RATIONAL EXPECTATIONS WITH MARKET POWER -

THE PARADOX OF THE DISADVANTAGEOUS TARIFF ON OIL

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This paper is circulated for discussion purposes only and its contents should be considered preliminary.

Introduction

The theoretical analysis of exhaustible resources has to date largely ignored the "geo-political realities" which preoccupy policy makers and has concentrated instead on the logically prior problem of analyzing market equilibrium in an autarkic economy. Autarky is a useful framework for the study of competitive equilibrium but is ill-suited to analyze the taxation of those exhaustible resources which are traded between large sovereign nation-states.

One feature that internally traded commodities such as oil share is the difficulty of enforcing future contracts. This property, together with the irreversibility of time - the fact that the past cannot be replayed - is crucial to our analysis and leads to the rather counter-intuitive conclusion that a large importing country may actually be harmed by its market power.

An assumption essential for obtaining this result is that a nation's tariff jurisdiction is limited. It cannot, in general, drive a tax wedge between all consumers and producers. Because tariffs on exhaustible resources figure so prominently in our discussion, we shall study them in some detail. Many economists, if asked to identify the important difference between domestic and trade taxation would argue that trade taxes are necessarily distortionary, whilst domestic taxes on rents, pure profits, etc. need not be.

The first task of this paper is to demonstrate that this distinction is often irrelevant for exhaustible resources. In section 1, we shall establish that, under certain assumptions, an ad valorem tax on output is equivalent to a rent tax and, therefore, non-distortionary. In a world of only one oil importing country (and many oil producers), the importer effectively has complete tax jurisdiction and can tax the producers' rent efficiently with an import tariff. Indeed, with constant extraction costs the importer can extract (almost) all the rent. If, however, other countries import oil, our importer may lose his tax power with a vengeance, even if (in fact, especially if) he remains a large importer, while others constitute a more competitive fringe. As we suggested above, his problem arises because he cannot enter, explicitly or implicitly, into long-term contracts with foreign suppliers, or more accurately cannot be bound to such contracts. Suppliers' current actions depend on the future behaviour of our importer, but, in the absence of binding contracts, they may have difficulty forecasting this behaviour. In section 2, we exhibit a model where this difficulty occurs. In section 3, we show that the same difficulty occurs in a much simpler model, which we adopt for its analytic convenience. We also discuss myopic expectations on the part of suppliers as a way of "predicting" future actions of the importer. In section 4, we consider rational expectations and show that, in this case, our importer may be severely disadvantaged. After providing a numerical example (in section 5) which demonstrates that the importer may be left worse off than a pure competitor in his position, we investigate what happens when he can impose quotas (i.e. when he can ration suppliers). Up to this point, we suppose that importing countries find oil too costly to store. In sections 7 and 8, we drop this assumption and permit costless storage. We discuss our main results in section 9. In section 10, we investigate conditions under which behaviour in our model coincides with that which would occur under binding contracts. Finally, section 11 discusses some of the connections of our analysis to other work.

1. The Taxation of Competitive Industry within National Boundaries

It is a familiar proposition of conventional tax theory that a tax on rent (or pure profits, correctly defined) is non-distortionary. This is also true for exhaustible resources using the natural definition of rent, providing the future is predictable.

Suppose the cost of extracting x units of exhaustible resources (called oil, for brevity) at date t, when the remaining stock is S is $C(x, S, t)$. Suppose also that there is a perfect substitute which can be produced indefinitely from a backstop technology at a cost $B(z, t)$ for supply z.[1] Let the dollar value of consumption be $U(x + z, t)$ so that the efficient path solves

$$(1) \qquad \text{Max} \int_0^\infty \left[U(x + z, t) - C(x, S, t) - B(z, t) \right] e^{-rt}\, dt$$

$$\text{subject to } x = -\dot{S},$$

$$\int_0^\infty x\, dt \leqq S_0$$

where r is the rate of discount and S_0 is the initial stock of oil. The necessary conditions for optimality can be found by applying the Maximum Principle to the Hamiltonian

$$(2) \qquad He^{rt} = U - C - B - \mu x$$

where μe^{-rt} is adjoint to $\dot{S}$. Choosing x, z, to maximize H gives

$$(3) \qquad \left.\begin{matrix} \dfrac{\partial U}{\partial x} - \dfrac{\partial C}{\partial x} - \mu \leqq 0 \\ x \geqq 0 \end{matrix}\right\} \text{complementarily} \qquad \left.\begin{matrix} \dfrac{\partial U}{\partial z} - \dfrac{\partial B}{\partial z} \leqq 0 \\ z \geqq 0 \end{matrix}\right\} \text{complementarily}$$

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1. This appears the simplest method of handling the post-exhaustion world. It is neither necessary that the substitute be perfect, not even that it ever be introduced, though in such cases it becomes more difficult to guarantee the existence of an optimum extraction policy. See Dasgupta and Heal (1974).

The shadow price of oil, μ, must satisfy

$$\frac{d\mu}{dt} - r\mu = -\frac{\partial He^{rt}}{\partial S} = \frac{\partial C}{\partial S}$$

Given reasonable assumptions on the functional forms, these equations will have a unique solution of the following form

$$(4) \qquad \frac{dp}{dt} = \frac{dc}{dt} + \frac{\partial C}{\partial S} + r(p - c) \qquad 0 \leqq t \leqq T$$

$$p = \frac{\partial B}{\partial z} \qquad T \leqq t$$

where p is the demand price for energy, U_x, or U_z, and c is the marginal extraction cost, C_x. The date of exhaustion, T, is found as the first date at which the price of oil, p, has risen to the marginal cost of replacing oil by the backstop. The initial price of oil is low enough to exactly exhaust S_0 by date T. (We shall assume that it is not too costly to preclude complete exhaustion.) Figure 1 shows a possible configuration where $z^*(t)$ is the solution to

$$B_z(z, t) = U_z(z, t)$$

and T' is the date of first introduction of the backstop. If marginal extraction costs are non-decreasing it will be possible to decentralise this optimum plan if resource owners are perfectly competitive and perfectly well informed about future prices. This can be seen as the special case of a zero rent tax in the following. Let rents, defined as $px - C$ be taxed at a constant rate τ, so that producers choose x to maximise

