i.e., setting $\partial C(q,i_2,S_2)/\partial S_2=0$, condition (4.43) states that the breakout level q^* is determined by equality of the period two net social value generated from the two bidders; i.e., we have bidding parity. In the absence of moral hazard, this would be the optimal breakout rule in a manufacturing industry. In the petroleum industry, having an intertemporal dependence in extraction costs due to the resource constraint, the optimal breakout rule has an additional term. If the net social value of a given petroleum deposit is increasing in the producer type [11], which is a plausible assumption, it is clear from condition (4.43) that, for the partnership types $q<\bar{q}$, the stock effect will imply a bias in favour of the incumbent: To be awarded the license, the potential entrant must bid a higher q than the extraction level securing equality of net social value of the two

10 See section 3.4 for a more detailed explanation.

11 I.e., if $p_t q - C(q,i_t(q),S_t) - i(q) - \frac{\lambda+\mu}{1+\lambda}(p_t - \frac{\partial C(q,i_t(q),S_t)}{\partial q})\frac{F(q)}{f(q)}$ is increasing in q.

partnerships, i.e., q^* is increased as a consequence of the stock effect. The discrimination result can be verified by implicit derivation of (4.43):

(4.45)

$$\frac{dq^*}{d(\partial C/\partial S)} = \frac{\frac{\lambda+\mu}{1+\lambda}\frac{1-F(q)}{f(q)}}{p_2 - \frac{\partial C}{\partial q^*} - \frac{di'}{dq^*} + \frac{\lambda+\mu}{1+\lambda}\frac{\partial^2 C}{\partial q^{*2}}\frac{1-F(q)}{f(q)} - \frac{\lambda+\mu}{1+\lambda}\left(p_2 - \frac{\partial C}{\partial q^*}\right)\frac{d}{dq}\left(\frac{1-F(q)}{f(q)}\right)}$$

The derivative is positive, due to convexity (A3), monotone hazard rate (A9 '), and the monotonicity constraint (appendix 3.2).

The economic interpretation is that discrimination of the potential entrant raises the probability of prolonged license period for the incumbent, causing a larger part of the stock effect to be internalised. The incumbent's intertemporal incentive constraint is thus relaxed, and enhanced rent capture is the result.[12] Rent capture is now improved both by careful design of incentive contracts (with distortive investment taxes), and by the biased auction rule. MIE is thus equipped with an additional means for rent extraction.

Improved rent extraction of the incumbent is obtained at the expense of optimal selection. Rearranging equation (4.43), yields

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[12] For type $\bar{q}$ bidding parity is still obtained. Full internalisation is always secured for the most efficient producer type since it does not run the risk of being replaced.

(4.46)

$$-(\lambda+\mu)\frac{\partial C(q,i_2(q),S_2)}{\partial S_2}(1-F(q))dq =$$

$$\left[(1+\lambda)[p_2 q^* - C(q^*,i'(q^*),S_2) - i'(q^*)] - (\lambda+\mu)(p_2 - \frac{\partial C(q^*,i'(q^*),S_2)}{\partial q^*})\frac{1-F(q^*)}{f(q^*)}\right] f(q)dq$$

$$-\left[(1+\lambda)[p_2 q - C(q,i_2(q),S_2) - i_2(q)] - (\lambda+\mu)(p_2 - \frac{\partial C(q,i_2(q),S_2)}{\partial q})\frac{1-F(q)}{f(q)}\right] f(q)dq$$

It follows from (4.46) that the critical extraction level q^* is determined by equality of the welfare gain of relaxation of the incumbent's incentive constraint (left hand side) and the expected welfare loss of inefficient selection (right hand side).

The selection loss is equal to the difference in expected net social value from the two bidders. The welfare gain of distorting q^* can be seen by comparing equations (4.34) and (4.35). By increasing q^* an expected marginal resource rent is shifted from the potential entrant to the incumbent. Assuming the two partnerships have the same welfare weight $(1-\mu)$, i.e., the same foreign equity share μ, the shifting of rent does not have a direct welfare effect. Due to the intertemporal dependence in extraction costs, the incumbent experiences an additional effect. A higher q^* means a higher probability of prolonging the license period, and, therefore, a larger share of the stock effect will be internalised. As a consequence, expected overall rents are reduced at the rate $\partial C(q,i_2(q),S_2)/\partial S_2$. We recognise this term from the left hand side of equation (4.46). The explanations of the other terms are as follows: The rent is reduced for all incumbent types with higher extraction capacity, having probability $(1-F(q))$, and the value-weight of increased rent extraction is $(\lambda+\mu)$; the value of transferring one unit of income from the partnership to the government.

