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Implementing Environmental Taxes on Intermediate Goods in Open Economies

James M. Poterba[1] & Julio J. Rotemberg[2]

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Implementing Environmental Taxes on Intermediate Goods in Open Economies

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Institute for Policy Reform

June, 1994

Many proposed and actual environmental taxes are taxes on intermediate goods. These goods, such as fossil fuels, are typically tradable, and they are also used in the production of many tradable final goods. How should imports of intermediate and final goods be taxed if the government does not want environmental tax policy to alter the competitive positions of domestic and foreign producers? Not surprisingly, imports of the intermediate good itself can be taxed at the same rate as domestic intermediate goods. Imports of final goods that are produced using these intermediate goods can be taxed based on their intermediate good intensity, provided there is no joint production. Under conditions of joint production, however, such as those that characterize the petroleum refining and petrochemical industries, it is difficult to define the intermediate good intensity of any single product. Arbitrary assignments of intermediate good content, for example on the basis of output weight or value, are unlikely to preserve the competitive positions of domestic and foreign producers.

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IMPLEMENTING ENVIRONMENTAL TAXES ON INTERMEDIATE GOODS IN OPEN ECONOMIES

James M. Poterba & Julio J. Rotemberg

Executive Summary

Many proposed and actual environmental taxes are taxes on intermediate goods. These goods, such as fossil fuels, are typically tradable, and they are also used in the production of many tradable final goods. How should imports of intermediate and final goods be taxed if the government does not want environmental tax policy to alter the competitive positions of domestic and foreign producers? This is an important and growing issue in tax policy design, and it is particularly relevant to trade between resource-rich developing nations and currently developed nations. Not surprisingly, imports of the intermediate good itself can be taxed at the same rate as domestic intermediate goods. Imports of final goods that are produced using these intermediate goods can be taxed based on their intermediate good intensity, provided there is no joint production.

When several final goods are produced jointly using the taxed intermediate good, however, it is difficult to define the intermediate good intensity of any single product. Yet these are precisely the conditions that characterize two of the industries that are most directly affected by environmental taxes: petroleum refining and petrochemicals. This paper explains how actual tax policies have attempted to measure intermediate good content in such joint production situations, and explores the degree to which alternative approaches will preserve the competitive positions of foreign and domestic firms. We present a simple example in which taxing imported final goods based on the "natural" definition of intermediate good intensity raises the

marginal cost of foreign producers by less than the increase in marginal costs for domestic producers, who directly face the intermediate good tax.

The problem of allocating joint intermediate good inputs across different final goods, while not a prominent issue in tax policy discussions, closely parallels a perennial problem in regulatory economics. This is the question of how to allocate joint fixed costs of production across various outputs of regulatory firms when setting prices for such a firm. Previous work in regulatory theory has shown the limitations of arbitrary cost allocation rules, based for example on the value, quantity, or weight of various joint outputs. Tax policy-makers must recognize that similar problems are likely to plague the design of "border tax adjustments" associated with environmental taxes.

Tax policies are increasingly being used as instruments of environmental policy. Recent proposals to tax carbon fuels in the European Community and the United States are motivated at least as much by concerns about the effects of fossil fuel combustion on global climate as by revenue needs. In the United States, reductions in consumption of chlorofluorocarbons (CFCs) to comply with the terms of the 1987 Montreal Protocol have been achieved in part through a federal tax on products that contain CFCs. Growing environmental concern in both developed and developing nations suggests that the use of such taxes is likely to increase in the future.

The basic principles of environmental tax design are well understood. Diamond (1973) and Sandmo (1975) show that each commodity's tax rate should equal the aggregate value, over all households, of the commodity's marginal externalities. Such a system of commodity taxes is equivalent to a Pigouvian tax on the externality itself. In practice, measuring the environmental consequences of each good is difficult, and a tax system that imposes a different tax rate on each good is administratively complex. Practical environmental tax policies therefore typically tax a small set of goods associated with particularly significant externalities. These goods are often intermediate goods, such as fossil fuels.