$$(5) \qquad \int_0^\infty (1 - \tau)(px - C)\, e^{-rt}\, dt$$

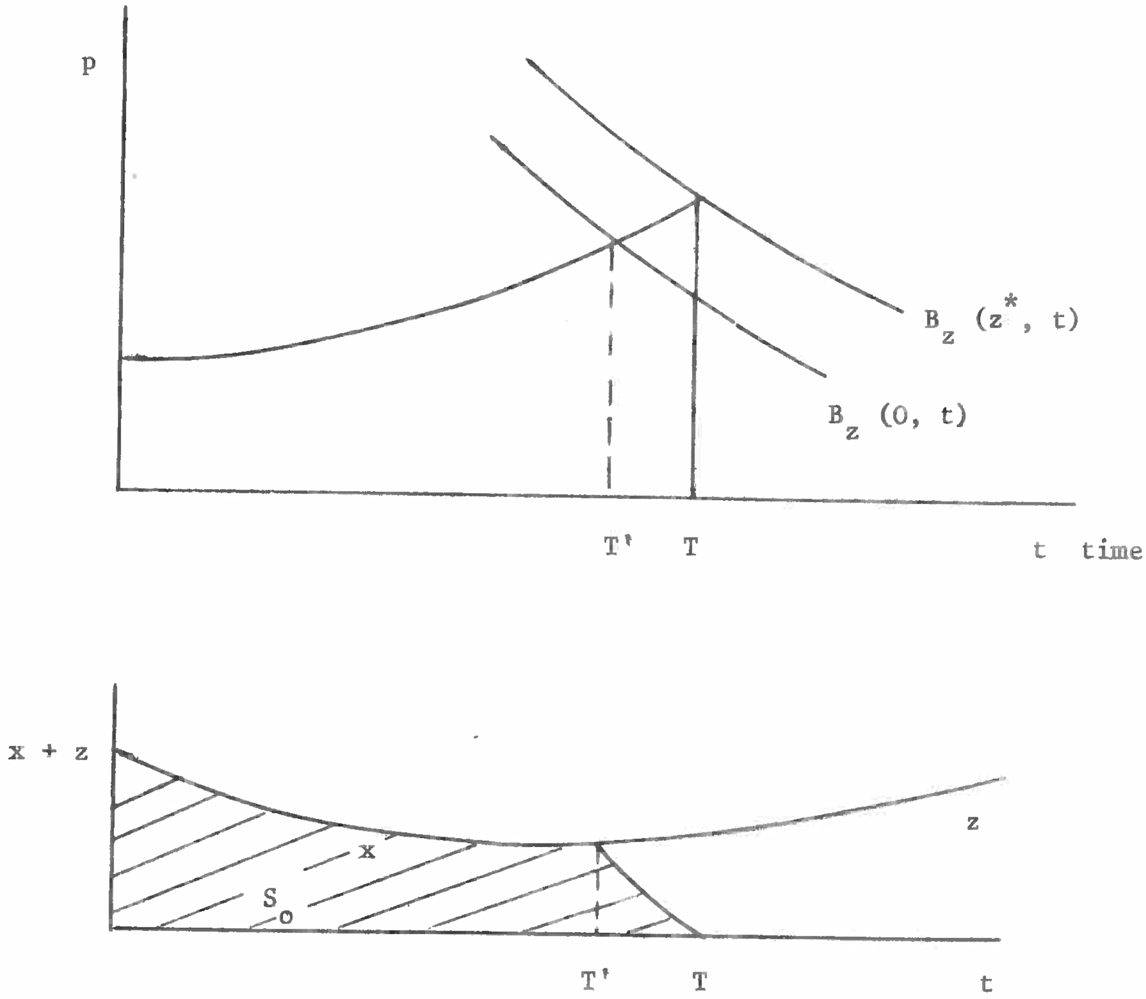

Figure 1 - Price and consumption paths

subject to the same conditions as before. As before

$$\text{(6)} \qquad He^{rt} = (1 - \tau)\ (px - C) - \lambda x$$

$$p \leqq c + \frac{\lambda}{1 - \tau}$$

$$\frac{d\lambda}{dt} = r\lambda + (1 - \tau)\frac{\partial C}{\partial S}$$

Since if $\mu = \lambda/1 - \tau$ the equations are identical to (3), the same price equation results from eliminating λ, and, if the same boundary conditions are imposed, we have thus established

Proposition 1 : Any constant ad valorem tax on rent defined as revenue less current extraction costs imposed on a competitive exhaustible resource industry leaves extraction Pareto efficient.

An excise tax on the output of a normal competitive industry is distortionary unless supply is completely inelastic, just as monopoly control of such an industry is distortionary. However, we know that under some conditions (constant elasticity of demand, zero extraction costs) a monopolized exhaustible resource may be efficiently extracted and the monopolist may have no monopoly power. It turns out that for essentially similar reasons, though under a wider range of conditions, an excise tax on oil may be non-distortionary. Indeed, in special cases an excise tax will be identical to a pure rent tax, allowing all the surplus to be taxed away.

Let p be the consumer (after tax) price, and p_n be the net producer price, so that the excise tax τ_e is $p - p_n$. Efficiency requires equation (4) to hold:

$$(4) \qquad \frac{dp}{dt} = \frac{dc}{dt} + \frac{\partial C}{\partial S} + r(p - c), \qquad 0 \leqq t \leqq T .$$

The producer price facing competitive resource holders must satisfy

$$(7) \qquad \frac{dp_n}{dt} = \frac{dc}{dt} + \frac{\partial C}{\partial S} + r(p_n - c)$$

together with the complementary slackness conditions of equation (3), and the boundary conditions. Excise taxes will be efficient, if, subtracting equation (7) from (4)

$$(8) \qquad \frac{d\tau_e}{dt} = r\,\tau_e$$

and

$$(9) \qquad p_n - c \geqq 0, \qquad 0 \leqq t \leqq T.$$

The requirement that net rent remains positive is non-trivial, since it may severely limit the degree of excise taxation. In particular, if some oil is left in the ground because it is too expensive to extract, then the rent on this marginal oil will be zero, and there is no non-distortionary excise tax. Summarising, we have

Proposition 2 : An excise tax which rises at the rate of interest is non-distortionary provided that it does not drive producer rents below zero.

It is interesting to note that although both excise taxes and rent taxes are non-distortionary, the time profile of tax payments will differ if costs are stock dependant for the rent tax payments per unit of oil $T = \tau(p - C)$ will behave as

$$\frac{dT}{dt} = r\,T + \tau\,\frac{\partial C}{\partial S}$$

from equation (4), whilst the excise tax rises at the rate of interest. If costs are independant of stocks the two taxes are exactly equivalent.

The intuitive explanation of these results is that an excise tax rising at the rate of interest has constant present value, so that it acts as a lump sum tax provided it does not affect the amount of oil sold; that is, provided marginal oil is still worth extracting. It is equivalent to the static problem of an excise tax on an inelastically supplied commodity. If, in addition, marginal costs are constant and stock independant, the excise tax is exactly the same as the non-distortionary rent tax.

