Disadvantageous Oil Tariffs and Dynamic Consistency

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A large importer who places relatively greater weight on future than current oil consumption will import less oil in the future than if it were able to commit itself in advance to future tariffs, and may find itself worse off than if it were unable to impose tariffs at all. Futures markets and storage modify these adverse effects and may avoid the problem of dynamic inconsistency. (JEL 026)

The analysis of natural resource taxation has largely concentrated on the taxation of resources extracted within the legal jurisdiction of the government.[1] With few exceptions,[2] the analysis of import tariffs on natural resources has been neglected, presumably on the grounds that it raises no issues not covered in the standard international trade literature.

Theodore Bergstrom (1982) is one of these exceptions, and he argues that tariffs on oil have a special and attractive property. He observes that excise taxes on inelastically supplied goods fall entirely on the supplier. If oil is available in a fixed amount and is (essentially) costless to extract, then its total supply will be inelastic. If it is competitively supplied, then a constant *ad valorem* tax will fall entirely on the supplier, and in a closed economy the government could use the tax to extract the entire rent. With international

trade in oil and many noncooperative consuming nations, he shows that if each nation chooses the optimal constant *ad valorem* tariff, taking the choices of other governments as given, and if suppliers are competitive, then again the entire incidence of the tariffs will fall on producers and cause no distortion.[3]

Bergstrom's paper is mainly concerned with the exercise of monopsony power on the part of importers, and it thus falls within the standard optimal tariff framework. Two other arguments for tariffs have been advanced, though neither will be considered here. The first is the argument that if supplies of oil are subject to random interruptions then it may be optimal to impose a tariff to reflect the increased vulnerability that oil imports imply. (See the discussion in William Nordhaus, 1974, and, for a more recent treatment of policies to reduce vulnerability, James Plummer 1982.) The other argument is that of countervailing power against the OPEC cartel.[4] In practical policy

[1] See, for example, Mason Gaffney (1967); Gerard Brannon (1975); Partha Dasgupta, Geoffrey Heal, and Joseph Stiglitz (1980); Ross Garnaut and Anthony Clunies Ross (1983).

[2] Since our (1978) working paper pointing out the likely dynamic inconsistency of an open loop import tariff, several other papers have appeared that explore consistency issues in the international oil market. As we explain below, these papers work with quite different models and for the most part ask different questions.

[3] This argument continues to go through if the marginal cost of extraction is positive but constant. It fails, however, if marginal cost is an increasing function of the quantity extracted. Indeed, Larry Karp (1984) shows that a monopsonist importer's optimal open-loop tariff will be dynamically inconsistent if competitive sellers face increasing extraction costs. If the importer could impose a fixed tax in addition to the *ad valorem* tariff on any seller supplying a positive quantity of oil, then it could extract all the rent from the oil and restore the dynamic consistency of the open-loop tariff even in the presence of increasing costs. Neither conclusion remains if, as in our model below, there are competitive buyers as well as the large importer.

[4] See Theodore Bergstrom, John G. Cross, and Richard Porter (1981) for the case of bilateral monopoly.

discussions it is clearly necessary to recognize the bilateral monopoly (or oligopoly) aspect of the world oil market, but for a theoretical understanding it seems to us worthwhile to clarify a problem that arises with tariffs even with monopsony power alone.[5]

There is a significant difference between the choice of an optimal tariff on an ordinary (perishable)[6] produced good, and that on an imported exhaustible resource such as oil: in choosing an optimal tariff on a normal good, all the country need announce is the current rate of the tariff, since whether the supplier wishes to supply now depends only on the current price. In the case of oil, suppliers will only sell now if to do so is more advantageous than keeping the oil in the ground for later extraction and sale. They thus need to compare current oil prices with predicted future prices, and these will in turn depend on future levels of the tariff. In principle, then, when choosing an oil import tariff, the government should be choosing a time path for the oil import tariff. (Thus, in

Bergstrom's 1982 model the government chooses a constant *ad valorem* rate, which producers expect to continue into the future, and to which they respond.)

If governments can commit themselves to an announced time path of import tariffs, (i.e., to an "open-loop" strategy), then standard optimization techniques can be used to find the optimal path of the tariff, which, as will be shown below, has a particularly simple and intuitive form. The critical issue is, however, whether governments can so commit themselves. Even within a national jurisdiction there are obvious difficulties facing a government wishing to commit its successors, and there is certainly widespread skepticism on the part of oil producers about the stability of announced tax regimes. But even if governments could overcome this local difficulty, they would find it more difficult to do so on the international front, for it is the essence of national sovereignty to be free to change trading arrangements when it is advantageous. International agreements such as the GATT may have some effect in providing stability in trade tax regimes, but it is notoriously easy to circumvent that agreement by apparently domestic taxes, or by other means. When it comes to trade in such a strategically sensitive product such as oil, it is equally clear that neither long-term contracts on the part of suppliers nor long-term commitments on the part of buyers are normally credible—neither can be readily enforced since no supranational body has the power to impose effective sanctions on those who break contracts.

In this paper we explore the implications of the inability of countries to commit to future tariffs. We show precisely why the optimal open-loop tariff (the optimal tariff assuming commitment) is dynamically inconsistent, that is, why an importer would wish to change the time path of the tariff in midstream. More importantly, we shall point out the qualitative differences between equilibrium with and without commitment.

The literature on the dynamic inconsistencies of open-loop policies is, by now, quite large. It embraces macroeconomic policy (Finn Kydland and Edward Prescott, 1977), the exploitation of a free access resource

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Bergstrom (1982) briefly discusses the case in which all importing countries choose the *same* constant *ad valorem* tariff against a single monopoly supplier, but this will be optimal only in very special circumstances. Albert Nichols and Richard Zeckhauser (1977) consider the related problem of choosing the optimal stockpile to countervail a monopoly supplier, which, as David Newbery (1984) shows, can be done better by the choice of a countervailing tariff. All these papers suffer from the difficulty that the monopolist is modeled as implausibly passive—see Newbery (1984).