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Chapter 5

Petroleum taxation and regulation. Policy implications from principal-agent theory, and a comparison with the current Norwegian system*

5.1 INTRODUCTION

Asymmetric information about costs is a generic problem for taxation. The international nature of the petroleum industry, together with the high degree of vertical integration and the technological complexity, implies that the problems of private information are bound to be more pervasive in this sector. The specific cost structure in the petroleum industry, with intertemporal dependence in extraction costs (stock effect), leads to a special regulatory response to asymmetric information.

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When designing the petroleum tax system, the special features of the industry should be taken into account. Still, the Norwegian system of petroleum taxation is directly based on the onshore corporate tax system. The petroleum tax system is adjusted to take into account one of the special features of the industry; the presence of resource rents. The present system seems to be more of a complicated patchwork than the result of careful and conscious design. Instead of creating a new tax system that is specially designed to capture the resource rent, taking into account special features of the petroleum industry, the government simply added a few extra taxes on top of the existing on shore corporate tax system. There may be some benefits of having similar tax systems on and off shore; in particular to prevent tax arbitrage between the two sectors.[1] A major implication of this monograph, however, is that the theoretical underpinnings of the on shore tax system, which presupposes symmetric information, are not adequate for the petroleum industry where private information is prevalent.

The recent petroleum tax reform was, parallel to the reform in on shore corporate taxation, based on principles of neutrality and uniformity. If the economic decisions of the petroleum companies are socially optimal in the absence of taxation, a neutral (non-distorting) petroleum tax system is optimal. In the presence of market imperfections, however, a second best optimum may call for distortive taxation. The introduction of a carbon dioxide emission tax, correcting for environmental externalities, indicates that this is recognised by the government. The market imperfection represented by asymmetric information, however, is not accounted for in the tax system. Uniform taxation (level playing field) secures an optimal allocation of capital among sectors; again under the assumption of no market imperfections. Attempts have been made to level the playing field among the various licenses, but there is a large deviation between the marginal tax rates on and off shore, thus causing an inoptimal allocation of capital among the two sectors. If the extent of private information differs among petroleum fields, moreover, second best optimum does not imply uniform taxation.

[1] Tax arbitrage, however, relies more on differences in marginal tax rates than on differences in tax systems. With marginal tax rates of 28 and 78 per cent on and off shore, respectively, the problem of tax arbitrage is not accounted for in the present tax system.

The adverse selection and moral hazard models of the previous chapters have endogenously determined optimal mechanisms for regulation and taxation of the petroleum industry under asymmetric information. In this chapter I compare these normative recommendations with the current Norwegian system.

Norwegian petroleum taxation and regulation are set to serve many objectives and it is subject to political constraints. The principal-agent models of petroleum regulation, in comparison, focus on the single objective of rent extraction. The models abstract from political constraints and the multitude of objectives. With the emphasis on asymmetric information, however, principal-agent theory introduces incentive constraints. It appears that such constraints have been neglected in design of the current Norwegian system.

Principal-agent theory (adverse selection and moral hazard models) generates the following normative recommendations: Licenses should be awarded by auctioning of incentive contracts, and the tax system should consist of simple menus of linear contracts. The recommended tax system is neither neutral nor uniform. The petroleum companies should bear a considerable part of the risk. Recommended response to the problem of private information is a combination of incentive schemes and monitoring.

Present Norwegian petroleum regulation is based on discretionary licensing. The petroleum tax system is complex, with a stated intention of neutrality and uniformity. The government bears most of the risk. Problems of asymmetric information are mitigated by control measures.

This was a brief comparison, indicating that current Norwegian petroleum taxation and regulation have little in common with the regulatory framework endogenously determined by regulation theory. By elaborating on this comparison, I will in this chapter show that the deviation between theory and regulatory practice is not so fundamental as it may appear at first sight. Furthermore, I will discuss whether some of the differences can be justified by the following political explanations: a) The government's objective function is more complex than is assumed in the theoretical analyses, and b) The electorate disapproves of repatriations of funds made by foreign petroleum companies. The complexity of the current system might be explained by a), and b) might be the reason for the high level of risk borne by the government.