2. Optimum Tariffs for Competitively Supplied Imports

The previous section showed that an excise tax could be non-distortionary. Implicit in this demonstration, however, was the assumption that producers could rely on the price trajectory's satisfying (7) in the future. (7), the well-known arbitrage equation (see Dasgupta and Heal (1974)) must be satisfied if producers are to supply oil at each instant t. If, for example, they believed that at some future date producer prices were going to rise more quickly than (7) entails, producers would refuse to supply oil until that date.

As long as oil is bought and sold within national boundaries, (7) can be guaranteed by futures contracts or law. International trade in oil, on the other hand, is a prime example of a market where futures contracts are often impossible to enforce. This limitation has profound consequences. As we shall see, the impossibility of binding forward agreements may prevent a large country from benefitting from its market power (exercised through reduced imports, as with the conventional optimal tariff). Ironically, that very market power may leave the country worse off than if it had no market power at all. Moreover, in such a framework, it is no longer possible to use optimal control theory to calculate the optimum tariff; a more sophisticated approach is required.

When agents' current decisions depend on their forecasts of the system's future evolution, decision-making is radically different from when agents act only on the basis of current and past observations. As Kydland and Prescott (1977) have observed in another context, optimal control theory is not then an appropriate tool for choosing a course of action. This point is clearly illustrated by the following example, in which we show why the tariff calculated by optimal control is incorrect.

To make the argument more transparent, assume that extraction costs are independent of stocks and flows and that every country has access to the backstop technology. The backstop can provide unlimited supplies of energy at a constant cost $\bar{p}(t)$. Our country derives dollar benefits $U(x)$ from the consumption of x units of oil, and the demand by the rest of the world for oil of price p is $y(p)$. The problem is to choose a level of imports x a production level z from the backstop technology, and a price trajectory p to maximize

$$(10a) \qquad W = \int_0^\infty \{ U(x+z) - px - \bar{p}z \} e^{-rt} \, dt$$

subject to

$$(10b) \qquad -\dot{S} = x + y(p)$$

$$(10c) \qquad \dot{p} = \dot{c} + r(p - c) \; .$$

Equation (10c) is just the arbitrage equation. At some date T stocks of oil $S(T)$ will be exhausted and $p(T) = \bar{p}$, with the rest of the world switching to the backstop technology. The Hamiltonian is

$$H = (U - px - \bar{p}z)e^{-rt} - \mu(x + y(p)) + \lambda(\dot{c} + r(p - c)).$$

Maximizing with respect to x, z:

$$\left.\begin{array}{l} U' \leq p + \mu e^{rt} \\ x \geq 0 \end{array}\right\} \text{complementarily}$$

$$\left.\begin{array}{l} U' \leq \bar{p} \\ z \geq 0 \end{array}\right\} \text{complementarily}$$

$$-\partial H/\partial S = \dot{\mu} = 0.$$

If q is the consumption price, $q = U'(x)$, then

(11) $$p = c + (p_0 - c_0)e^{rt}$$
$$q = \text{Min}\ \{c + (q_0 - c_0)e^{rt},\ \bar{p}\},$$

and the import tariff $q - p$ rises at the rate of interest, just as did the efficient excise tax of the previous section. Indeed, given the cost assumptions, such a tax is equivalent to a rent tax.

But this will not do. If there were no other consumers, then our country could extract the entire surplus from the competitive producers. As it is, our country has to convince other consumers and producers that it will set an initial excise tax μ, raise it at the rate of interest, and cease importing at the point where the consumer price reaches the backstop price $\bar{p}$. But the <u>import</u> price will still be below $\bar{p}$, and it will then be rational for the country to change its tax plan and continue to import until $p = \bar{p}$. This policy is satisfactory as long as suppliers are naive enough not to anticipate it. But suppose they do forsee it. Naturally they will alter their own behaviour to take the impending tax change into account. This alteration in turn induces the large importer to change his tax policy, implying a further change in supply, and so on. It may not be clear that there is an equilibrium in which behaviour by each side is consistent with "rational expectations" about the actions of the other side. In fact, an equilibrium - though, a rather strange one - does exist, as we shall now demonstrate. To make the nature of the equilibrium transparent, we shall first strip our model of all inessentials.

3. A Simple Multi-period Model of Monopsony

Let us suppose that competitive oil producers must exhaust a stock of oil S in the first two periods before a cheap substitute becomes available in period 3. Extraction is costless, so that producers supply in both periods only if they expect the price at i, p_i, to satisfy

$$p_1 = \beta\, p_2$$

where β is the world discount factor. A large oil importer, B, derives net utility

$$U' = a' \log x_1 + \beta \log x_2 - (p_1 x_1 + \beta\, p_2 x_2)$$

from consumption of oil x_i in period i. The rest of the world has demand for oil

$$(12) \qquad y_1 = \frac{b'}{p_1} \;, \quad y_2 = \frac{1}{p_2} \;.$$

Demand by the 'rest of the world' can, to close the model, be thought of as demand by the producers themselves, and equation (12) as the solution to the following problem:

$$(13) \qquad \underset{(x_1,\, x_2,\, y_1,\, y_2)}{\text{Max}} \; U_A = p_1 x_1 + \beta p_2 x_2 + b' \log y_1 + \beta \log y_2$$

subject to $x_1 + x_2 + y_1 + y_2 = S$.

For convenience, define new variables

$$a = a'/\beta \qquad b = b'/\beta, \quad U = U'/\beta.$$

$$p = p_2, \quad \therefore p_1 = \beta b$$

The phenomena we intend to study are essentially inter-temporal in nature, and would not arise in a one-period world. The Arrow-Debreu model is essentially a one-period world, for with a complete set of futures and insurance markets agents can conclude all transactions in the first period and spend the rest of the time fulfilling contracts. In order to prevent our model collapsing into this static one-period economy we assume that there are no futures markets and no binding contracts, in both cases because of the absence of a global legal authority. We shall, however, compare our equilibrium with the one which would have emerged with such contracts.

Initially we shall also assume that it is too costly to store oil above ground. The reason is that costless storage makes it possible to purchase second period oil in the first period, and might be thought to substitute for futures markets. Later (in sections 7 and 8) we shall examine the extent to which storage can replace forward contracts.

As a reference point the competitive equilibrium $(\bar{x}_1, \bar{x}_2, \bar{p})$ satisfies

$$(14) \qquad \bar{p} = \frac{a + b + z}{S} \;, \; \bar{x}_1 = \frac{a}{\bar{p}} \;, \; \bar{x}_2 = \frac{1}{\bar{p}} \;.$$

Notice that in this competitive framework, it makes no difference whether binding futures contracts exist or agents simply forecast future prices correctly. Agents' behaviour and the competitive outcome are the same regardless. We shall soon see that this absence of distinction exists precisely because no agent has market power and vanishes as soon as power is introduced.

