The Welfare Cost of Resource Taxation

by

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1. Introduction

The appropriate tax treatment of extractive resources has been extensively and heatedly debated over the last 25 years. The windfall profits tax on oil is only the latest in a series of special tax provisions which affect resource industries; much of the discussion has centered on the wisdom of maintaining these provisions. The arguments are not over trivial amounts: the windfall profits tax alone is expected to raise at least $227.7 billion in net revenues over the next ten years.[1] The magnitude of the revenues involved suggest that efficiency considerations are significant. For this reason, the welfare costs of such taxes should be analyzed, especially since there are unusual features to resource production.

The central feature of extractive resources for the purposes of this paper is their exhaustibility--that is, fixed (although possibly unknown) supply at a given cost of exploration and extraction. Among the implications of exhaustibility are that the value of the resource is greater than the cost of extraction at the margin--along both the competitive equilibrium and socially optimal time paths of extraction, and that intertemporal choice is an essential part of the production decision.[2]

The theoretical literature on the taxation of exhaustible resources notes that, because of the scarcity rent associated with the resource, it is possible to levy taxes which generate revenue but cause no loss in allocative efficiency--i.e., a first-best tax.[3] Such a tax requires either the ability to tax directly the owners of the mineral rights, or an exact knowledge of the cost structure of the industry and the freedom to change tax rates over time. Practically speaking, these require-

ments may be very difficult or impossible, at least if private ownership is maintained.

Since many governments, including our own, levy taxes which alter the intertemporal extraction path, the effect of these taxes should be considered. Various papers address this point, but stop after determining the partial equilibrium effect of a particular tax on the time path of production.[4] Thus, for example, Dasgupta and Heal (1979) note that a constant-rate sales tax or a profits tax result in slower initial extraction rates than the undistorted equilibrium, while the percentage depletion allowance results in more rapid usage.

There are two basic objections to basing tax policy on this type of analysis. First, the undistorted competitive rate of extraction may not be socially optimal. There may be externalities in the production of the resource, including vulnerability to an embargo and separate ownership of a single pool.[5] More importantly, there are many other distortions which exist in the economy, including those caused by other taxes.[6] In light of these preexisting distortions, especially since taxes on exhaustible resources raise revenues which might be used to reduce other taxes, the optimal tax policy for resource industries has not yet been determined.

This paper is substantially directed to a different albeit closely related question: given that a government chooses--through either calculation or ignorance--to levy a tax on an exhaustible resource that changes the rate of extraction, what is its welfare cost? In particular, is this cost greater or less than an equivalent tax on a conventional good or on an elastically supplied factor of production?

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To address these questions, a simple model which highlights the intertemporal choice associated with exhaustible resources is developed. As a basis for comparison, as well as for its own intrinsic interest, the case of an open economy without any of the resource (which is equivalent to an elastically supplied factor) is considered in section three. The welfare cost of distorting the time path of extraction of a domestically-owned exhaustible resource in a closed economy is examined in section four. Section five considers the same model under an assumption of an open rather than a closed economy.

The analyses in sections four and five suggest that the deadweight loss associated with the distortionary tax is smaller than if the resource were not exhaustible or domestically-owned; this suggests further that exhaustible resources should be taxed relatively heavily and has implications regarding the welfare gain from such policies as oil price decontrol. The final section reviews these conclusions and considers the problem of optimal tax policy.

2. Description of the Model

To analyze the welfare cost of resource taxation, I shall use a simple model which highlights the intertemporal choice faced by the society.[7] Consider a two-period model where there is only one output, Y. There are two factors of production: capital (K) and resources (R). They produce final output in accordance with the following production function, which is assumed to have constant returns to scale:

$$(1) \quad Y = F(K,R) \ , \quad F_K \geqslant 0 \ , \ F_R \geqslant 0 \ , \ F_{KK} \leqslant 0 \ , \ F_{RR} \leqslant 0 \ .$$

Capital is fixed in the first period, but it then depreciates (D) and is increased by saving (S):

$$(2) \quad K_1 = \overline{K} \ , \quad K_2 = K_1 - D + S \quad .$$

Consumers are assumed to be price-takers with respect to the resource, which is priced in units of final output. First-period output, after payment to the resource owner, can be either consumed or saved. Since there are only two periods, consumers will not save in the second:

$$(3) \quad C_1 = Y_1 - S - P_1 R_1 \ , \quad C_2 = Y_2 - P_2 R_2 \quad ,$$

where C_i is consumption and P_i is the price of the resource in the ith period.