5.2 ASYMMETRIC INFORMATION AND ITS MANIFESTATIONS

The problems of asymmetric information are more severe for petroleum companies than for on shore companies. The reasons for this are two-fold: 1) Due to presence of large rents, the *incentive* for exaggerating true costs is higher on the continental shelf, and 2) The vertically integrated multinational petroleum companies have more *opportunities* to camouflage its costs.

The petroleum industry is extracting a scarce and exhaustible natural resource, yielding a considerable resource rent. Consequently, there is much to gain from strategic reporting of costs. Furthermore, certain characteristics of this industry make it difficult for the tax authorities to monitor costs. First of all, the tax subjects are vertically integrated multinationals. A special monitoring problem pertaining to multinational companies, due to imperfect international harmonisation of the national tax systems, is the problem of international tax arbitrage by the use of tax-minimising transfer pricing, e.g., borrowing at a high interest rate or purchasing expensive insurance from an affiliated company located in a tax haven. An incentive for transfer pricing exists when the effective tax rates, taking into account procedures for credit of taxes paid to foreign governments, vary between countries.[2]

[2] In the present Norwegian petroleum tax system, having marginal tax of 78 per cent, the incentives for tax arbitrage are enormous. Not only is it profitable, by means of transfer pricing, to shift profits from the Norwegian continental shelf to tax havens, but it is also lucrative for Norwegian companies to shift resource rents from off shore to on shore activities, with marginal tax rates of 78 and 28 per cent, respectively.

A distinguishing feature of multinational corporations is that the interfirm transactions are not valued in an open market. Instead, within the limits established by the monitoring opportunities and efforts of the national tax authorities, these firms choose an optimal transfer price. The problem of transfer pricing is particularly severe in the petroleum sector due to a high degree of vertical integration, giving many interfirm transactions. Another part of the problem is the fact that many of the inputs in the offshore industry are not standard commodities with an established market price, making it hard to monitor costs or impose norm prices.[3] Some costs can be controlled by auditing, but this is not the case for calculated costs, e.g., capital costs. Due to the high investments in the petroleum industry, the companies' capital costs are important.

As pointed out, there are several obstacles to a direct ex post auditing of costs in the petroleum industry. Alternatively, the regulatory agency might attempt to deduce true costs from observable variables, e.g., the extraction levels chosen. If the regulator knows the cost function, i.e., the total costs for a given extraction level and a given intrinsic efficiency parameter, and if extraction levels and efficiency are observable, there is symmetric information about costs. Through their operating activities, however, the petroleum companies obtain field-specific information that is not available to the government. Examples of such private information are knowledge about the estimated size and quality of a particular petroleum reservoir, and knowledge of how adequate the company's internal resources are in developing a given deposit. Consequently, a petroleum company has private information about its intrinsic efficiency parameter, causing asymmetric information about costs. A necessary condition for the persistence of this private information, is a complex production technology that has not been standardised. This condition pertains to deep water operations on the Norwegian continental shelf, but more rarely to industries on shore.

Moreover, being residual claimant for only 22 per cent of its cost savings, the petroleum companies are not given incentives to cost consciousness in the present tax system. An obvious remedy is to reduce the marginal tax rate and, at the same time, maintain the revenues by imposing fixed payments, either in form of discretionary license fees or up front payments determined by auctions.

[3] Examples are tailor-made parts or modules to production platforms, and specialised consulting services.

On the basis of experience from a number of petroleum deposits, the government can be assumed to know the general cost function. It has, however, only imperfect information about reservoir characteristics and the internal efficiency of a partnership at a particular petroleum reservoir, i.e., there is private information about an intrinsic cost parameter. In this situation it is in the interest of the partnership to misrepresent its own type; it can obtain an information rent by imitating a partnership with lower efficiency and a smaller deposit. To effectively masquerade as a partnership with high extraction costs, it will choose the extraction level that is optimal for this type, i.e., it produces a suboptimal quantity of petroleum. The information rent obtained, relative to the marginally less efficient company, is equal to the cost advantage. Hence, the manifestation of private information about costs, is that petroleum companies report a lower efficiency than their true level.[4]

5.3 THE REVELATION PRINCIPLE

As argued, monitoring of costs is especially difficult in the petroleum industry. The control measures are not only bound to be imperfect, they will also require many resources. This may give scope for revelation mechanisms, i.e., incentive systems securing a voluntary revelation of information.