One way to capture market power and the ideal that buyer B is relatively large (Note: we shall throughout consider the case of a large buyet and small sellers. We could, of course, have just as easily considered the opposite symmetric case)[1] is to allow buyer B to behave as a Stackelberg leader. To behave as leader, in this case, means to choose the prices p_1 and p_2, which other agents then accept as parametric. Since B chooses p_1 and p_2 at the same time - presumably in period 1 - we must specify whether p_2 is in fact <u>binding</u> or whether, once period 2 arrives, agent B can change it. Let us first consider binding contracts. To be supplied in both periods, B must choose

$$p_1 = p_2 = p$$

His maximisation problem is, therefore, to choose x_1, x_2 and p to

$$(15) \qquad \begin{aligned} &\text{Max } U_B = a \log x_1 + \log x_2 - p(x_1 + x_2) \\ &\text{subject to } x_1 + x_2 = S - \frac{1 + b}{p} = X(p) \end{aligned}$$

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1. We shall investigate the case of large buyers in future work.

Solving, we obtain

$$(16a) \qquad \bar{\bar{x}}_1 = \frac{a\ X(p)}{1 + a} \quad , \quad \bar{\bar{x}}_2 = \frac{X(p)}{1 + a}$$

which, when inserted into U_B give $U_B(p)$. Choosing p gives

$$(16b) \qquad \bar{\bar{p}} = \frac{1 + b + \sqrt{(1 + b)^2 + 4(1 + a)\ (1 + b)}}{2\ S}$$

Notice that we have considered B choosing import levels rather than import tariffs. Either formulation yields the same result, but the first is simpler. The implied tariff is simply $q - p$, where q is the demand price or dollar marginal utility. Thus

$$(17) \qquad \tau_1 = \tau_2 = \frac{1 + a}{X(p)} - p = \left(\frac{a + b + 2 - pS}{pS - (1 + b)}\right) p$$

While $(\bar{\bar{x}}_1, \bar{\bar{x}}_2, \bar{\bar{p}})$ in equation (16) solves B's two period maximization problem, that is not to say that, once period 2 arrives, B would not like to deviate from $(\bar{\bar{x}}_2, \bar{\bar{p}})$. In fact, B would like to deviate, in general. This is because the constraint $p_1 = p_2$ holds only for the original maximization problem of equation (15). Once period 1 has elapsed, the constraint is no longer binding, because time is irreversible and whatever transpired in the first period cannot be undone. Since we usually expect the solution to maximization problem to change after we drop a constraint it should not be surprising that B should want to break his contract. B's optimal contract breach is given by the solution to the following problem:

Let $S_1 = S - \bar{\bar{x}}_1 - \frac{b}{\bar{\bar{p}}}$, stocks at the start of period 2.

Choose p_2 and x_2 to maximize

$$(18) \qquad \log x_2 - p_2 x_2 \quad \text{subject to} \quad x_2 + \frac{1}{p_2} = S_1$$

The solution is given by

$$(19) \qquad p_2^* = \frac{g}{S_1} \ , \quad x_2^* = \frac{g-1}{p_2^*} \ , \quad \text{where} \quad g \equiv \frac{1}{2}(1+\sqrt{5}) \approx 1.618$$

It is easy to see that, depending on the parameters of the model, p_2^* can either be lower or higher than $\bar{\bar{p}}_2$. Only by accident will p_2^* equal $\bar{\bar{p}}_2$ (for example, when $a = b$ and all consumers have the same intertemporal preference pattern). Thus, it is very unlikely that B will wish to fulfill his contract.

One interesting feature of the case $p_2^* > \bar{\bar{p}}_2$ (where B would like to break the contract by offering a <u>higher</u> second period price) is that both principal parties - B and the competitive suppliers - are, in fact, better off when B breaks the contract $(\bar{\bar{p}}_1, \bar{\bar{p}}_2)$ than when contracts are binding. (To evaluate suppliers' welfare we assume that suppliers consume the "rest of the world" oil and are endowed with utility function (13).) Such a Pareto improvement, of course, is made possible by the fact that the binding contract configuration is not a competitive allocation. It has the peculiar implication that all parties to a trade agreement may agree to dispense with binding contracts in favor of an arrangement where binding contract prices prevail some of the time but are broken occasionally, and <u>in a way unforseeable to the suppliers</u>, by the monopsonistic buyer.

We emphasized the phrase in the last sentence because the success of contract reneging depends, of course, on the suppliers' not forseeing it. If a supplier <u>knew</u> beforehand that, in the second period, B was going to raise the price offered from $\bar{\bar{p}}_2$ to p_2^*, he would defer selling any oil until the second period, and if <u>all</u> suppliers knew, then B would fail to be supplied in the first period at all. Notice too that the failure of contract reneging does not require perfect foresight (i.e.,it is not necessary that the suppliers be able to calculate p_2^*), only an awareness that the monopsonist has an incentive to raise the second period price. If suppliers have rational expectations in this rather weak sense, agent B faces a dilemma. Even if he is an "agent of good faith" and promises to stick to the binding contract prices, he will not, in the absence of enforceable contracts, be able to be supplied in the first period (if $p_2^* > \bar{\bar{p}}_2$) or the second period (if $p_2^* < \bar{\bar{p}}_2$). His promises will simply not be credible. This dilemma is reminiscent of the problem of commitment, in the game theory literature. (see, for example, Schelling (1963). In many games, a player would be better off if somehow he could commit himself beforehand to pursue a certain strategy. Commitment would force other players to optimize with respect to his own strategic choice. Inability to self-commit on the other hand might induce the other players to choose strategies which are less favorable for him.

Before we discuss the resolution of this problem we should discuss the interpretation of the reneged contract equilibrium. If it was necessary for B to announce his original plans, and so enter into some kind of implicit contract, then the other agents were perhaps unwise to believe this plan, but their price expectations were reasonable given this belief. Suppose, on the other hand, that there is no explicit plan or contract, but that suppliers' naive price expectations remain naive. In this case B may be able to do even better than the reneged contract, for he can feely choose p_1 and p_2. Suppose, for example, that suppliers have static price expectations (i.e. they believe that the present value of tomorrow's price is the same as today's and thus are willing to supply in both periods). As before, B's second period problem is the same as equation (18) and the solution is given by equation (19)

$$(19) \qquad x_2 = \frac{S_1 (g - 1)}{g} \quad , \quad p_2 = \frac{g}{S_1} \ .$$

Supply in the first period will be as in equation (16a) with p_1 instead of p (reflecting suppliers' myopic price expectations):

$$x_1 = \frac{a}{1 + a} \left(S - \frac{1 + b}{p_1} \right) = S - \frac{b}{p_1} - S_1$$

whence

$$S_1 = \frac{S + \dfrac{a - b}{p_1}}{1 + a} \ .$$

B's overall problem is to

$$\max_{p_1} \quad a \log \left(S - \frac{1 + b}{p} \right) + \log \left(S + \frac{a - b}{p_1} \right) - \frac{a p_1 S}{1 + a}$$

where constants have been ignored. Setting $S = 1$ for simplicity, the solution is given by the cubic

$$a p_1^3 - a(1 + 2b - a)\, p_1^2 - (b(1 + a)^2 + a(a - b)(1 + b))p + (1 + b)(b - a)\,(1 + a)^2 = 0$$

In the numerical example calculated at the end of the next section, B does considerably better by exploiting myopic price expectations than he does by starting along the implicit contract path only to subsequently deviate from it.