[5]Jonathan Eaton and Zvi Eckstein (1984) study several models with both a large importer and exporter (although they also include a brief discussion of the 1978 version of this paper). Rather than analyze how the inability of parties to commit themselves to future actions affects the time paths of prices and quantities (i.e., computing the open-loop and dynamically consistent paths), they concentrate on the role that oil reserves (storage) can play in improving the importer's position. However, they run into the usual difficulty of modeling timing that bilateral monopoly creates: does the importer or exporter move first or do they move simultaneously?

[6]Goods that can be stored share some of the durability properties of exhaustible resources, and hence face similar problems to those discussed here. See Stokey (1982), and the discussion of storage later.

(Jennifer Reinganum and Nancy Stokey, 1985, and David Levhari and Leonard Mirman, 1980), and sales by a durable good monopolist (Jeremy Bulow, 1982, and Stokey, 1982), among other topics. There is, moreover, a small set of papers that deals with inconsistency in exhaustible resource settings. Alistair Ulph and Folie (1980) and David Newbery (1981) (which builds on Eric Maskin and David Newbery, 1978) treat the case of monopoly sellers, whereas, in addition to the papers mentioned above,[7] Murray Kemp and Long (1980),[8] and Eckstein and Martin Eichenbaum (1985)[9] examine large importers. Indeed, there is an interesting contrast between modeling large suppliers and large buyers in the absence of commitment. In the former case, the open-loop strategy is dynamically inconsistent only in certain cases, and for a large class of other cases will be dynamically consistent. (See Newbery, 1981.) As we shall see below, the open-loop optimal tariff is always dynamically inconsistent except in one borderline case.

In Section I, we present the model and exhibit the conventional open-loop optimal tariff for a large importer. In Section II we argue that this tariff policy is almost certain to be dynamically inconsistent. We also define the dynamically consistent equilibrium that would prevail if the importer could not commit to future tariffs. In a two-period (present/future) version of the model, we show that this latter equilibrium entails lower

oil prices, lower future and total imports, and higher tariffs than in the open-loop equilibrium, if the large oil importer places greater relative weight on future imports (compared to current imports)—as would be the case for an importer with rapidly depleting oil reserves, like the United States.[10] Just the reverse is true if the importer places comparatively *less* weight on future imports.

The inability to commit itself to future tariffs can serve only to lower the importer's welfare. In Section III we show by example that if it places sufficiently greater weight on the future, the large importer may actually be made worse off for having the ability to impose tariffs than if it had no tariff setting power at all. That is, it may be harmed by its monopsony power.

The analysis through Section III assumes that futures markets in oil are absent and that the importing country cannot store oil cost effectively. In Section IV we argue that the availability of a futures market can overcome the dynamic inconsistency of the open-loop tariff. If, however, spot markets continue to operate in the future, the importer may actually have to sell oil, only to buy it back later. We also show that the ability to store oil can serve as a partial substitute for a futures market.

I. The Open-Loop Tariff

Suppose that the marginal cost of extracting oil is c. Suppose also that at date T a cheap alternative to oil (for example, fusion) will become available in unlimited quantities at a constant marginal cost $c^* < c$. If oil producers act competitively, that is, as price takers, and face prices p_t at date t, then each will choose an extraction/sales rate s_t to maximize the present discounted value of profits, subject to the condition that cumulative extraction does not exceed the total initial stock, S. Because $c^* < c$, no oil producer will be able to operate profitably after date

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[7]That is, those by Karp (1984) and Eaton and Eckstein (1984), which, as noted above, use quite different models and emphasize different issues from those treated here.

[8]Murray Kemp and Ngo Long (1980)—like David Newbery (1976) (the immediate precursor to the present paper) on which it builds—recognizes the inconsistency of the open-loop tariff policy but fails to exhibit the consistent tariff.

[9]Zvi Eckstein and Martin Eichenbaum (1985) do not explicitly model sellers. Instead, they simply postulate an inverse supply function with no assurance that this derives from a seller optimization problem. Their model, therefore, is not suitable for considering the strategic interaction between buyers and sellers that is the concern of this paper.

[10]Strictly speaking, this is true only if the importer has no discretion over the rate of domestic depletion, otherwise the problem is more like that of optimal storage, considered in Section IV.

T. The producer's problem, therefore, is to choose s_t to maximize

$$(1) \qquad \sum_{t=1}^{T} \left\{ (p_t - c)s_t \right\} \delta^{t-1},$$

subject to

$$(2) \qquad \sum_{t=1}^{T} s_t \le S,$$

where δ is the discount factor. Hence, in any period in which s_t is positive,

$$(3) \qquad (p_t - c)\delta^{t-1} = \lambda,$$

where λ is the Lagrange multiplier for (2). This gives the standard arbitrage condition

$$(4) \qquad p_t - c = \delta(p_{t+1} - c).$$

Henceforth, assume that the marginal utility of oil at zero consumption is larger than c. Then, in equilibrium, s_t is positive in every period and the initial price determines the entire trajectory. This boundary condition is determined by market clearing:

$$\sum_{t=1}^{T} d_t = \sum_{t=1}^{T} s_t,$$

where d_t is demand in period t.

Now consider the problem of choosing the amount of oil to import, x_t, for a country large enough to influence the world market price of oil. Suppose that the demand for oil by all other consumers in aggregate is $y_t(p)$.[11] Suppose that the importer announces a time path x_t at date zero, and all producers believe that the plan will be followed. There is full information about $y(p)$, stocks, and extraction costs, so that all producers can predict future prices and choose

their extraction and sales plans at date zero. We assume that neither is there a futures market in oil, nor can consumers store oil for future consumption (but see Section IV where these assumptions are dropped). The importer's problem is to choose x_t to maximize domestic welfare, where the dollar benefit of oil at date t is $U(x, t)$. The discounted value of benefits less costs is given by

$$(5) \qquad \sum_{t=1}^{T} \left\{ U(x_t, t) - p_t x_t \right\} \delta^{t-1},$$

and this has to be maximized subject to the resource constraint

$$(6) \qquad \sum_{t=1}^{T} \left\{ x_t + y_t(p_t) \right\} \le S,$$

and subject to the arbitrage condition (4) that producers are willing to supply at each date. If we let the domestic price of oil be $q_t = \partial U(x_t, t)/\partial x$, then $q_t - p_t$ represents the importer's tariff on oil. The optimal tariff satisfies

$$(7) \qquad \tau_t \equiv q_t - p_t = \tau_1 \delta^{t-1},$$

where τ_1, the initial tariff, is just the Lagrange multiplier for (6). Notice that if the other consumers were not present so that $y_t(p) = 0$, the importer could extract all the producers' profit by adjusting the tariff so that $p_1 = c$. This reflects the general proposition that an import tariff rising at the rate of interest acts as a lump sum tax since oil is in fixed supply.