To avoid placing domestic producers at a competitive disadvantage, proposals to tax domestic production of intermediate goods are usually coupled with plans to tax imports at the same rate as domestically-produced intermediate goods. Imports of final goods that are produced using the taxed intermediate good are more problematic. Not taxing such imports would place domestic producers at a disadvantage, and encourage offshore production, but determining the taxed-good content of finished goods can be difficult.

How imported finished goods should be taxed depends critically on the government's objective. If it is concerned about pollution at home, but assigns no penalty to pollution elsewhere, and if the production process in question generates only local pollution, then it may not be concerned about encouraging production elsewhere. If the government's objective is to reduce the level of emissions everywhere, either because of concerns for the welfare of citizens of other nations or because the production process generates global externalities, as for example in the case of ozone-depleting chemicals, then policies that simply rearrange the geography of production will seem unattractive.

In this paper, we consider alternative policy rules for imputing taxes to imported final goods, when the government's objective is to levy the same effective tax on foreign and domestic producers. This objective is equivalent to raising the marginal cost of foreign and domestic producers by the same amount. We show that provided there is no joint production, an import tax based on the intermediate good intensity of domestic production achieves this goal. When final goods are produced jointly, however, it is difficult to assign intermediate good consumption to particular final goods. This problem is analogous to the problem of allocating joint costs in regulatory proceedings that must set prices for multiproduct firms, and in most cases, the definition of the intermediate good content of a given product is arbitrary. We explore the problems this poses for the design of international tax policy.

This paper is divided into six sections. The first describes the current treatment of imported products under the U.S. environmental excise tax system. The second section considers the taxation of finished goods in a competitive industry that exhaustively uses a taxed intermediate good, and derives the tax on imported final goods that raises marginal costs for foreign and domestic producers by the same amount.

Section three generalizes the analysis to the case of a multiproduct firm that uses the intermediate good in the joint production of several final goods. When goods are produced jointly, border tax adjustments that neglect this fact can place domestic final good producers at a competitive disadvantage relative to foreign producers. The fourth section shows rigorously that a social planner who attaches the same disutility to consumption of intermediate inputs at home and abroad would set the same tax rates on domestic and foreign producers.

Section five explores the potential link between the stylized models of joint production that we consider, and actual production and marketing practices in the petroleum refining and petrochemical industries. These industries use crude oil as an intermediate input in the joint production of many different products, and their products are subject to many environmental taxes. A brief concluding section describes several directions for future work.

1. Current Practices: Imported Goods & U.S. Environmental Excise Taxes

The U.S. government currently levies three environmental excise taxes: a Superfund tax on petroleum, a tax on ozone-depleting chemicals (ODCs), and a tax on toxic chemicals other than ODCs. The tax on petroleum and petroleum products is levied at a rate of 9.7 cents per barrel of crude oil or petroleum product, or less than one percent of the current world price of crude oil. The tax on ODCs is levied on a set of chemical compounds, principally chlorofluorocarbons (CFCs). Manufacturers who use ODCs must report the number of pounds of each ODC that they used, and then compute their tax bill using a schedule with different tax rates on different chemicals. The 1993 tax rate on most CFCs is $3.35 per pound. Finally, the tax on chemicals other than ODCs specifies a list of forty-two chemicals, primarily hydrocarbons and metal compounds, with associated tax rates. The 1993 tax rate for many hydrocarbons, for example butane, ethylene, toluene, and xylene, is $4.87 per ton; the rates on metal compounds vary widely. A copy of IRS Form 6627, Environmental Taxes, which specifies the taxed goods and their tax rates, is shown as Figure 1.

Each of these taxes includes a provision for treatment of imported products. Under the Superfund tax, imports of petroleum products are taxed at the same per barrel rate as crude oil received at U.S. refineries. This treatment of imports implies different burdens on U.S. and foreign refiners, since refineries consume some of their crude inputs in production. A tax on domestic refinery inputs equal to the per-barrel tax on imported refinery outputs places a higher tax burden on domestic than foreign

Figure 1

n 6627
. July 1993)
artment of the Treasury
al Revenue Service

Environmental Taxes

► See the separate instructions.
► Attach to Form 720.