Adverse selection models, i.e., models of regulatory settings where the agent (petroleum company) obtains private information before entering into a contract with the principal (the Ministry of Industry and Energy; MIE), make use of the revelation principle. During the negotiating process the private companies will, in return for an information rent, reveal their private information to MIE. In the primal formulation of these models, the agents, subject to

[4] This is not to say that the companies commit crime or fraud. In measuring efficiency parameters, and even more in estimating the size of a petroleum deposit, there is not always an unquestionable truth to be found. To calculate these measures one has to choose which data to use and which measurement methods to apply. The companies, seeking to maximise the payoff to the shareholders, may act strategically by not reporting their best estimate, but rather using a selective choice of methods and a selective presentation of data in order to obtain highest possible profits.

an incentive constraint, announce their true intrinsic cost parameter to the principal. The dual approach is closer to present tax systems; revelation is achieved by self selection, i.e., by offering the partnership a carefully designed net tax schedule (e.g., the one depicted in figure 3.1), the private information is revealed by the choice of extraction levels. With the high number of tax instruments in the present complex tax regime, it should be possible, by simulation, to generate a concave net tax schedule of the type illustrated in figure 3.1. As shown in chapter 3, however, the concave schedule can be implemented by a menu of hyper planes. To generate these hyper planes, we need only two tax instruments; royalties and license fees.

The present Norwegian petroleum regulation has features that may serve the function as revelation mechanisms, e.g., the licence applications and the offering of work programmes may convey some information about the company's assessment of profitability of the various licenses.

5.4 MORE ON IMPLEMENTATION

To compare the present Norwegian petroleum tax regime with the recommendations from the normative theory of the previous chapters, one should note some fundamental features of implementation of optimal auctions and incentive contracts. The taxation regime generated by the static model of chapter 2 implied a relatively simple tax scheme: A menu of linear contracts, composed of a license fee and a proportional royalty. In section 3.5 I showed that the optimal regulatory outcome in a dynamic model is also implementable by proportional royalties and license fees. Chapter 4 analyses repeated auctions of incentive contracts. These contracts follow the pattern of the previous chapters; the incumbent is offered a two-period contract along the lines of chapter 3, whereas the potential entrant bids for static contracts analogous to the linear schemes in chapter 2. In the model with private information about extraction levels (section 4.4), the linear contract is generated by licence fees and an investment tax.[5]

In the auction models, the partnerships bid by announcing efficiency parameters (section 4.3) or extraction levels (section 4.4). The regulatory contracts can be given an alternative implementation that is closer to real life auctions.[6] The optimal allocation is implemented in two stages; first the partnerships are asked how much they are willing to pay for the license, and thereafter they select among a menu of contracts generated by license fees and royalties.

5.5 COMPLEX TAX SYSTEM

The present Norwegian petroleum taxation system, in comparison, is complex. It is a hybrid scheme, composed of an income tax, a state tax, a special tax, a capital tax, a withholding tax, and a carbon dioxide emission tax. The complexity is not primarily caused by the number of taxes, but the fact that the various taxes have different tax bases. The tax package also contains license fees, but these are negligible. Royalties are abolished for new licenses.

An interesting question is whether the optimal schemes from chapters 2-4 can be combined with other forms of taxation, i.e., if royalties can correct for private information, carbon dioxide emission tax secure internalisation of environmental effects, income taxes capture resource rent, etc. Under symmetric information there is usually no problem, as long as the various objectives do not outnumber the means. Since the means are numerous in petroleum regulation (licensing conditions, equity shares, various tax instruments, etc.), MIE should be in a fortunate position. When there is asymmetric information, however, serving many objectives is not straightforward. Based on a motive of rent extraction subject to asymmetric information, royalties and license fees are endogenously determined by regulation theory as

[5] Since extraction levels in this model are assumed to be non-observable to the regulator, the regulatory contract is made contingent on the observable investment levels. To enhance rent extraction, the investment decision is distorted, by the introduction of an investment tax.

[6] See Laffont and Tirole [1993], section 7.5.2.

the optimal tax instruments. To reach this conclusion the revelation principle is applied, with binding incentive constraints in optimum. Let us, on top of the endogenous royalties and license fees, introduce an income tax, a state tax, a carbon dioxide emission tax, or a special tax. A relevant question now is whether a menu of license fees and royalties can be applied to obtain self selection, and, at the same time, other objectives can be achieved by applying these other tax instruments. The answer to this question is negative. Whereas the tax schemes proposed in chapters 2-4 are contingent only on observable variables (extraction levels chosen, price levels etc.), the added taxes are contingent on reported costs, that MIE is assumed unable to observe. The incentive constraints will be strengthened since the partnership now has two motives for exaggerating its costs: 1) To obtain a more favourable (license fee, royalty) bundle, and 2) To reduce other taxes. Due to the additional motive, the revelation of the basic tax scheme will no longer hold when supplemented with the other tax forms.[7] Consequently, the complexity of the petroleum tax system reduces its capability of rent extraction. Conversely, enhanced rent extraction by the use of incentive contracts, cannot be achieved by simply introducing a system of royalties and license fees on top of the existing tax structure; a more radical system revision is required.