To call the solution, $x^*(\cdot)$, of the program (4)–(6) the "importer's optimum" presumes that the importer can commit itself to this time path.[12] If it cannot make such a commitment, then at time $\hat{t} > 0$ it will face the problem

$$(8) \qquad \text{Max} \sum_{t=\hat{t}}^{T} \left\{ U(x_t, t) - p_t x_t \right\} \delta^{t-\hat{t}},$$

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[11] Hence the other consumers are assumed to be price takers and their current demand is independent of future prices. This can be derived from preferences which are additively separable in the oil consumption of different periods and linear in other commodities.

[12] We shall sometimes argue as though the importing country's policy instrument is its level of imports. Setting an import level, of course, is equivalent to the more conventional policy of setting a tariff.

subject to (4) and

$$\sum_{t=\hat{t}}^{T} \{ x_t + y_t(p_t) \} \le S_{\hat{t}},$$

where $S_{\hat{t}}$ is the stock remaining at time $\hat{t}$. Let $\hat{x}(\cdot)$ be the solution to the latter program. As we shall see in the next section, only by mere happenstance will $\hat{x}_t$ and x_t^* coincide for $t \ge \hat{t}$. But without coincidence, x_t^* cannot be regarded as the importer's optimum, because, once period $\hat{t}$ arrives, the importer will prefer an alternative time path.

Clearly, in a world where it cannot predetermine its future oil imports (or, equivalently, cannot bind itself to future import tariffs), the importer must optimize subject to the additional constraint that it should not later wish to change its plan. After all, announced future import levels that will later be changed have no bearing on rational suppliers, who can forecast what the real levels will be. In the remainder of this paper, we explore the nature of the importer's optimum under this additional constraint.

II. Dynamically Consistent Tariffs

When the importer cannot commit itself in advance to a tariff trajectory, we must consider the relative timing within each period: does the importer set its tariff before, simultaneously with, or after the sellers choose their supplies? We wish to argue that it makes the most sense to suppose that the importer moves first.[13] Suppose that we enrich the model slightly to allow for small random shocks each period to the importer's oil requirements (i.e., to its utility function). Assume, furthermore, that the realizations of these shocks are better known to the importer than to the sellers. Then, because in any period the import tariff will depend on the realization of the shocks, the sellers are better off waiting until the importer has set

its tariff before determining their supplies. This would be true even if a seller could, at a cost, learn the value of the realization directly: given its small size, the seller cannot affect the importer's behavior by moving earlier, and so therefore can delay its selling decision without cost (i.e., it will not gain from learning the value and so will not pay the cost). Note that this reasoning does *not* symmetrically apply if the sellers, as well as the importer, are subject to shocks. Because it is big, the importer profits from moving first and so would be willing to sacrifice the additional information it could acquire by delay.

We can solve for the importer's optimum by dynamic programming. Suppose that in the final period T the remaining stock of oil is S_T. The importer chooses the level of imports, x, knowing that this will affect the import price, p, through the market clearing relations $x + y(p) \le S_T$. The dependency of price on imports is best handled as a standard constrained maximization problem,

$$(9) \qquad \text{Max}_{x,p} \{ U(x, T) - px \},$$

subject to

$$x + y_T(p) \le S_T.$$

Let $x_T(S_T)$ and $p_T(S_T)$ be the maximizing choices of x and p, and define

$$V_T(S_T) \equiv U\{ x_T(S_T), T \}$$
$$- p_T(S_T) x_T(S_T).$$

Proceeding by backward induction, the importer faces the following problem in period t if the remaining stock is S_t:

$$(10) \quad \text{Max}_{x,p} \big[U(x, t) - px$$
$$+ \delta V_{t+1} \{ S_t - x - y_t(p) \} \big]$$

subject to

$$x + y_t(p) \le S_t$$

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[13]We are grateful to Oliver Hart for discussions on this point.

and the arbitrage condition

$$p - c = \delta\left[\,p_{t+1}\{\,S_t - x - y_t(\,p)\} - c\,\right].$$

Let $x_t(S_t)$ and $p_t(S_t)$ be the maximizing values of the control variables, and take $V_t(S_t)$ to be the maximized value of the objective function. Solving these T iterative programming problems determines the dynamically consistent equilibrium.

To study the qualitative properties of this equilibrium, we shall simplify by making the following assumptions:

A1 There are two periods ($T = 2$), 'now' and 'the future,' and the marginal extraction cost c is zero.

A2 The preferences of the large importer are $U(x, 1) = aU_1(x)$, $U(x, 2) = U_2(x)$, where the U_i are increasing and strictly concave ($U_i' > 0$, $U_i'' < 0$), and a is a parameter to be varied.

A3 The rest of the world has demand $y_i(\,p_i)$ in period i, where

$$y_i' < 0, \quad p_i y_i''(\,p_i) + 2 y_i'(\,p_i) < 0$$

$$< p_i y_i''(\,p_i) + y_i'(\,p_i),$$

and

$$\frac{y_2''(\,p)}{y_2'(\,p)} \geq \frac{\delta y_1''(\delta p)}{y_1'(\delta p)}.$$

These conditions are sufficient to ensure that the first-order conditions guarantee an optimum, as shown in the Appendix, and are satisfied for $y(\,p) = b_i p^{-\varepsilon}$, $0 < \varepsilon \leq 1$—a constant elasticity of demand schedule. The large importer's preferences can be written

$$(11) \quad aU_1(x_1) + \delta U_2(x_2) - p_1 x_1 - \delta x_2 p_2.$$

For numerical illustrations (see Section III and the Appendix) we consider the example $U_1(x) = \delta \log(x)$, $U_2 = \log(x)$, $y_1(\,p) = \delta b/p$, $y_2(\,p) = 1/p$. In this case, the importer's objective function is

$$(12) \qquad \delta a \log(x_1) + \delta \log(x_2)$$

$$- p_1 x_1 - \delta p_2 x_2.$$

In the Appendix we give the analytical solution to this example. (These functional forms may obscure the fact that here—as in the rest of the paper—the discount factor δ is common to everyone.)