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Consumers have identical tastes and income, thereby eliminating distributional issues. Consumption in the two periods are the arguments of the utility function:

$$(4) \qquad U(C_1, C_2) \;, \qquad U_1, U_2 \geqslant 0 \qquad U_{11}, U_{22} \leqslant 0 \qquad U_{12} \leqslant 0$$

This model was chosen for several reasons. Resources enter as factors of production. A second factor--capital--enters the production function, allowing a general equilibrium response to changes in resource prices. Capital was chosen over labor since it has only one control variable--saving in the first period, and since it inherently involves intertemporal choice, as does the production of an exhaustible resource. The consequences of adding labor as a factor will be discussed in the final section. Limiting the model to one good and two periods facilitates the analysis without changing the nature of the conclusions.

Assumptions regarding the production of the resource have not yet been presented. Three quite different models will be considered and their differences analyzed. The case of a small, open economy without any domestic supply of the resource is discussed in the next section. This sets the stage for an analysis of tax policy in a closed economy with a privately-owned exhaustible resource. In the third model, the economy is open with some domestically-owned quantity of the resource.

3. Open Economy without Resource

In assuming a small, open economy without any resource, I take the pre-tax price of the resource to be exogenous in both periods. The pre-tax competitive equilibrium can then be found by maximizing the utility function subject to the production and budget constraints. The Lagrangian can be written as:

$$(5) \quad L = U(C_1, C_2) - \lambda[C_1 - F(\overline{K}, R_1) + S + P_1 R_1] - \mu[C_2 - F(\overline{K} - D + S, R_2) + P_2 R_2] \quad .$$

Since $\overline{K}$ and D are pre-determined in this problem, $F(\overline{K} - D + S, R_2)$ will be written as $G(S, R_2)$ for notational convenience.

The first-order conditions are familiar:

$$(6) \qquad U_1 = \lambda \quad ,$$

$$(7) \qquad U_2 = \mu \quad ,$$

$$(8) \qquad G_S = \frac{\lambda}{\mu} \quad ,$$

$$(9) \qquad P_1 = F_R \quad ,$$

$$(10) \qquad P_2 = G_R \quad ,$$

$$(11) \qquad C_1 = F(\overline{K}, R_1) + S - P_1 R_1 \quad ,$$

$$(12) \qquad C_2 = G(S, R_2) - P_2 R_2 \quad .$$

I will make the assumption that capital is sufficiently productive on the margin that the desired amount of gross saving is positive.

Consider a tariff levied on the resource. I shall restrict the tax rate to be the same in both periods for reasons that will be made clear in section four. What is the welfare cost of such a tax in this model?

This paper uses several specific measures of welfare costs. As is usual in the public finance literature, the focus is on the loss of utility from a tax over and above that which would have occurred had the same revenue been raised from a lump-sum tax. Tax revenues are assumed to be redistributed in a lump-sum manner, since this paper uses the concept of compensating variation in utility.[8] A second-order approximation is employed. The problem is more straightforward because of the assumption that the demand for the resource is purely a derived demand.

The change in resource use induced by the tariff is, to a second-order:

$$(13) \qquad dR_1 = t/F_{RR} \quad , \qquad dR_2 = t/G_{RR}$$

The change in consumption in each period can be found by taking a second-order approximation to equations (11) and (12) about the initial equilibrium, remembering that the country is a price-taker in the world market and that tax revenues are redistributed:

$$(14) \qquad dC_1 = F_R dR_1 - dS - P_1 dR_1 - tR_1 + \frac{1}{2} F_{RR}(dR_1)^2 + tR_1 \quad ,$$

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(15) $dC_2 = G_R dR_2 + G_S dS - P_2 dR_2 - tR_2 + \frac{1}{2}G_{RR}(dR_2)^2 + \frac{1}{2}G_{SS}(dS)^2 + G_{RS}dSdR_2 + tR_2$.