4. Equilibrium with Rational Expectations

How then is agent B to behave in a world of no enforceable future contracts facing suppliers with intelligent predictive abilities? The answer is that, if he is to be supplied in both periods - which he certainly will require, given the logarithmic terms in his utility function - he must not only choose p_1 and p_2 subject to the constraint that $p_1 = p_2$ but also that, once the second period arrives, he has no incentive to alter p_2. Only then can he convince suppliers that p_2 will actually prevail. To solve B's problem we must work back from the last period. Suppose, then, that p_1 and x_1 prevailed in period 1, leaving a stock of oil

$$S_1 = S - x_1 - \frac{b}{p_1} .$$

Agent B's second period maximisation problem is:

$$\text{(20)} \qquad \text{Max} \log x_2 - p\, x_2 \quad \text{subject to } x_2 = S_1 - \frac{1}{p}$$

where B chooses x_2 (or, equivalently, p, which is simpler).
This yields

$$p\, S_1 = g \ (= \frac{1}{2} (1 + \sqrt{5})$$

or

$$\text{(21)} \qquad x_2 = \frac{g - 1}{p}$$

It is interesting to note that here, as in the reneged contract of equation (19), that the tariff required to sustain this import level is

$$\frac{\tau_2}{p} = \frac{\frac{1}{x_2}}{p} - 1 = g - 1 = .618$$

In addition, $p_1 = p$, so

(21b) $$x_1 = S - \frac{G}{p}, \quad G \equiv g + b .$$

Substituting these values of x_i in the full maximization problem:

(22) $$\underset{p}{\text{Max}} \quad a \log \left(S - \frac{G}{p}\right) + \log \left(\frac{g - 1}{p}\right) - p \left(S - \frac{1 + b}{p}\right)$$

whence

(23) $$p = \frac{G - 1 + \sqrt{(G + 1)^2 + 4 a G}}{2S} .$$

Since B has this equilibrium forced upon him, it is obvious that it makes him worse off than the binding contract equilibrium, which he would choose if he could. What is more surprising is that the Rational Expectation Equilibrium (REE) can make B worse off than in the competitive equilibrium, as the example below shows. In such cases B's market power is his undoing, and he would be better off without it. His problem is that there is no obvious way he can convince the rest of the world that he is renouncing this power (short of granting full fiscal autonomy to its States). It is B's potential ability to change future prices that induces expectations and responses in the other agents which are so unfavourable to B.

5. A numerical example

Consider the above model with parameter values

$a = 0.2, \quad b = 5, \quad S = 1$

	Competitive (1)	Binding Contract (2)	Reneged Contract (3)	Myopic forecasts (4)	REE (5)
p_1	7.2	7.025	7.025	9.077	6.788
p_2	7.2	7.025	6.129	4.121	6.788
τ_1/p_1	0	0.171	0.171	-0.390	0.177
τ_2/p_2	0	0.171	0.618	0.062	0.618
x_1	0.028	0.024	0.024	0.057	0.025
x_2	0.139	0.122	0.100	0.229	0.091
$U_A + 4$	1.403	1.375	1.275	1.057	1.344
$U_B + 5$	1.109	1.125	1.173	1.495	1.079

Note : U_A, U_B have had constants added to produce positive numbers.

Observe that $U_B^4 > U_B^3 > U_B^2 > U_B^1 > U_B^5$, where superscripts refer to equilibria. B's market power makes him worse off in the REE than if he were a competitive importer and could divide himself up into small importing units, thereby divesting himself of the ability to set prices. Aggregating suppliers with other consumers as in equation (13) we notice that

$$U_A^1 > U_A^2 > U_A^5 > U_A^3 > U_A^4$$

and suppliers would also prefer the binding contract to either the REE or reneged contract equilibrium. Both parties would be interested in finding a means of credibly enforcing contracts. If we distinguish between producers and the other consumers, this harmony of interest vanishes - the consumers prefer 5 to 3 to 2 to 1 to 4.

In this example the monopsonist is disadvantaged because he places a relatively high premium on second period imports, and has relatively greater monopsony power then. (In competitive equilibrium B counts for only 4% of the first period demand, but 50% of the second period's.) His incentive to renege on the initial tariff plan is thus great, and can only be eliminated by reducing second period supplies to the point where his great need for consumption offsets his monopsony power. This is done by producers, who, fearing a low second period price, sell more in the first period and so drive the price below the binding contract level. The example is rather extreme, but bears an unpleasant similarity to the U.S. position, itself derived from past profligacy in consuming domestic oil stocks. The boundary values for a, b, such that the REE is no worse than the competitive equilibrium roughly satisfy $b^* = 2 + 4.6\, a^*$, for $0 < a < 1$. For $b < b^*$ or $a > a^*$ the monopsonist is advantaged by his market power.

6. Quotas

Notice that in the preceding example $p_2^* < \bar{\bar{p}}_2$; that is, B would like to renege on the second period price so as to lower this price. In the REE this incentive has been removed. But suppose B can impose import quotas in the first period. Suppliers, forecasting a fall in price in period 2, try to sell everything in the first period, but fail, as B refuses to import more than $\bar{\bar{x}}_1$, and are forced to sell at the lower second period price. Does this mean that B can take actions in the first period to force suppliers to accept the reneged contract equilibrium (or some alternative even more favourable to B)? Does B benefit from imposing quantity constraints which prevent the market from clearing? Somewhat surprisingly, the answer is no.

If the other consumers are distinct from the suppliers, then B will be unsuccessful in preventing p_1 falling to p_2, since suppliers will off-load oil onto the remaining consumers until $p_1 = p_2$. Suppose therefore that the suppliers themselves are the remaining consumers, and if they fail to sell oil to B they are forced to either consume it themselves or retain it for the second period. Then, the opportunity cost to the suppliers of consuming oil is not the high price p_1, but the lower price p_2. This means that the only question affected by p_1 is how much B pays for his period 1 purchases. Thus, B might as well drive p_1 down as low as is consistent with being able to purchase what he wants - that is, down to p_2. A similar argument holds when $p_2^* > \bar{\bar{p}}_2$. Thus it is impossible to sustain different prices in the two periods with rationale expectations, and quotas act no differently from tariffs.