Suppose that there exists a_0 such that if $a = a_0$ the open loop equilibrium coincides with the dynamically consistent equilibrium. (In the example the critical value is $a_0 = b$, at which point all importers value future consumption equally relative to current consumption.) We claim that at all values $a \neq a_0$, the open loop equilibrium is not dynamically consistent. To see why this is so, it will be helpful to consider how the importer would behave in the second period if it had the opportunity to renege on its tariff commitment. The following proposition is our main result.

PROPOSITION 1: *Given assumptions* (A1–A3) *above, suppose there exists a_0 such that if $a = a_0$ the open loop (binding contract) equilibrium (x_i^*, p_i^*, τ_i^*) coincides with the dynamically consistent equilibrium (x_i^e, p_i^e, τ_i^e). Then if $a > a_0$,*

$$(i) \quad p_2^{**} > p_2^*, \quad x_2^{**} > x_2^*, \quad \tau_2^{**} < \tau_2^*,$$

and

$$(ii) \quad p_i^e > p_i^*, \quad x_2^e > x_2^*, \quad \tau_2^e < \tau_2^*,$$

$$x_1^e + x_2^e > x_1^* + x_2^*, \quad i = 1, 2,$$

where $(x_2^{**}, p_2^{**}, \tau_2^{**})$ *are the large importer's optimal choices in the second period if the binding contract is reneged. The inequalities go the other way if $a < a_0$.*

The proof is given in the Appendix. It is not difficult to explain this result intuitively. If the importer places comparatively greater weight on first-period oil consumption, (i.e., $a > a_0$), it would like to ensure that a relatively low first-period price prevails. But it must also induce the competitive producers to supply at this low price rather than holding off until the second period. In other words, it is constrained by the arbitrage condition (4). The importer satisfies the arbitrage condition—that is, it also keeps the second price low—by committing itself to a

high second-period tariff (thereby restraining second-period demand). Once the second period actually arrives, however, there is no longer a need for a high tariff; the arbitrage condition is now irrelevant because the first-period oil has already been sold. Thus if the importer can somehow get out of the commitment, it will reduce the tariff, import more oil, and thereby drive the market price up. The oil suppliers will also profit from this reneging, although, of course, if they had anticipated its occurrence, they would not have been willing to sell in the first period.

If $a < a_0$, the argument is just the reverse. The solution now requires an exceptionally *low* tariff in the second period in order to keep the market price high enough to induce producers to sell then. With the arrival of the second period, the importer will have the incentive to raise the tariff, and, if successful, will make the suppliers regret that they did not sell all their oil in the first period.[14]

This sort of argument also explains the discrepancy between the open loop and dynamically consistent equilibria. The proposition implies that for $a > a_0$, $p_i^e > p_i^*$, $i = 1, 2$, $x_2^e > x_2^*$, and $\tau_2^e < \tau_2^*$. To see why these relations hold, recall that the second-period reneging price p_2^{**} is greater than the open loop price p_2^*. Then, if $p_2(S_2)$ is the optimal second-period price for the large importer when the stocks at the start of period 2 are S_2 (the solution to (6) in the Appendix) $p_2^{**} = p_2(S_2^*)$, and so

$$(13) \qquad p_1^* < \delta p_2(S_2^*).$$

To satisfy the arbitrage equation in the dy-

namically consistent equilibrium, the importer must bring the left- and right-hand sides of (13) into equality, that is, it must (a) make first-period prices more attractive and (b) make second-period prices less attractive to suppliers. But (a) implies that $p_1^e > p_1^*$, and, since $p_2^e = p_1^e/\delta$, it must be that $p_i^e > p_i^*$, $i = 1, 2$. Hence $y_i^e < y_i^*$, $i = 1, 2$.

To accomplish (b), and drive down the second-period price, S_2 must be made larger than S_2^*. Since $p_2^e > p_2^*$ and $y_2^e < y_2^*$, $S_2^e > S_2^*$ implies that $x_2^e > x_2^*$. Finally, $(x_2^e, p_2^e) > (x_2^*, p_2^*)$ implies that $\tau_2^e > \tau_2^*$.

Without making stronger assumptions, we cannot say which of x_1^e and x_1^* is larger when $a > a_0$. Although $p_1^e > p_1^*$ and $S_2^e > S_2^*$ (which suggests that x_1^e should be less than x_1^*), it is possible for $p_1^e + \tau_1^e$ to be less than $p_1^* + \tau_1^*$ (which would imply that $x_1^e > x_1^*$). (In the example given in the Appendix it is possible to show that $x_1^e < x_1^*$.)

Proposition 1 therefore gives an almost complete characterization of the dynamically consistent equilibrium relative to the easily solved open loop equilibrium, in which the optimal tariff would rise at the rate of interest—the only incompleteness concerns the level of first-period imports. The proposition starts by defining a benchmark for the relative importance of consumption in the two periods for the large importer. The benchmark is that weight on first-period consumption which provides no incentive to renege on the open loop equilibrium. The main result can be summarized as follows. If the large importer places greater weight on first-period consumption (relative to the benchmark weight), then the dynamically consistent equilibrium will be characterized by a higher price, a higher second-period level of imports and a larger total level of imports by the large importer, than in the open loop equilibrium. The inability to commit to the open loop tariff is advantageous to oil producers but harmful to the large importer and other consumers. In the opposite case in which the large importer places relatively less weight on first-period consumption, prices are lower, other consumers are better off, and the large importer and the suppliers are worse off than in the open loop equilibrium.