By using equations (9) and (10), these can be simplified to:

(16) $dC_1 = \frac{1}{2}F_{RR}(dR_1)^2 - dS$,

(17) $dC_2 = G_S dS + \frac{1}{2}G_{RR}(dR)^2 + \frac{1}{2}G_{SS}(dS)^2 + G_{RS}dSdR_2$.

If saving were completely inelastic, each period's consumption could be found independently. The problem would be partial equilibrium in nature. In that case, the expression for the welfare loss of imposing the tariff would be:

(18) $dU = U_1 dC_1 + U_2 dC_2 = \frac{\lambda}{2}\frac{(t)^2}{F_{RR}} + \frac{\mu}{2}\frac{(t)^2}{G_{RR}}$.

More generally, an expression can be derived for the welfare loss associated with the tariff after allowing saving to vary. Taking the second-order approximation for the utility change:

(19) $d\bar{U} = U_1 dC_1 + U_2 dC_2 + \frac{1}{2}U_{11}(dC_1)^2 + \frac{1}{2}U_{22}(dC_2)^2 + U_{12}dC_1 dC_2$.

Recall that, from the first-order conditions:

(20) $U_1 = G_S U_2$

Totally differentiating:

$$(21) \qquad U_{11}dC_1 = U_{22}G_S dC_2 - U_{12}dC_2 + U_{12}G_S dC_1 + U_2 G_{SS}dS + U_2 G_{SR}dR_2 \qquad .$$

Replacing (20) into (21), using the expressions for dC_1 and dC_2, and eliminating the higher order terms, one obtains:

$$(22) \qquad dU = U_1 [\tfrac{1}{2}F_{RR}(dR_1)^2 - dS] + U_2 [G_S dS + \tfrac{1}{2}G_{RR}(dR_2)^2 + \tfrac{1}{2}G_{SS}(dS)^2$$

$$+ G_{RS}dSdR_2] + \tfrac{1}{2}(-dS)[U_{22}(G_S)^2 dS - U_{12}G_2 dS - U_{12}G_S dS$$

$$+ U_2 G_{SS}dS + U_2 G_{SR}dR_2] + \tfrac{1}{2}U_{22}(G_S)^2(dS)^2 + U_{12}G_S(dS)^2 \qquad .$$

Most terms cancel, leaving:

$$(23) \quad dU = \tfrac{U_1}{2}F_{RR}(dR_1)^2 + \tfrac{U_2}{2}G_{RR}(dR_2)^2 + \tfrac{U_2}{2}G_{SR}dSdR_2$$

The sign of dS is ambiguous, since the reductions in resource use caused by the tariff cause U_1 and U_2 to increase, while the reduction in R_2 increases or decreases the marginal product of saving, G_S, depending on whether G_{SR} is negative or positive. To put it another way, the income effect of the tariff on saving is uncertain, since consumption is reduced in <u>both</u> periods, and the substitution effect depends on whether capital and resources are substitutes or complements. If G_{SR} is positive, as would be the case if F were a linear homogeneous function, and if U_1 and U_2 increased proportionately, then saving would decrease.

The expressions derived up to now have assumed no other taxes exist in the economy. As Wright (1980) has shown, the modifications which must be made if a tax on saving, t_C has been imposed are relatively minor, assuming that the tax revenues are redistributed to consumers. One of the first-order conditions becomes:

$$(24) \qquad U_1 = U_2 [G_S - t_C]$$

Proceeding in a manner similar to the case without a tax on saving, the welfare cost of the tariff is found to be:

$$(25) \qquad dU = \frac{\lambda}{2} F_{RR} (dR_1)^2 + \frac{\mu}{2} G_{RR} (dR_2)^2 + \frac{\mu}{2} G_{SR} dSdR_2$$

$$+ \mu t_C dS + \frac{1}{2} U_{22} t_C G_S (dS)^2 - \frac{1}{2} U_{12} t_C (dS)^2$$

The last two terms are negative, so if the tariff reduces saving—i.e., aggravates the distortion—its welfare cost is greater than if saving were untaxed.

Equations giving a second-order approximation to the welfare cost of an equal tariff on the resource in each period have now been derived for three situations: no variation in saving (18); variable saving (22); and variable saving with a distortionary tax on saving (25). These equations will be used for comparison with similar equations in the next section, which has quite different assumptions about resource supply.