One might think that the complexity of the Norwegian tax system for the petroleum sector is caused by a complex objective function. In addition to the objective of rent extraction, from which the theoretical results are derived, Norwegian petroleum regulation is also supposed to serve regional, industrial, and macroeconomic policies. The complexities of the tax system, however, do not seem suited to achieve these objectives. If securing of stable demand and employment in specific regions and industries is to be achieved by means of petroleum regulation (which is questionable), it is more effectively done by the discretionary licensing conditions than by the tax system. In the case of an auctioning system, employment is best regulated by the selection and timing of licenses to be auctioned. The complexity of the present petroleum tax system is perhaps better explained by its origin; it is based on the

[7] An exception is the carbon dioxide emission tax, provided the cost function is additively separable in abatement and extraction costs.

onshore corporate tax system, and augmented with special features to extract resource rent, e.g., the special tax.

5.6 UNIFORMITY AND NEUTRALITY

In the recent petroleum tax reform, there was a stated objective of a neutral tax system that should not discriminate between licenses (level the playing field).[8] The argument in favour of uniform taxation is that maximal payoff from a given level of investment is obtained when the allocation of capital remains undistorted. Following this argument, one might argue, however, that the perspective has been too limited. With marginal tax rates of 28 and 78 per cent off shore and on shore, respectively, there is not uniformity between these two sectors of the economy. As pointed out, the differences in marginal tax rates creates incentives for transfer pricing.

In the petroleum industry, however, where asymmetric information is prevalent, the objective of uniform taxation is questionable. The theoretical underpinnings of uniform taxation presupposes symmetric information, and are not adequate for cases of private information. One of the most important implications of regulation theory, is the recommendation of individualised contracts for each license. It will be optimal for MIE to tailor the incentive scheme to the information structure in each separate case. As the extent of private information most likely will differ among licences, this calls for discrimination. Optimal discrimination can be implemented by field-specific royalties and licence fees. Norway had a field-specific royalty system, but in the recent tax reform this was abolished for new licenses. The purpose was to create a non-discriminatory tax system. According to O.t.prp. 12, 1991-92, benefits of uniform taxation are efficient trading of oil between the operators of different oil fields, and realisation of welfare-improving inter-field projects. If the

[8] See O.t.prp. 12, 1991-92.

discriminatory royalties are properly designed to correct for marginal information costs, however, they will secure these benefits.

Despite the stated policy of non-discrimination, the Norwegian government has a record of tailoring the tax system. Selective tax relieves have been given to supplementary projects, and the choice of equity shares in the various licenses is an important differentiation device.

Abolishing royalties, along with other features of recent tax reforms, also had the intention of creating neutrality.[9] Due to asymmetric information in the petroleum sector, however, the policy objective of neutrality is neither implementable nor second best optimal. A system based on net income taxes, where the companies due to private information can manipulate their reports on costs or extraction levels, will not be neutral. In the adverse selection models of chapters 2, 3, and 4, distortive royalties are a second best response to asymmetric information. With the purpose of enhanced rent extraction, extraction levels are deliberately distorted away from the first best levels. The economic explanation is the following: The partnership's information rent is derived from its bargaining position; instead of revealing its true costs it may choose to camouflage as a producer group with marginally higher costs. The imitation is done by selecting the extraction level meant for the marginally less efficient partnership, and the information rent, relative to this partnership, is equal to the difference in extraction costs. It is second best optimal for MIE to distort (reduce) the extraction level for the marginally less efficient partnership, since it will reduce the cost difference, and therefore also the information rent. Following the same argument, it will be optimal to distort the extraction levels for all types but the most efficient.[10] The neutrality result, therefore, although generally applicable under symmetric information, only applies as an asymptotic result under asymmetric information.

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[9] The only tax with a stated distortive purpose is the carbon dioxide emission tax, correcting for environmental externalities.

[10] The production of the most efficient type remains undistorted, since no other producer has anything to gain by imitating his type.