OMB No. 1545-0245
Expires 12-31-95

ne (as shown on Form 720)	Quarter ending	Employer identification number

art I Tax on Petroleum

	(a) Barrels	(b) Rate	(c) Tax
Crude oil received at a U.S. refinery			
Crude oil taxed before receipt at refinery			
Taxable crude oil (subtract line 2 from line 1). Enter in column (c) the amount of tax by multiplying column (a) by column (b)		$ .097 bbl.	$
Crude oil used in or exported from the U.S. before the tax was imposed. Enter in column (c) the amount of tax by multiplying column (a) by column (b) .		$ .097 bbl.	$
Total domestic petroleum superfund tax (add lines 3 and 4, column (c)). Enter here and on Form 720 on the line for IRS No. 53 . . . . ►			$
Imported petroleum products superfund tax. Enter the number of barrels imported in column (a). Enter in column (c) the amount of tax by multiplying column (a) by column (b), and also enter it on Form 720 on the line for IRS No. 16 . . . . ►		$ .097 bbl.	$

art II Tax on Chemicals (Other Than Ozone-Depleting Chemicals (ODCs)), IRS No. 54

Chemical (General formula or symbol)	(a) Tons	(b) Rate	(c) Tax (multiply column (a) by column (b))	Chemical (General formula or symbol)	(a) Tons	(b) Rate	(c) Tax (multiply column (a) by column (b))
Acetylene (C_2H_2)	....	$4.87		22 Hydrochloric acid (HCl) . .	....	$0.29	
2 Ammonia (NH_3)	....	2.64		23 Hydrogen fluoride (HF) . .	....	4.23	
3 Antimony (Sb)	....	4.45		24 Lead oxide (PbO) . . .	....	4.14	
4 Antimony trioxide (Sb_2O_3) .	....	3.75		25 Mercury (Hg)	....	4.45	
5 Arsenic (As)	....	4.45		26 Methane (CH_4)	....	3.44	
6 Arsenic trioxide (As_2O_3) . .	....	3.41		27 Naphthalene ($C_{10}H_8$) . . .	....	4.87	
7 Barium sulfide (BaS) . . .	....	2.30		28 Nickel (Ni)	....	4.45	
8 Benzene (C_6H_6)	....	4.87		29 Nitric acid (HNO_3) . . .	....	0.24	
9 Bromine (Br)	....	4.45		30 Phosphorus (P)	....	4.45	
0 Butadiene (C_4H_6)	....	4.87		31 Potassium dichromate ($K_2Cr_2O_7$)	....	1.69	
1 Butane (C_4H_{10})	....	4.87		32 Potassium hydroxide (KOH) .	....	0.22	
2 Butylene (C_4H_8)	....	4.87		33 Propylene (C_3H_6)	....	4.87	
3 Cadmium (Cd)	....	4.45		34 Sodium dichromate ($NaCr_2O_7$)	....	1.87	
4 Chlorine (Cl)	....	2.70		35 Sodium hydroxide (NaOH) .	....	0.28	
5 Chromite ($FeCr_2O_4$) . . .	....	1.52		36 Stannic chloride ($SnCl_4$) .	....	2.12	
6 Chromium (Cr)	....	4.45		37 Stannous chloride ($SnCl_2$) .	....	2.85	
7 Cobalt (Co)	....	4.45		38 Sulfuric acid (H_2SO_4) . .	....	0.26	
8 Cupric oxide (CuO) . . .	....	3.59		39 Toluene (C_7H_8)	....	4.87	
9 Cupric sulfate ($CuSO_4$) . .	....	1.87		40 Xylene (C_8H_{10})	....	4.87	
0 Cuprous oxide (Cu_2O) . .	....	3.97		41 Zinc chloride ($ZnCl_2$) . . .	....	2.22	
1 Ethylene (C_2H_4)		4.87		42 Zinc sulfate ($ZnSO_4$) . . .		1.90	

3 Total Chemical Tax (add lines 1–42, column (c)). Enter here and on Form 720 on the line for IRS No. 54 . ► $

or Paperwork Reduction Act Notice, see the separate instructions. Cat. No. 43490I Form 6627 (Rev. 7-93)

Part III Tax on Imported Chemical Substances, IRS No. 17

	(a) Imported chemical substance	(b) Tons	(c) Taxable chemical used in manufacture of substance	(d) Conversion factor, percentage of metal, or entry value	(e) Rate	(f) Tax (see instructions)
1						
2						
3						