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4. Closed Economy with Exhaustible Resource

In the closed economy model, the exhaustibility of the resource becomes critical. In saying that the resource is exhaustible, I mean:

$$(26) \qquad R_1 + R_2 \lesseqqgtr \bar{R}(b) \qquad ,$$

where $\bar{R}(b)$ is the stock of the resource with extraction costs less than or equal to b. I assume that the resource is owned by price-taking, present-value-maximizing firms. These firms can choose to extract in the first or second period or not at all; intertemporal decisions are inherent in the problem. Since there is a finite supply of the resource that is cheap to extract, scarcity rents exist if the constraint is binding.

It is easy to show that present-value maximization with a positive rate of interest implies that a lower cost resource will not be extracted after the higher cost resource. The following conditions must hold if the producers are in equilibrium:

$$(27) \qquad (1 + r)(P_1 - b_1) = P_2 - b_1 \qquad ,$$

$$(28) \qquad P_2 = b_2 \qquad ,$$

where b_1 is the extraction cost for a producer indifferent between selling in the first period and the second period, b_2 is the extraction cost for the producer who is indifferent between selling in the

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second period and not at all, and r is the producers' rate of time preference.

These equilibrium conditions together with the consumer demand functions and the resource constraint can be solved for P_1, P_2, R_1, and R_2. This competitive equilibrium is also a social optimum since it maximizes the following:

$$(29) \quad L = U(C_1, C_2) - \lambda[C_1 - F(\overline{K}, R_1) + S + \int_0^R b(x)\,dx]$$
$$- \mu[C_2 - G(S, R_2) + \int_{R_1}^{R_1+R_2} b(x)\,dx] - \gamma[R_1 + R_2 - \overline{R}(b)] \;.$$

Both the notation and the explanation will be clearer if I consider the special case of a constant cost of extraction. In this case the Lagrangian becomes:

$$(30) \quad L = U(C_1, C_2) - \lambda[C_1 - F(\overline{K}, R_1) + S + bR_1]$$
$$- \mu[C_2 - G(S, R_2) + bR_2] - \gamma[R_1 + R_2 - \overline{R}] \quad ,$$

and two of the first-order conditions are:

$$(31) \quad \lambda F_R - \gamma - \lambda b = 0 \quad ,$$

$$(32) \quad \mu G_R - \gamma - \mu b = 0 \quad .$$

Substituting,

$$(33) \quad (G_R - b)/(F_R - b) = \gamma/\mu$$

that is, the difference between marginal product and extraction cost rises at the interest rate for a social optimum. The equilibrium condition (27) and the consumer's first-order conditions yield this result in the undistorted competitive economy.[9]

What, then, is the welfare cost of taxing the resource in this framework? As noted earlier in the paper, the existence of scarcity rents allows the possibility of a tax which raises revenue but does not change R_1 or R_2, and therefore does not have a dead-weight loss. For example, if the government could tax the difference between price and each producer's extraction cost (which includes a normal profit), it could, in effect, expropriate the resource without distortion. In the special case of constant extraction cost, a unit sales tax that increases at the interest rate is another example of a non-distortionary tax.[10]

Many taxes do distort the intertemporal extraction path, however; for reasons discussed in section one, this is the situation I will analyze.

Consider then, a sales tax (e.g., \$1/barrel) levied on the resource at the same rate in both periods. A producer who, prior to the imposition of this tax, was indifferent between selling the resource in the first or second period would now choose to wait; any producer indifferent between selling in the second period and not extracting the resource will shut down. The new equilibrium conditions are:

(34) $(1 + r)(P_1' - b_1' - t) = (P_2' - b_1' - t)$,

(35) $P_2' = b_2' + t$,

where the prime superscript is used to distinquish these conditions
from the pre-tax case.

Several general characteristics of this equilibrium are apparent.
First, P_1' is greater than P_1, since if b_1' were greater than or equal
to b_1, equation (34) would not hold at P_1, while b_1' less than b_1 implies
that R_1' is less than R_1 which is true if P_1' is greater than P_1. Second,
the change in R_1 is smaller in magnitude than that induced by the ta-
riff in section three. If this were not true, P_1 would rise by the
full amount of the tax, as would P_2 to maintain equation (34); demand
would fall in both periods without any corresponding reduction in de-
sired supply. The two preceding propositions can be summarized by
saying that the consumer bears some, but not all, of the burden of
the tax in the first period.