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[14]This may seem to suggest that when $a < a_0$ the importer can implement the binding contract equilibrium, even when commitment is impossible, by using an import quota: the importer can set $x_1 = x_1^*$ as in the open loop equilibrium and refuse to import more than x_1^* in an attempt to keep up the first-period price. Of course, rational suppliers will forecast a fall in next period's price and will try to unload all their oil in the first period. While the import quota stops them selling more to the large importer, the fall in price will induce other importers to increase their demand, and so the price will fall below p_1^* after all.

This suggests that one should ask whether there are simple examples in which the open loop equilibrium is dynamically consistent, for then one can consider perturbations about these special cases. Newbery (1976) shows that if the large importer and the rest of the world each have unchanging demand schedules of constant elasticity, and if extraction costs are zero, then the only case in which the open loop tariff is dynamically consistent is that in which the demand elasticities are the same. The result can be generalized slightly as follows.[15] Suppose that oil is costless to extract and must be used up by date T. At date t demand by the rest of the world is $y(p) = b_t p^{-\varepsilon}$, and by the large importer is $x_t = a_t q^{-\alpha}$, where q is the tariff-inclusive price, and a_t and b_t vary over time. At date t the optimal open loop tariff is given by

$$\tau = \frac{X_t}{\varepsilon Y_t} = \frac{p_t^{\varepsilon - \alpha}(1 + \tau)^{-\alpha}}{\varepsilon}$$

$$\times \frac{\int_t^T a_u e^{-\alpha r u}\, du}{\int_t^T b_u e^{-\varepsilon r u}\, du},$$

where X_t and Y_t are the remaining amounts of oil which will be consumed between t and T by the large importer and the rest of the world, with $S_t = X_t + Y_t$ being remaining stock. (The derivation is given in the Appendix.) Thus if $\varepsilon = \alpha$, and $a_t = kb_t$, then the *ad valorem* tariff rate is constant (as required for the open loop tariff), and there is no temptation to deviate. The share of imports by the large importer remains the same and so the future always looks the same. If $\alpha = \varepsilon$, but a grows more slowly than b (that is, the large importer places relatively more weight on the present), then the formula shows that the importer would like to lower the tariff in the future and import more than in the open

loop equilibrium. The case will be just as in Proposition 1 with $a > a_0$.

III. Disadvantageous Monopsony

The inability to commit to future tariffs clearly acts as a constraint on the importer's behavior. The importer's welfare is lower in the dynamically consistent equilibrium than in the open loop equilibrium (since, with commitment, the importer always has the option of reproducing the dynamically consistent quantities). What we shall argue now is that, in the absence of commitment, the importer's market power may actually work to its *disadvantage*. That is, its very ability to set import tariffs may leave it worse off than had it had no tariff-setting powers at all.[16]

To make this point we must first describe the equilibrium that would emerge were the importer unable to set tariffs. We shall refer to this as the *competitive* equilibrium. In the two-period model, a competitive equilibrium is a vector of prices and imports (p_1^c, p_2^c, x_1^c, x_2^c) such that

$$(14) \qquad \frac{\partial}{\partial x}\left\{ U(x_t^c, t) - p_t^c x_t^c \right\} = 0,$$

$$t = 1, 2,$$

$$(15) \qquad \sum_{t=1}^{2}\left\{ x_t^c + y_t(p_t^c) \right\} = S,$$

and

$$(16) \qquad p_1^c = \delta p_2^c,$$

where, as before, other importers choose $y_i(p_i^c)$ and (16) reflects the assumption that extraction costs are zero.

Because there are no tariffs in the competitive equilibrium, prices must be higher than in either the open loop or dynamically consistent equilibria. We first show that, in the

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[15]The suggestion to pursue this line of inquiry comes from Bergstrom.

[16]We should point out that, although we use the term "disadvantageous monopsony," the phenomenon we are concerned with is completely distinct from that considered by Robert Aumann (1973).

TABLE 1—COMPARISON OF EQUILIBRIA

| Variable | Values in Various Equilibria | | | |
	Competitive	Open-Loop	Consistent	Reneged
p_1	7.2	7.025	6.788	7.025
p_2	7.2	7.025	6.788	6.131
x_1	0.028	0.024	0.025	0.024
x_2	0.139	0.122	0.091	0.101
W	1.109	1.125	1.079	1.173
τ_1/p_1	0.0	0.171	0.177	0.171
τ_2/p_2	0.0	0.171	0.618	0.618
S_2	0.278	0.264	0.238	0.264

case $a > a_0$, prices in the dynamically consistent equilibrium must be intermediate between the competitive and open loop prices. To see this, notice that, because it is always desirable to have a positive tariff,

$$(17) \qquad p_2^c > p_2(S_2^c),$$

where again $p_2(S_2)$ is the optimum second-period price for the large importer given stock S_2. Thus, p_1^c and $p_2(S_2^c)$ do not satisfy the arbitrage condition. To bring them into line, we must reduce p_1 (and raise $p_2(S_2^c)$). Hence the dynamically consistent first-period price, p_1^e must be less than p_1^c, and so $p_1^* < p_1^e < p_1^c$ by the Proposition.

The welfare of the large importer is a concave function of prices, with a maximum at the open loop prices, and so when $a > a_0$, the importer's welfare in the dynamically consistent equilibrium is between the welfare levels for the competitive and open loop equilibria.

By contrast, when the importer places greater relative weight on second-period imports than do other consumers ($a < a_0$) the dynamically consistent prices are *less* than the open loop prices. Thus we can no longer bound the importer's welfare between the competitive and open loop levels. Indeed, as the following example shows, if the importer places sufficient relative weight on the second period, its dynamically consistent welfare may actually be less than the competitive level.

Example: Consider the logarithmic utility function and unit elastic demand schedules of the example of equation (12) (analyzed in

the Appendix), and let $a = 0.2$, $b = 5$, $S = 1$, and $\delta = 1$. We obtain Table 1, where W refers to the total importer welfare (plus 5), and τ_i/p_i ($i = 1, 2$) is the proportional tariff in period i.

In this example, the importer's incentive to raise the tariff in the second period of the open loop equilibrium is so strong that, for dynamic consistency, it is forced to set an exceptionally high second-period tariff and, consequently, to import exceptionally little oil. Given the importance of second-period oil to welfare, this ability to set high tariffs turns out to be the importer's undoing.