7. Market equilibria with storage

We suggested earlier that costless storage would allow agents to conclude transactions in period 1, and might, by collapsing the problem into a one period, remove the paradoxical results. It is certainly true that stroage can make a difference to the equilibria, but not necessarily to B's advantage. To see this, we shall continue with the original model and recompute the various market equilibria. The competitive equilibrium remains unaltered, as does the binding contract equilibrium - in both cases all transactions are effectively concluded in the first period, and agents either lack the power or the right to renegotiate in the second period. However, this is not true if B can break his contract in period 2. If B knows that the rest of the world is myopic, his problem is to choose purchases X_i, and consumption x_i in period i to:

$$(24) \qquad \text{Max} \quad a \log x_1 + \log x_2 - (p_1 X_1 + p_2 X_2)$$

$$\text{subject to} \quad X_1 = 1 - \frac{1+b}{p_1}, \quad X_2 = \frac{1}{p_1} - \frac{1}{p_2}$$

$$x_1 \leqq X_1, \ x_1 + x_2 = X = X_1 + X_2$$

(The rest of the world stores $\frac{1}{p_1}$, and will sell some if $p_2 > p_1$)

Consider the case in which $X_1 > x_1$, and replace p_2 by p. B's optimal consumption plan is, as in equation (16a), to set

$$x_1 = \frac{a}{1+a} X, \quad x_2 = \frac{X}{1+a}, \quad X = 1 - \frac{b}{p_1} - \frac{1}{p}$$

whereupon the problem of equation (24) simplifies to

$$(25) \qquad \max_{p,\, p_1} \quad (1+a) \log X - (p_1 + \frac{p}{p_1}),$$

omitting an irrelevant constant term. The solution requires the prices p, p_1 to simultaneously satisfy

$$(26a) \qquad p = \frac{p_1}{2b} \left\{ \sqrt{4b\, p_1 + 1} - 1 \right\}$$

$$(26b) \qquad p = \frac{p_1}{2(p_1 - b)} \left\{ 1 + \sqrt{1 + 4(1+a)(p_1 - b)} \right\}$$

Using the same numerical values as before gives

	p_i	τ_i/p_i	X_i	x_i	y_i
Period 1	6.947	0.170	0.136	0.025	0.720
Period 2	7.523	0.082	0.011	0.123	0.133

$$U_B + S = 1.134 \qquad U_A + 4 = 1.368$$

With these parameter values B is, of course, better off than with the binding contract, but worse off than if there had been no storage. A is worse off than with the binding contract, but better off because of storage. However, storage is a mixed blessing and the results can go the other way. Consider the interesting symmetric case in which $a = b = 1$. Without storage the binding contract, reneged contract and REE are identical, because B has no incentive to change the second period price.

	Without Storage	With Storage
p_1	3.236	2.968
p_2	3.236	3.840
X	0.382	0.403
τ_1/p_1	0.62	0.67
τ_2/p_2	0.62	0.29
$U_B + 5$	0.453	0.533
$U_A + 4$	2.887	2.828

In this case, storage is attractive for B and unattractive for A and this continues to be true if the reneged price $p_2^* > \bar{\bar{p}}_2$ without storage. The symmetric example shown above shows that storage can still be attractive to B if $p_2^* < \bar{\bar{p}}_2$, but the earlier example shows that it need not be. Notice that with storage there is no difference between the reneged and the myopic price expectations equilibria.

8. Rational Expectations Equilibrium with storage

The most interesting case is, of course, the REE. Suppose first of all that B can pay for stocks of oil in period 1 which suppliers (or some trustworthy third party) will hold until period 2. B thus commits himself to store a known amount z. Again, his purchases are X_i, consumption x_i, and his second period problem is

$$\text{(27)} \qquad \text{Max } \log (X_2 + z) - p\, X_2 \text{ subject to } X_2 = S_1 - \frac{1}{p}$$

which yields

$$\text{(28a)} \qquad x_2 = \frac{1}{p^2\, S_1} = X_2 + z = S_1 - \frac{1}{p} + z$$

(28b) $$S_1 = \frac{1 - zp + \sqrt{(1 - zp)^2 + 4}}{2p}$$

This solution is plugged into the first period problem:

(29) $$\max_{z,\, p} \quad a \log x_1 + \log x_2 - p\left(S - \frac{1 + b}{p}\right)$$

$$x_1 = S - \frac{b}{p} - (S_1 + z)$$
$$x_2 = S_1 + z - \frac{1}{p}$$

provided, at least, that $z \geqq 0$. Differentiating with respect to z gives

$$\left.\begin{array}{l} \dfrac{x_1 - a\,x_2}{x_1\,x_2}\left(1 + \dfrac{\partial S_1}{\partial z}\right) \leqq 0 \\ z \geqq 0 \end{array}\right\} \text{complementarily}$$

At $z = 0$

$$1 + \frac{\partial S_1}{\partial z} > 0, \quad S_1 = \frac{g}{p},$$

(29a) $$x_1 = S - \frac{b + g}{p}, \quad x_2 = \frac{g - 1}{p}$$

and

(29b) $$x_1 \geqq a x_2 \quad \text{if} \quad Sp \geqq b - a + g(1 + a).$$

Suppose this to be satisfied with inequality, then

(30) $$x_1 = a x_2 = \frac{a}{1 + a}\left(S - \frac{1 + b}{p}\right).$$

Differentiating with respect to p gives

$$\frac{x_1 - a\,x_2}{x_1\,x_2}\,\frac{\partial S_1}{\partial p} + \frac{1}{p^2}\left(\frac{1}{x_2} - \frac{ab}{x_1}\right) - S = 0\ .$$

Substituting from equation (30) gives

$$p = \frac{1 + b + \sqrt{(1 + b)^2 + 4(1 + b)(1 + a)}}{zs}$$

which satisfies the strict inequality of equation (29b) if $b > a$. If $b \leq a$, $z = 0$, and the solution is found by substituting (29a) in equation (29) to yield once more the REE without storage. Summarising, we have the remarkable result that if B wishes to <u>lower</u> the price in the second period (i.e $b > a$) then the storage RE equilibrium is exactly the binding contract equilibrium of equation (16) whilst if B wishes to raise the price in the second period ($b < a$) the storage RE equilibrium is the same as the REE without storage. In the first case the extreme disadvantage of the no-storage REE is avoided, whilst in the second case, where the REE was superior to the competitive equilibrium, storage makes no difference.