5.7 DIVIDE AND RULE

Provided it can avoid collusion, I have shown that by holding an auction, MIE can improve the regulatory outcome. By inducing competition among partnerships, rent extraction is improved. For reasons of tractability, I have in the adverse selection models assumed that the companies in a partnership form a stable cartel in negotiations with the government.[11] Following the above reasoning one step further, however, MIE might increase its negotiation power by exploiting conflicts of interest among the companies working together in a license group. Such conflicts of interest, some of which have been exposed in the media, often result from difference in portfolios (if one or several of the partners participate in adjacent licenses) and different investments in infrastructure (competing transport and refining facilities). Conflicts are likely to reduce the bargaining power of the partnership, making it possible for MIE to achieve revelation at a lower cost. As a possible strategy for further improvement of its bargaining position, MIE could introduce discriminatory policies with the intent to increase the conflicts of interest among the partners.

5.8 CONTINGENT LICENSING

Norwegian petroleum policy has, as one of its objectives, the task of securing a stable employment in the engineering and construction industry. Hence, in periods of idle capacity in the mechanic industry, the government is eager to develop new petroleum fields. The petroleum companies, realising MIEs position, thereby gain more negotiating power and are likely to enjoy higher rents. This illustrates the fact that introducing additional objectives in petroleum regulation, may reduce MIEs ability of serving its primary objective of rent extraction.

[11] The methodological advantage is that the cartel assumption makes regulation a problem of optimisation, whereas with heterogeneous companies we must resort to less developed equilibrium models; see section 1.10.

This discussion is related to the screening models in the following way: MIE loses negotiating power in periods of idle capacity because the partnerships know that the project will be implemented no matter costs or reservoir sizes, i.e., MIE has no reservation point with relation to the agents' types. In other words, a postponement strategy is not credible, and the regulator loses the option of waiting. If MIE were to serve the single objective of rent extraction, or, with the present objective function in periods of full employment in the mechanic industry, it may benefit from making the implementation contingent on the companies' types being in a certain range.[12] For the strategy of contingent licensing to be successful, the government is dependent on credibility in its claim that it will postpone awarding of the license to a later licensing round if the reported cost parameter is above a certain predetermined level.

5.9 AUCTIONS VERSUS DISCRETION

The potential benefit of auctions is increased rent extraction, by truncating the support of the asymmetry of information.[13] MIE applies a discretionary licensing system instead of auctions. The arguments against auctions are two-fold:

1) Collusion. The bids will be too low as a consequence of imperfect competition. According to Rowland and Hann [1987], the exposures to risk, the scale, and the heavy front-end loading of costs, tend to restrict the offshore industry to an oligopolistic structure.

2) Political risk. Low bids may be the consequence of the fact that the government is not able to commit not to tax the companies heavily after irreversible investments have been sunk.

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[12] See the analysis of optimal cutoff type in section 2.8.

[13] See section 2.11.

In addition, there are problems of underinvestment (due to moral hazard) and overproduction (derived from the stock effect). As shown in chapter 4, however, these problems can be mitigated by introducing a biased auction procedure.

Laffont [1994] argues that the assumption of noncooperative behaviour in auction theory is somewhat naive; realising that the purpose of auctions is to extract a maximal surplus, the firms are likely to protect themselves by collusion. In the current Norwegian discretionary licensing system, there is usually a high number of applicants in the licensing rounds. This may give hope of competitive behaviour. On the other hand, due to specialisation of competence and improved profitability of developing tracts close to a company's existing extraction, accommodation, and transport facilities, the various companies are often not interested in the same blocks. In addition, limited resources introduce an upper level on the number of licenses a company wishes to undertake. In this economic environment, one might suspect the following form of tacit collusion: We will not actively seek licenses in your back yard, if you keep out of our interest sphere. In the recent years, necessary conditions for collusion have been reduced. As the Norwegian petroleum industry has become mature, increased geological knowledge has made it easier to raise external capital. Together with diffusion of technology, barriers to entry have been reduced. At the same time, the domestic petroleum industry has become competitive.

Norway clearly applies a discretionary regulation of the petroleum industry, as the licensing process (especially the distribution of equity shares in licences) and the tax system is responsive to changes over time in prices, technology and estimates of recoverable reserves. In this non-commitment environment, auctions are not likely to be a fruitful regulatory instrument; petroleum companies will not be willing to pay much up front for a petroleum license without a credible guarantee as to future taxation. With a change of policy, however, the Norwegian government might improve its commitment credibility; see section 1.7.