Less can be said about the second period. Some of the resource
that would have been consumed in the first period in the pre-tax
equilibrium is shifted to the second period, while some of the re-
source may no longer be profitable to extract, so that the sign of
dR_2 is ambiguous. If dR_2 is negative, however, it must be less ne-
gative than the corresponding change induced by the tariff in the
open economy case. If dR_2 is positive, it cannot be greater in mag-
nitude than dR_1, since imposing the tax does not cause any previously

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unprofitable resource to become profitable.

To get a measure of the welfare loss, take a second-order approximation to the first two constraints in equation (29) around the initial equilibrium:

$$(36) \quad dC_1 = F_R dR_1 - dS - b\big|_{R_1} dR_1 - \tfrac{1}{2}F_{RR}(dR_1)^2 - \tfrac{1}{2}b_R\big|_{R_1}(dR_1)^2 \quad .$$

$$(37) \quad dC_2 = G_R dR_2 + G_S dS - b\big|_{R_1+R_2} dR_2 - [b\big|_{R_1+R_2} - b\big|_{R_1}] dR_1$$

$$+ \tfrac{1}{2}G_{RR}(dR_2)^2 + \tfrac{1}{2}G_{SS}(dS)^2 + G_{SR} dS\, dR_2 - b_R\big|_{R_1+R_2} dR_1 dR_2$$

$$- \tfrac{1}{2}b_R\big|_{R_1+R_2}(dR_2)^2 - \tfrac{1}{2}[b_R\big|_{R_1+R_2} - b_R\big|_{R_1}](dR_1)^2 \quad ,$$

where $b\big|_{R_1}$ is the extraction cost after R_1 units of the resource has been extracted and $b_R\big|_{R_1}$ is the rate of change of the extraction costs with cumulative extraction evaluated at R_1.

In the case of constant extraction cost, (36) and (37) simplify to:

$$(38) \quad dC_1 = F_R dR_1 - dS - b dR + \tfrac{1}{2}F_{RR}(dR_1)^2 \quad ,$$

$$(39) \quad dC_2 = G_R dR_2 + G_S dS - b dR_2 + \tfrac{1}{2}G_{RR}(dR_2)^2 + \tfrac{1}{2}G_{SS}(dS)^2$$

$$+ G_{SR} dR_2 dS \quad ,$$

and $dR_1 = -dR_2$ as long as t is less than $P_1 - b$.

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The partial equilibrium welfare loss corresponding to equation (18) is:

$$(40) \quad dU = \frac{\lambda}{2}F_{RR}(dR_1)^2 + \frac{\mu}{2}G_{RR}(dR)^2 + \lambda(F_R-b)dR_1 + \mu(G_R-b)dR_2$$

By equation (33) and the resource constraint,

$$(41) \quad dU = \frac{\lambda}{2}F_{RR}(dR_1)^2 + \frac{\mu}{2}G_{RR}(dR_2)^2$$

This equation is the same as equation (18), but by the argument earlier in this section, dR_1 and dR_2 are smaller in magnitude in this case than in the case of the open economy without any resource. Therefore, the welfare loss is smaller for the tax on exhaustible resource than for an equivalent import tariff on the elastically-supplied resource. By an identical argument, it can be shown that the welfare cost measures corresponding to equations (23) and (25) are smaller for this special case of constant extraction cost than for the earlier model discussed in section three.

Returning to equations (36) and (37), if $dR_1 = -dR_2$, almost all of the terms involving extraction cost and its derivatives cancel, leaving equations (38) and (39) with b evaluated at R_1. The arguments of last two paragraphs carry through exactly, so the welfare cost is less than in the section three model whenever the resource is merely shifted from one period to the other. This result is independent of the particular tax that causes the change in the ex-

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traction path.