IV. Futures Markets and Storage

In Sections I–III we assumed that futures markets do not exist and that consumers cannot store oil. This meant that all consumption arose directly from spot purchases. We next investigate how our results change in the presence of forward trading or storage.

Clearly, if a futures market for date 2 oil merely replaced the date 2 spot market, then the importer could duplicate its open loop program in our two-period model, and the issue of commitment to future tariffs would not arise. All the importer would have to do at date 1 is to buy x_1^* on the spot market (at price p_1^*) and x_2^* on the forward market (at price $\delta p_2^* = p_1^*$).[17]

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[17] We speak of the importer as doing the purchasing, as though it were government policy. But of course no government intervention is needed: the consumers buy x_i^* at price $p_i^* + \tau_i^*$.

The more delicate question arises when there is a futures market in *addition* to the date 2 spot market. In that case, it will not suffice for the importer simply to buy x_1^* and x_2^* at date 1 because there is nothing preventing it from reentering the market at date 2 and altering its date 2 consumption.

To see the issues involved, consider the importer's problem at date 2, assuming that it purchased z units of oil on the futures market[18] and that S_2 is the remaining stock (including z). The importer chooses x_2^* and p_2 to

$$(18) \qquad \underset{p_2, x_2}{\text{Max}} \, U_2\{x_2\} - p_2(x_2 - z),$$

subject to

$$x_2 + y_2(p_2) \le S_2.$$

The first-order conditions are

$$(19) \qquad U_2' - p_2 - \lambda = 0,$$

$$(20) \qquad -(x_2 - z) - \lambda y_2' = 0,$$

and

$$(21) \qquad x_2 + y_2(p_2) - S_2 = 0.$$

Suppose that the importer tried to implement the open loop equilibrium quantities. If we replace the variables in (19)–(21) with their open loop values, the left-hand sides of those equations become

$$(22) \qquad U_2'(x_2^*) - p_2^* - \lambda^*,$$

$$(23) \qquad -(x_2^* - z) - \lambda^* y_2'(p_2^*),$$

and

$$(24) \qquad x_2^* + y_2(p_2^*) - S_2^*.$$

By definition of the open loop equilibrium, (22) and (24) equal zero. Moreover, we

can always choose a value of z (possibly negative) so that (23) is zero too. Thus the importer can, after all, ensure the open loop outcome, even though it cannot prevent the spot market opening in the second period.

Now, if $a < a_0$, we know from Proposition 1 that $x_2^{**} < x_2^*$, $p_2^{**} < p_2^*$, so $y_2'(p_2^{**}) < y_2'(p_2^*)$. Consequently, at $z = 0$, (23) is negative, where (23) is the marginal gain from raising p_2 above p_2^*. Hence, in this case the optimal z is positive. However, if $a > a_0$, the optimal z is negative, that is, it is optimal for the importer to *sell* oil forward and buy it back in the second period. This peculiar behavior is simply a device for ensuring that the importer has no incentive to raise the price of oil in the second period: the more oil it has to buy, the lower the market price it prefers.

Turning to storage, we see that if we reinterpret z as the amount of oil the importer buys and stores, then (19)–(21) are the importer's first-order conditions in the second period, assuming that storage is possible and costless but that futures markets are absent. Of course, negative values for z now make no sense. Thus we conclude that in the case $a < a_0$, the possibility of storage enables the importer to implement the open loop equilibrium,[19] whereas, in the case $a > a_0$, storage makes no difference at all to the dynamically consistent equilibrium (since any worthwhile deviation from zero storage would require negative, infeasible, levels of z).

Although storage is of no use in the case $a > a_0$, it has a dramatic effect on the possibility of disadvantageous monopsony, since, from Section IV, this is possible only if $a < a_0$. In this case storage, if feasible and not too costly, restores the open loop option and eliminates the disadvantage. A strategic oil reserve may thus make sense for a large importing country faced with rapidly declining domestic oil reserves.

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[18] Again, we can think of the consumers themselves doing the buying, as long as we interpret the tariff as a subsidy when z is negative.

[19] This result breaks down if extraction is costly (even if storage is not) since, given discounting, it would be preferable to extract the stored oil in the future—it would be better to store the oil in the ground, not above it.

V. Concluding Comments

In this paper we have explored the consequences for a large oil importer of an inability to commit its future import tariff levels. Our main objective has been to derive qualitative results within a general two-period model. We have shown that in comparing the dynamically consistent equilibrium with the committed, or open loop, equilibrium, the critical determinant is the relationship between the rate at which the large importer trades off current versus future oil in consumption. If the large importer places relatively greater weight on current oil consumption (compared to future consumption)[20] it will set a lower tariff on imported oil, and, in the future will import less oil than if it were able to commit itself in advance to future tariff levels (i.e., to an open loop tariff). When the large importer places relatively greater weight on future consumption, the results reverse, and in that case the importer can find itself worse off than were it unable to impose tariffs at all. Only in the knife-edge intermediate case will the open loop tariff be dynamically consistent.

We also examine the extent to which futures markets and the ability to store oil get around the dynamic inconsistency problem. If oil extraction costs and storage costs are both zero, then storage can restore the dynamic consistency of the open loop equilibrium in the case where, otherwise, the importer would reduce the tariff in the future. Thus, in particular, it solves the problem of disadvantageous monopsony. But if either oil is costly to extract (so that its price appreciates less rapidly than the rate of interest), or if oil is costly to store (above the interest costs) then storage can be at best partially successful. Moreover, it is no use at all in the case where the importer is tempted to *raise* the future tariff in the open loop equilibrium.