Summing up, there have been serious obstacles to applying auctions on the continental shelf. The situation is changing. In a mature petroleum industry there might be scope for the introduction of auctioning of licenses. This would be compatible with the increased integration of Norway in the European Union.

5.10 ADVERSE SELECTION VERSUS MORAL HAZARD

I have considered two types of asymmetric information models, 1) Moral hazard (section 1.9 and 2) Adverse selection (chapters 2-4). Adverse selection models refer to the case where agents have precontractual private information. Applying this framework to the petroleum industry, I have analysed regulatory problems when a partnership has private information about its intrinsic efficiency level and its production capability from a given tract. The focus of adverse selection models is on screening and rent extraction. Moral hazard models, focusing on the trade-off between provision of incentives and optimal risk sharing, refer to situations of symmetric information at the contracting stage, but where the agents' actions or the circumstances of the actions are non-observable to the regulator. I have discussed the regulatory situation where the partnership has private information with respect to its effort to increase production and reduce costs.

An important question is whether the results of the two types of models, applied to petroleum regulation, are in conflict. Is there a trade-off between optimal risk-sharing and type-revelation? It appears that the answer is no; the qualitative results of adverse selection and moral hazard are compatible in the petroleum industry. It is also clear that the present Norwegian risk sharing between the government and the petroleum companies, is not in line with the normative recommendations from incentive theory.

The total risk in petroleum projects is the sum of risk related to production and costs (idiosyncratic risk) and income risk (systematic risk).[14] Income risk (price and exchange rate risk) is exogenous to the petroleum companies, i.e., there is no moral hazard attached to this type of risk. Hence, the risk is to be shared among the government and the companies according to their risk aversion.[15] Production and costs, on the other hand, are dependent on the companies' effort, which is not observable to the regulatory agency (moral hazard). Maximal incentives are given when the companies are residual claimants for all of their cost savings. With this contract, however, all the idiosyncratic risk is borne by the agent. Since the risk related to production and costs can be effectively diversified in their portfolio of petroleum projects, however, the petroleum companies are not negatively affected by this risk.[16] Hence, we do not get the conventional trade-off between incentives and risk sharing.

Summing up the normative recommendations of the theory of moral hazard, the partnerships are to bear all the idiosyncratic risk, whereas the systematic risk should be split among the government and the companies. In other words, a considerable part of the total risk is to be borne by the petroleum companies. The adverse selection models of previous chapters, assuming both principal and agents to be risk neutral, are not suited for analysing risk-sharing. Nevertheless, the implementation of the optimal adverse selection contracts includes auction payments and license fees as essential elements. These are fixed payments made by the partnership before the petroleum field is put on stream, i.e., before uncertainty resolves. Hence, much risk is borne by the petroleum companies.[17] In qualitative terms, therefore, there does not seem to be a conflict concerning petroleum risk sharing between the two main theory branches of asymmetric information.

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[14] See section 1.8.

[15] Optimal risk sharing under symmetric information is given by equality of the parties' marginal rates of substitution of income between the different states of nature.

[16] If a company has a portfolio of 10-15 imperfectly correlated projects of about the same size, most of the idiosyncratic risk (i.e., risk with relation to production and costs) will be diversified; see section 1.8. Even with a smaller portfolio of projects, a petroleum company should not be averse to idiosyncratic risk since the shareholders can diversify this risk on their own behalf, by holding shares in several petroleum companies.

[17] Since risk is not explicitly accounted for in the adverse selection models, they do not give answer to what types of risk that are to be borne by the companies and the government.

Comparing the theoretical recommendations with the present Norwegian petroleum regulatory system, however, there seems to be a major conflict. The overall effect of the Norwegian discretionary licensing system (with negligible license fees and a high direct state participation) and a complex tax system, is that the government bears most of the risk, regardless of whether it is idiosyncratic or systematic.[18] A major element of the tax system, contributing to the shifting of risk from the companies to the government, is the high marginal tax rate on net income (78 per cent). As discussed in chapter 1, a high marginal tax rate also leads to problems of transfer pricing and low cost consciousness. A major policy recommendation from incentive theory, therefore, is to select an alternative means of extracting rent from the petroleum companies, by introducing a system of up front payments (auction payments and license fees). These payments will give room for lower marginal tax rates, and more of the risk will be borne by the private companies.