When a tax reduces the cumulative resource use, the comparison is not as straightforward. A reduction of this kind represents a relaxation of the fundamental inelasticity imposed by the exhaustibility assumption, so it is not surprising that the potential welfare loss increases. The smaller reduction in use of the exhaustible resource, by comparison as usual with the perfectly elastic resource, suggests a smaller welfare loss but this is at least partially offset by the greater cost of each unit lost, due to the difference between marginal product and extraction cost.

5. Open Economy with Exhaustible Resources

The third model--a small open economy which owns some of the resource--is one that combines the features of the other two models. I intend that the pre-tax import price is again exogenous, but that the country can supply some or all of its resource requirements domestically. The country will produce some of the resource and also import in both periods if and only if the equilibrium conditions (27) and (28) are satisfied.

The welfare implications of various tax policies in this model depend on whether the country imports in both periods before and after the tax. In this section, I will assume that it does. A sales tax that is imposed on both the importer and the domestic producer has a welfare cost identical to that in section three and raises the same revenue, since the consumer bears the full burden of the tax. Domestic producers have no incentive to shift production between periods.

If, however, the tax is solely on the imported resource, the same welfare cost applies although the government raises less tax revenue. If the tax is solely on the domestic resource, consumers bear none of the burden, and the welfare cost of such a tax is solely the loss in the present value of producer surplus plus tax revenue. If the same amount of domestic resource is produced, the upper bound on this welfare cost is the difference between the producer surplus in competitive equilibrium and the producer surplus if all of the resource is produced in the least favorable period. In the special case of constant cost of extraction, with the producers being indifferent between periods, the tax will be borne completely by the producers and there will be no dead-weight loss.

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6. Conclusions

The basic conclusion of this paper is that a tax on an exhaustible resource which only changes the intertemporal extraction path causes less distortion than an equivalent tax on a similar commodity which is elastically supplied. In the course of the analysis, many simplifying assumptions were made so that the models could be manipulated. This conclusion, however, is quite robust to changes in the specification of the model. For instance, increasing the number of goods or periods would not change the intuition of section four. Adding labor as a factor would increase the general equilibrium feedback between the resource and the rest of the economy, but not alter the impact of the exhaustibility condition.

Exhaustible resources have, by definition, a fundamental inelasticity of supply. This is what gives rise to the scarcity rent. Even if the government is unable to costlessly tax away this rent, its existence implies that the tax burden should be heavier on these resources than on equivalent constant-returns-to-scale manufactured goods or elastically-supplied factors. The imperfect elasticity of resource supply implies that part of the rent is taxed away.

The intertemporal elasticity of exhaustible resource supply, which is not present in a factor like land, implies, however, that taxes whose present value varies substantially with the choice of production date are likely to have greater dead-weight losses and

raise smaller revenues than more continuous taxes, at least when expectations are accurate.

The inability of the government to raise enough revenue from non-distortionary lump-sum taxes leads to the problem of picking the optimal level of distortionary taxes. The results of this paper are relevant. Since I ruled out the possibility of a distortion-free rent tax, the optimal excise tax on the resource is larger if the resource is exhaustible than if it is elastically supplied--even in the presence of a tax on capital income. A complete second-best analysis, which would be sensitive to the tax structure allowed, has not be done in relation to this or other resource models. It remains an important undertaking.

FOOTNOTES

[1]This figure is the conservative estimate of the Senate Finance Committee. Within six months of their estimate, revenues were running at a higher rate than they predicted.

[2]Among the many proofs of this, see Stiglitz articles (1974).

[3]See Dasgupta and Heal, especially Chapter 12.

[4]Besides Dasgupta and Heal, see also Sweeney, as well as Dasgupta, Heal and Stiglitz, and Jacobsen.

[5]This has been mentioned by Wright (1980) and Dasgupta, Heal and Stiglitz.

[6]Dasgupta, Heal, Stiglitz and Wright have all raised the issue of second-best taxation, but have not examined it in any detail.

[7]Wright (1980) considers a similar model, but he is interested in a quite different question and does not consider a domestically-owned resource. The model in this section was developed independently.

[8]This concept is discussed in Hicks, and by Willig. Harberger (1964) develops a second order approximation which is analyzed by Green and Sheshinski.

[9]This result has been developed many times. See Dasgupta and Heal, Chapter 6.

[10]This case is proven in Dasgupta and Heal, Chapter 12.

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