APPENDIX

Proof of Proposition:
We need to show that if $a > a_0$,

$$(1) \qquad p_2^{**} > p_2^*, \quad x_2^{**} > x_2^*, \quad \tau_2^{**} < \tau_2^*,$$

and

$$(2) \qquad p_t^e > p_t^*, \quad x_2^e > x_2^*, \quad \tau_2^e < \tau_2^*,$$
$$x_1^e + x_2^e > x_1^* + x_2^*, \quad i = 1,2,$$

where superscript e refers to the dynamically consistent equilibrium, $*$ to the open loop (binding contract) solution, and where $(x_2^{**}, p_2^{**}, \tau_2^{**})$ are the large importer's optimal choices in the second period if the binding contract is reneged. Because the arbitrage condition $p_1 = \delta p_2$ must be satisfied, the binding contract equilibrium solves the program

$$\operatorname*{Max}_{x_1, p_2} a U_1(x_1) + \delta U_2 \{ S - x_1 - Y(p_2) \}$$
$$- \delta \{ S - x_1 - Y(p_2) \} p_2$$
$$- \delta p_2 x_1,$$

where $Y(p_2) = y_1(\delta p_2) + y_2(p_2)$ is total imports over both periods by other countries. The first-order conditions are

$$(3) \qquad a U_1' - \delta U_2' = 0,$$

$$(4) \quad -\delta U_2' Y' - \delta(S - x_1 - Y) + \delta p_2 Y' - \delta x_1 = 0,$$

where $Y'(p_2) = \delta y_1' + y_2'$, and $Y'' = \delta^2 y_1'' + y_2''$. Equation (3) gives the time path of the tariff. By definition, $a U_1' = q_1 = p_1 + \tau_1$ and $U_2' = q_2 = p_2 + \tau_2$, and so from (3) and the arbitrage condition, $q_1 = \delta q_2$ and $\tau_1 = \delta \tau_2$. Thus the tariff rises at the rate of interest, confirming the general result of Section III. The matrix of second derivatives is

$$\delta \begin{bmatrix} a U_1''/\delta + U_2'' & U_2'' Y' \\ & -U_2' Y'' + (Y')^2 U_2'' \\ Y' U_2'' & +2Y' + p_2 Y'' \end{bmatrix}.$$

Because $U_t'' < 0$ and $p_t y_t'' + 2 y_t' < 0$, $y_t'' > 0$, and $y_t' < 0$, the matrix is negative definite. Hence the first-order conditions are sufficient for an optimum.

In the second period, the large importer would like to choose p_2 to maximize

$$(5) \qquad U_2 \{ S - x_1 - y_1 - y_2(p_2) \}$$
$$- p_2 \{ S - x_1 - y_1 - y_2(p_2) \},$$

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that is, to satisfy

$$(6) \qquad -U_2'y_2' + p_2 y_2'$$
$$-(S - x_1 - y_1 - y_2) = 0.$$

Let the solution to this problem be p_2^{**}. Clearly, $p_2^{**} = p_2^*$ at $a = a_0$. Now, just as we showed that the maximand in the binding contract program is concave in p_2, so (5) is concave in p_2. Thus to show that $p_2^{**} > p_2^*$ for $a > a_0$, it suffices to show that, when we replace p_2^{**} by p_2^*, x_1 by x_1^*, and $y_1(\delta p_2^{**})$ by $y_1(\delta p_2^*)$, the left-hand side of (6) is increasing in a at a_0.[21] Differentiating the left-hand side of (6) with respect to a, we obtain

$$(7) \quad \{ -U_2'y_2'' + Y'(1 + y_2'U_2'') + p_2 y_2'' + y_2' \} \frac{dp_2^*}{da}$$
$$+ \{ 1 + y_2'U_2'' \} \frac{dx_1^*}{da}.$$

Implicitly differentiating (3) and (4) with respect to a and solving for dx_1^*/da and dp_2^*/da, we find

$$(8) \quad \frac{dx_1^*}{da} = -\frac{\delta U_1'}{\Delta} \{ (p_2 - U_2')Y'' + 2Y'$$
$$+ (Y')^2 U_2'' \} > 0,$$

where $\Delta > 0$ is the determinant of the matrix of second derivatives, and

$$(9) \qquad \frac{dp_2^*}{da} = \frac{\delta U_1'}{\Delta} Y'U_2'' > 0.$$

Formula (7) can be rewritten as

$$(10) \quad \frac{\delta U_1'}{\Delta} \big[U_2' \{ Y''(1 + y_2'U_2'') - y_2''Y'U_2'' \}$$
$$- (2Y' + p_2 Y'')(1 + y_2'U_2'') \big]$$
$$+ (p_2 y_2'' + y_2') dp_2^*/da.$$

The last term is positive, and, since $\delta U_1'/\Delta > 0$, so is the middle term, while the first term has the sign of

$$U_2' \left\{ Y'' + \delta y_2'U_2''(-y_1') \left[\frac{y_2''(p)}{y_2'(p)} - \frac{\delta y_1''(\delta p)}{y_1'(\delta p)} \right] \right\} > 0,$$

from the conditions on $y_i(p)$. Consequently, (7) is positive, as required. Hence $p_2^{**} > p_2^*$ if $a > a_0$ and, thus, since $y_2^{**} < y_2^*$, $x_2^{**} > x_2^*$ and $\tau_2^{**} < \tau_2^*$.

If (5) is written as $F(p, a)$ (ignoring subscripts), then (6) $F_p = 0$ (subscripts now indicating partial derivatives), which gives $F_{pp} dp + F_{pa} da = 0$, or $dp/da = -F_{pa}/F_{pp}$, so $dp/da > 0$ if $F_{pa} > 0$.

Let us turn to the dynamically consistent equilibrium. Let $p_2 = p_2(S - x_1 - y_1)$ be the solution to the program of maximizing (5). (Then $p_2^{**} = p_2(S_2^*)$). Implicitly differentiating (6) with respect to S and solving for $p_2' \equiv \partial p_2/\partial S$, we find

$$(11) \quad p_2' = \frac{1 + y_2'U_2''}{-U_2'y_2'' + (y_2')U_2'' + 2y_2' + p_2 y_2''} < 0,$$

since the numerator is positive and the denominator is negative.

Now, if the big importer chooses x_1 in the first period of the rational expectations equilibrium, the price $\bar{p}_2(x_1)$ must satisfy

$$(12) \qquad \bar{p}_2(x_1) = p[S - x_1 - y_1\{\delta\bar{p}_2(x_1)\}].$$

Implicitly differentiating (12) with respect to x_1 and solving for $d\bar{p}_2/dx_1$, we find

$$(13) \qquad \frac{d\bar{p}_2}{dx_1} = -\frac{p_2'}{1 + \delta y_1'p_2'} > 0,$$

as $p_2' < 0$ from (11).