The obvious question to ask is whether this dramatic reversal of B's fortunes in the case $b > a$ depends on his publicly committing hostages, in the form of stored oil, to fortune. What would happen if storage took place unobserved on his own territory? In such a case the rest of the world observes first period purchase X_1, but not z, so that B chooses z and X_2 (or p) to

$$\text{Max} \quad a \log (\overline{X}_1 - z) + \log (z + \overline{S}_1 - \frac{1}{p}) - p(\overline{S}_1 - \frac{1}{p})$$

Choosing z yields equation (30) again, choosing p gives (28a). Again, this solution is fed into the first period problem of equation (29), and again, the binding contract equilibrium results. It makes no difference whether B's consumption and storage decisions are observable with rational expectations, because agents can predict or deduce them.

The conclusion is that under some conditions ($b \geq a$), costless storage substitutes for binding futures contracts provided the other feature of futures markets - information about futures prices - can be supplied by rational forecasting. To the extent that agents are myopic there will be an incentive for B to depart from his original plan and falsify the assumptions on which the rest of the world based their supply and consumption decisions. Such intertemporal price discrimination works only if it is unanticipated for otherwise agents can arbitrage away the price difference.

9. Discussion

If the government has tax jurisdiction over oil suppliers and consumers the optimal excise tax rises at the rate of interest. If the government can enter binding futures contracts with foreign suppliers the optimal tariff will look exactly the same, as it will if oil can be costlessly stored, and the rest of the world has rational expectations, and B wishes he could lower the final period price below the binding contract level ($b \geq a$). However, if storage is costly, binding futures contracts do not exist, and complete tax jurisdiction is impossible, the optimal tariff changes dramatically. If suppliers are myopic, then the importer will continually revise his tariff, and depart from the apparently optimal plan. If suppliers are sophisticated enough to appreciate this temptation, or if they learn from experience that the import tariff is continuously revised, then they will change their behaviour considerably, and thus greatly alter the optimal import tariff. Their response can in fact, make the monopsonist importer worse off than if he were to behave competitively. This paradoxical result was demonstrated in a very simple two-period model and we should ask whether the model was very special, or whether the results are robust. (In defence of the model, it should be said that although it is the simplest model capable of exhibiting the paradox, it is surprisingly rich in the variety of equilibrium concepts it can display, and we think gives remarkably clear insights into the issues).

One obvious criticism of the model is that the supply response is perfectly elastic, so that producers sell only in the periods of highest expected price, and not at all in any period of lower expected price. If marginal extraction costs are increasing this will no longer be true, so that a variety of intertemporal price paths will be consistent with profit maximizing behaviour. The appendix shows, however, that this criticism does not weaken the results (though it greatly increases the complexity of the problem.)

The paradoxical result in which the monopsonist is harmed by his market power arises only when he has an incentive to lower the final period price. This induces the suppliers to drive down the earlier prices, which results in other consumers buying too much. If he wishes to raise the final period price he cannot be made worse off than acting as a competitive importer, for if he imported the competitive level of imports earlier on, suppliers would predict that he would drive down the final period price. Somewhere <u>between</u> the reneged contract plan and the competitive plan is one which leaves no incentive to deviate (i.e. the REE), and it will yield an intermediate level of utility.

This implies that if the backstop is available (at some cost) before oil is exhausted, and if the price of oil is set by this backstop, (as in the original optimal control problem) then the monopsonist does derive at least some benefit from his market power, and there is no paradox. This is because the binding contract plan requires him to switch to the backstop <u>before</u> other consumers, and makes it attractive for him to re-enter the market and <u>increase</u> prices later. Thus a paradox is more likely if a dramatic breakthrough in oil substitutes is anticipated, and less likely if there is a smooth transition from oil to the backstop. On the other hand, even if the paradox does not apply, it remains true that the optimum tariff with rational suppliers must be calculated recursively, as in the simpler model, and does not satisfy the appealing rule (of increasing at the rate of interest) of the optimal excise tax. Thus the model remains useful in characterising the equilibria.

What happens if there are more than two periods? It should be clear from the examples that it is difficult to characterise the general form of the REE. The problem is that market power differs in each period, and in general there is no simple relationship between consumption and the choice variable, price. There is, however, one special case in which the REE is readily calculable - when it coincides with the binding contract equilibrium.

10. The consistency of simple tax rules and repeated games

If, in the simple model, $a = b$, B has not incentive to change p_2, and the three equilibria (binding contract, reneged contract and RE) coincide. The same is true if $y_1 = cb/p_1$, $y_2 = c/p_2$ and $a = b$. This naturally prompts the question when will the monopsinist have no incentive to deviate from his initial plan? When, in short, does the REE collapse into the binding contract equilibrium? The following model shows how stringent are the conditions for this to happen, and given some insight into the general requirements.

Consider a model with zero extraction costs, with no backstop available before T, and initial stocks small enough to guarantee exhaustion by T. Let the price be p, the ad valorem tariff rate be τ (constant on the binding contract path) and let both B and the rest of the world exhibit constant elastic demand:

$$y(p) = p^{-\varepsilon}$$

$$V(p) = \frac{ap^{1-\alpha}}{\alpha - 1} \qquad \alpha > 1$$

where $V(p)$ is B's indirect function. Post-tariff net present discounted welfare will be

$$W = \frac{a\, p_0^{1-\alpha} (1 + \tau)^{-\alpha} (1 + \alpha\tau)\, \emptyset\, (\alpha r)}{\alpha - 1}$$

where p_0 is the initial price, $\emptyset(m) \equiv \frac{1}{m}(1 - e^{-mT})$ is a discount factor, and r is the rate of interest and the rate of increase of p. If X, Y are the total consumption of B and the rest of the world,

$$X = a\, p_0^{-\alpha} (1 + \tau)^{-\alpha}\, \emptyset\, (\alpha r)$$

$$Y = p_0^{-\varepsilon}\, \emptyset\, (\varepsilon r)$$

$X + Y = S$, initial stocks of oil.

The optimal choice of τ satisfies

$$\tau = \frac{X}{\varepsilon Y} = \frac{a p_0^{\varepsilon-\alpha} (1 + \tau)^{-\alpha}\, \emptyset\, (\alpha r)}{\emptyset\, (\varepsilon r)} .$$

In general τ will depend upon T, and, through p_0, on the initial stock S. As time elapses these will both change and B will wish to change τ. However, in the special case in which $\varepsilon = \alpha$,

$$\varepsilon\, \tau = a(1 + \tau)^{-\varepsilon}$$

solves for τ, which is independent of time (and stocks). Only in this very special case will the REE coincide with the binding contract equilibrium solved here. If extraction costs are not constant, or if both parties do not have inelastic demand curves, then, as time passes, the ratio

$$\frac{x(p(1+\tau))}{y(p)}$$

will change, changing the optimum tariff. If p_T is fixed (by a backstop) then the original argument shows that τ changes over time.