The deviation between actual practice and theoretical recommendations as to risk sharing, may have political explanations. If more of the risk is to be shifted to the private petroleum companies, they will, of course, have to be compensated for this added risk. Furthermore, by definition, this shifting of risk implies larger fluctuations in the companies' net after tax income (and, correspondingly, smaller fluctuations in net total government take). Losses in bad years will be compensated by large profits in good years. Herein is the political problem; the electorate will, in some years, have to accept large profits in private petroleum companies. Specifically, shareholders of domestic petroleum companies may receive large dividends, and foreign companies may repatriate billions of Norwegian kroner. A political consensus that the petroleum resources constitute a public property, may make such events hard to accept. The current system with large fluctuations in net total government take and relatively stable private profits, may be politically more acceptable since it gives the electorate an impression of effective rent extraction.

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[18] See section 1.9.

The government seems repeatedly to be taken by surprise each time there is a major change in the oil price. With a history of large fluctuations in both oil price and the exchange rate of US dollar, however, the oil price denominated in Norwegian kroner should not be expected to remain stable. Following price changes, the Ministry of Finance makes public an updated estimate of the consequence for the government net total take from the petroleum sector. This estimate often varies radically during the fiscal year, thus clearly illustrating the fact that most of the income risk is borne by the government. When the petroleum revenues fall below a certain level, the government proposes budget cuts. With this budget policy, inefficient risk sharing in the petroleum industry may also cause fiscal adjustment costs.

5.11 INCENTIVES VERSUS CONTROL

Focusing on asymmetric information and imperfect competition, this monograph contains principal-agent models that endogenously determine second best regulatory mechanisms in the petroleum industry. The optimal mechanisms are biased auctions and incentive contracts; distortive and individualised tax schedules designed to reveal private information and to capture as much resource rent as possible. The policy recommendations of this regulation theory approach contrast with those of the Chicago school, which by ignoring market imperfections, recommends that a petroleum license simply should be sold to the highest bidder.

The actual Norwegian regulatory system represents a third approach: Rent extraction is pursued by a uniform tax system, and the problem of asymmetric information is mitigated by control measures. The tax system is not designed to reveal private information by use of incentive contracts. Instead, resources are devoted to monitoring the private petroleum companies, thus reducing information rents by creating obstacles to strategic reporting of costs, extraction capabilities, etc. A special regulatory and controlling agency, Norwegian

Petroleum Directorate (NPD), has control of economic and technical data as one of its main objectives.

There are several specific factors reducing the effectiveness of monitoring as a means for enhanced rent extraction in the petroleum industry. As argued in section 5.2, due to the international nature of the petroleum industry, the high degree of vertical integration, the presence of considerable resource rents, the complex and non-standardised technology, and the uncertainty about the size and the quality of a given petroleum deposit, monitoring of costs is especially difficult in this industry. Consequently, the control measures will be imperfect; considerable noise in petroleum cost monitoring is inevitable. Moreover, in order to effectively deter misrepresentation of information, the controlling agency will have to impose high penalties if it detects deviations between reported and true costs. Limited liability restricts the size of these penalties.[19] Furthermore, monitoring and control activities are costly. To impose penalties the controlling agency must present verifiable documentation of misrepresentation, calling for detailed and costly investigations. Obviously, auditing the consolidated accounts of a multinational company, checking for transfer pricing between a large number of subsidiaries in many parts of the world, will be imperfect as well as resource demanding. Many resources will also have to be spent in control of technical data, e.g., by conducting independent geological and geophysical surveys. Finally, the present regime of discretionary licensing and monitoring, as opposed to auctions and incentive mechanisms, is based on discretion rather than rules, thus being more exposed to regulatory capture.

Taking into account the limitations and costs of control measures, optimal response to asymmetric information prescribed by regulation theory is a combination of monitoring and incentive mechanisms.[20] Norwegian petroleum regulation is based solely on control

[19] A possible penalty in the present system of discretionary licensing, is to deny equity shares in future licensing rounds. This penalty is not restricted by limited liability.

[20] An example is Baron and Besanko [1984]. In a model of private information about costs, the regulator has authority to ex post conduct an imperfect and costly audit and to impose penalties. Optimal regulatory policy implies incentive contracts. In addition, the regulator follows the following optimal auditing strategy: The company is audited if it reports sufficiently high costs, and the maximum allowable penalty is imposed if the realised costs are lower than reported.

measures. The focus on monitoring is not accidental; control measures are well founded in Norwegian industrial policy. Maybe now time has come to benefit from insights of the new regulatory economics.

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