Now, at $a = a_0$, $(x_1^e, p_2^e) = (x_1^*, p_2^*)$. Consider what happens as a rises slightly. We have already seen that x_1^* and p_2^* rise. Suppose, contrary to the claim, that $p_2^e \le p_2^*$ —we shall show that this is impossible. First we show that if $p_2^e \le p_2^*$, then $x_1^e < x_1^*$. Suppose not, and that $x_1^e \ge x_1^*$. Since by assumption $p_2^e \le p_2^*$, $y_1^e \ge y_1^*$, and so $S_2^e \le S_2^*$. From (11), $p_2^e = p_2(S_2^e) \ge p_2(S_2^*) = p_2^{**}$. But since $p_2^{**} > p_2^*$, this is inconsistent with $p_2^e \le p_2^*$. This means that $x_1^e < x_1^*$, so that

$$(14) \qquad (x_1^e, p_2^e) < (x_1^*, p_2^*).$$

But, because the matrix of second partials is negative definite, (14) implies that the left-hand sides of (3) and (4) must be positive at (x_1^e, p_2^e). But then a slight increase in x_1^e and p_2^e must be an improvement, and in view of (13), this is possible to do without violating constraint (6). Since this means that the importer was not optimizing, contra hypothesis, this means the original premise was false and so $p_2^e > p_2^*$. From the arbitrage condition, this implies that $p_1^e > p_1^*$. Thus, $y_i^e < y_i^*$, $i = 1, 2$, and so $x_1^e + x_2^e > x_1^* + x_2^*$. Finally, $p_2^e = p_2(S_2^e) < p_2^{**} = p_2(S_2^*)$, and so by (11), $S_2^e > S_2^*$. Since $p_2^e > p_2^*$, and $y_2^e < y_2^*$, we have $x_2^e > x_2^*$. Finally, $(x_2^e, p_2^e) > (x_2^*, p_2^*)$ implies that $\tau_2^e < \tau_2^*$. □

Example.
Let $U_1(x) = \delta a \log(x)$, $U_2 = \log(x)$, so the importer's objective function is given by (12) in the main text. If this is divided through by δ we have

$$(15) \qquad a \log(x_1) + \log(x_2) - p_2(x_1 + x_2).$$

Let $y_1(p) = \delta b/p$, $y_2(p) = 1/p$, so that $Y(p_2) = (1 + b)/p_2$. Then, solving (6) for x_2, p_2:

$$x_2(S_2) = \frac{g-1}{g} S_2; \quad p_2(S_2) = \frac{g}{S_2};$$

so

$$x_2 = \frac{g-1}{p},$$

where $g = (1 + \sqrt{5})/2$. The rational expectations solution is found by substituting these expressions into the objective function

(16) $\underset{p_1, x_1, S_1}{\text{Max}} \, a \log(x_1) + \log\{x_2(S_2)\}$

$$- p_2(S_2)\{x_1 + x_2(S_2)\},$$

subject to

$$p_1 = \delta g / S_2$$

and

$$S_2 = S - x_1 - \frac{\delta b}{p_1} = S - x_1 - b/p_2.$$

These last two conditions together give $x_1 = (S - g - b)/p_2$, and with this the objective function can be written as a function of p_2 alone. The solution is

(17) $x_1^e = S - G/p_2^e;$

$$p_2^e = \frac{G - 1 + \sqrt{(G+1)^2 + 4aG}}{2S};$$

$$x_2^e = (g-1)/p_2^e,$$

where $G \equiv g + b$. The open loop equilibrium is found by solving (3) and (4):

(18) $x_1^* = \frac{a}{1+a}\left\{S - \frac{1+b}{p_2^*}\right\};$

$$x_2^* = \frac{1}{1+a}\left\{S - \frac{1+b}{p_2^*}\right\};$$

$$p_2^* = \frac{1 + b + \sqrt{(1+b)^2 + 4(1+a)(1+b)}}{2S}.$$

Comparing (17) and (18), we observe that the two equilibria are the same only in the knife-edge case where $a = b$, that is, where the large importer and other oil buyers place the same relative weights on present versus future consumption.

Constant Elasticity Example.

Suppose that oil is costless to extract and must be used up by date T. At date t demand by the rest of the world is $y(p) = b_t p^{-\varepsilon}$, and by the large importer is $x_t = a_t q^{-\alpha}$, where q is the tariff-inclusive price, and a_t and b_t vary over time. The net welfare of the large importer when $q = p(1 + \tau)$ is

$$V(p) = \frac{a_t p_t^{-\alpha}(1+\tau)^{-\alpha}(1+\alpha\tau)}{\alpha - 1}.$$

On the open loop path the optimum *ad valorem* tariff is constant, and the price rises at the rate of interest, r, so the present discounted value of net welfare for the large importer at date t is

(19) $W_t = \dfrac{p_t^{-\alpha}(1+\tau)^{-\alpha}(1+\alpha\tau)}{\alpha - 1}$

$$\times \int_t^T a_u e^{(1-\alpha)r(u-t)} du.$$

The relationship between p_t and τ is given by the market clearing condition

(20) $S_t = X_t + Y_t$

$$= [p_t(1+\tau)]^{-\alpha} \int_t^T a_u e^{-\alpha r(u-t)} du$$

$$+ p_t^{-\varepsilon} \int_t^T b_u e^{-\varepsilon r(u-t)} du,$$

where X_t and Y_t are the remaining amounts of oil which will be consumed between t and T by the large importer and the rest of the world, and S_t is the remaining stock. The optimal committed tariff starting at date t is found by maximizing W_t with respect to τ, where from (20),

$$\frac{\partial p_t}{\partial \tau} = \frac{-p_t}{(1+\tau)(1+\varepsilon Y/\alpha X)}.$$

The optimal open loop tariff is therefore given by

$$\tau = \frac{X_t}{\varepsilon Y_t} = \frac{p_t^{\varepsilon - \alpha}(1+\tau)^{-\alpha}}{\varepsilon} \frac{\int_t^T a_u e^{-\alpha r u} du}{\int_t^T b_u e^{-\varepsilon r u} du}.$$

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