The other case in which B has no incentive to alter the tariff again occurs when the future continues to appear the same (in the relevant sense) with the passage of time. If the reminaing oil stock is unknown, then Gilbert (1978) has shown that if the probability distribution for the stock remaining is stationary, then the optimal extraction rate will be constant (if costs and demands are also stationary). In such a world the optimum tariff would also remain constant, for the future will always look like the present. (To some extent this finesses the problem by making oil quasi-inexhaustible and hence like a conventional produced good).

Another way the future can be rendered stationary is to consider a repeated version of a one-shot game. If our multi-period oil game could be played over and over again, we would find that the binding contract equilibrium emerges as a possible REE, as long as players' discount rates are not too high. This follows for much the same reasons that cooperative behaviour becomes viable in an indefinite repetition of the Prisoner's Dilemma. The market for oil, therefore, is an especially good vehicle for demonstrating our paradoxical results. An exhaustible resource, by its very nature, lends itself to a one-shot rather than to a repeated game theoretical formulation.

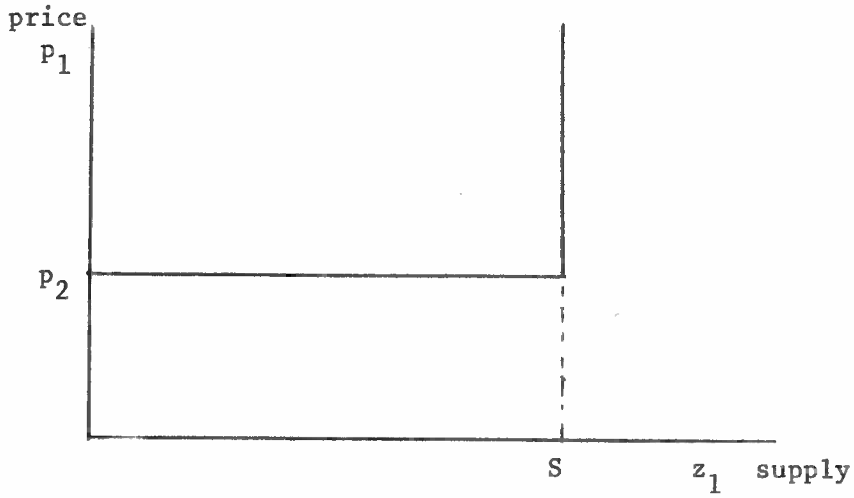
11. Related work

Aumann (1973) gives three examples of disadvantageous monopolies, in which the core allocation to the monopolist is inferior to his competitive allocation. However, as he points out, the "conclusion runs counter to common sense as well as to economic theory. Perhaps what is needed at this stage is a careful reappraisal of the ideas underlying the use of the core in economic analysis ... The kind of phenomenon illustrated for the core ... is of course impossible in classical theory. If the monopolist sets prices, he cannot end up worse off than at the competitive equilibrium ..." (ibid. p.9). In an example, the monopolist does set prices and individual agents take them as parametric, but nevertheless the monopolist may finish up worse off than in the competitive allocation because of our non-classical model.

Kydland and Prescott (1977) point out the shortcomings of the optimal control solution to policy making in a world of rational agents. They are concerned with repeated games, so that time does not have the same irreversibility of our problem, but they find that where the optimal control solution converges to a consistent policy (in which agents have learned how policy is chosen, and there appear to be no reason to change the policy) then typically this consistent policy is inferior to the true optimum (which may be very difficult to compute) and often inferior to simple policy rules (such as "expand the money supply by the trend growth in real output"). Their point is well-taken, but it leaves a number of unanswered questions. The true optimum would seem to be a rational expectation Stackelberg equilibrium, and it is interesting to ask whether this is likely to be a fairly simple rule or something much more complex. Obviously it would be hard to compute, but the case for "rules rather than discretion" looks otherwise incomplete. The other problem is that if the rules can be improved upon, then rational agents might anticipate deviations, and the problem re-emerges. Kydland and Prescott recognise the need to make it institutionally very difficult to change rules, thus reducing the importance of this criticism. It is clear, though, that there are important, unanswered questions remaining, and we hope that our paper will further stimulate interest in these problems.

Appendix - The effects of variable extraction costs

It might be thought that the paradox derives from the special assumption that the marginal costs of extraction for the producers are zero in each period, so that supply curve is a perfect step function, with



equilibrium on the horizontal section. This is not so, though it becomes more difficult to construct examples when the supply curve is a function of the intertemporal pattern of prices. As an illustration, suppose the present discounted marginal costs of supplying z_i in period i are mz_i (Again, it is easier to redefine units so that the rate of interest is zero.) The suppliers, expecting prices p_i, maximize profits

$$\Sigma(p_i z_i - \frac{m}{2} z_i^{z}) \quad \text{st} \quad \Sigma z_i \leqq S$$

which yields supply curves

$$z_1 = \frac{1}{2} (S + \frac{1}{m} (p_1 - p_2))$$

$$z_2 = \frac{1}{2} (S - \frac{1}{m} (p_1 - p_2))$$

The effect of this supply response is to change the equilibrium intertemporal price structure from $p_1 = p_2 = p$ to a more complex relationship $p_1 = f(p_2) = f(p)$, whose form will depend on the market structure (i.e. on the equilibrium concept). Thus, in the case of the competitive equilibrium

$$z_2 = \frac{2}{p_2} = \frac{1}{2}(S - \frac{1}{m}(p_1 - p_2))$$

or $$p_1 = p + m(S - \frac{4}{p}) = f_c(p)$$

The prices can be found as before from

$$\frac{a + b}{f(p)} + \frac{2}{p} = S$$

The solution is continuous in m (the slope of the supply curve) and as m tends to zero, so the new equilibrium converges to the equilibrium in the original problem. In the Stackelberg equilibrium we again have

$$x_2 = \frac{g - 1}{p_2}, \quad y_2 = \frac{1}{p_2}$$

$$z_2 = \frac{g}{p_2} = \frac{1}{2}(S - \frac{1}{m}(p_1 - p_2))$$

or $$p_1 = p + m(S - \frac{3.236}{p}) = f_s(p)$$

Notice the slight difference in functional form between the competitive and Stackelberg price patterns. The solution is found by noting that x_i are (more complex) functions of p, hence so is utility, and it can be maximized for a suitable choice of p. Again, the functions are continuous in m, from which it follows that there is a sufficiently small value of m which yields the paradox again.

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