4 Total Imported Chemical Substances Tax. Enter here and on Form 720 on the line for IRS No. 17 . . . . ► $

Part IV Tax on Ozone-Depleting Chemicals (ODCs), IRS No. 98

Elections.—If you elect to report the tax on post-1989 ODCs at the time you sell or use a mixture containing such chemicals instead of when you make the mixture, check this box (the 1990 election). ☐ If you elect to report the tax on post-1990 ODCs at the time you sell or use a mixture containing such chemicals instead of when you make the mixture, check this box (the 1991 election). ☐

	(a) Ozone-depleting chemical	(b) Number of pounds	(c) Tax per pound	(d) Tax (multiply column (b) by column (c))
1				
2				
3				

4 Total Ozone-Depleting Chemicals Tax. Enter here and on Form 720 on the line for IRS No. 98 . . . . ► $

Part V Tax on Imported Products Containing ODCs, IRS No. 19

Election.—If you elect to report the tax on imported products at the time you import the products instead of when you sell or use the products, check this box. ☐

	(a) Imported product	(b) Number of products	(c) ODC weight of product	(d) Tax per pound	(e) Entry value	(f) Tax (see instructions)
1						
2						
3						

4 Total Tax on Imported Products Containing ODCs. Enter here and on Form 720 on the line for IRS No. 19 . . . . ► $

Part VI Tax on Floor Stocks of ODCs, IRS No. 20

	(a) Ozone-depleting chemical	(b) Number of pounds	(c) Tax per pound	(d) Tax (multiply column (b) by column (c))
1				
2				
3				

4 Total Floor Stocks Tax. Enter here and on Form 720 on the line for IRS No. 20 . . . . ► $

production. If a fraction s of each barrel of input is consumed during refining, then a tax of one dollar on domestic inputs translates to a 1/(1-s) dollar tax on imported refinery outputs, not a one dollar tax as currently imposed.

The tax legislation on ozone-depleting chemicals includes explicit provisions for imports of products containing ODCs. The tax on "an imported taxable product ... is computed by reference to the weight of the ODCs used as materials in the manufacture of the product." (U.S. Code of Federal Regulations, 26 CFR 52.4682.3). There are several ways for an importer to determine the tax basis of a product containing ODCs: (i) the exact method, which requires documentation on the weight of each ODC used in production; (ii) the table method, which can be used for the small set of products for which the U.S. Treasury has estimated the typical ODC use in U.S. production[1]; and (iii) the value method, which specifies that "if an importer cannot determine the ODC weight ... under the exact method ... and the table ODC weight of the product is not specified, the tax imposed on the product ... is one percent of the entry value." (26 CFR 52.4682.3). Table 1 presents examples of items that are listed in the table of imported ODC-using products.

The U.S. tax on chemicals other than ODCs treats imports in a fashion similar to the tax on ODCs. The tax rate on imported products that embody 50% or more of taxable chemicals, measured either by weight or value, is set equal to the tax that would have been collected if the taxable chemicals used in production had been sold

[1]This table was compiled from a U.S. Treasury survey of firms producing various products using ODCs.

in the United States. In the absence of any information regarding the content of non-ODC taxable chemicals, the Secretary of the Treasury may prescribe a tax rate based on the use of taxable substances in the predominant method of production for the imported product[2], or the Secretary may impose a five percent ad valorem tax on imported chemical products.

2. Import Neutrality Without Joint Production

The imported product tax rules described above are designed for the case in which inputs are exhaustively used in producing a given output. For example, if ethylene and benzene are combined to produce ethylbenzene, with no economically-significant chemical byproducts, then it is straightforward to compute the amount of the two taxed inputs, ethylene and benzene, in a given quantity of ethylbenzene. This section formalizes the problem of taxing imports when producing the product in question exhaustively consumes a given set of inputs. This provides a starting point for our subsequent discussion of import taxation with joint production.

We assume that a final good (Q) is supplied by both domestic and foreign producers using inputs of labor (L) and an intermediate good (E). Foreign and domestic production are denoted by superscripts F and D respectively. Domestic and

[2]The IRS Cumulative Bulletin (1989-1, page 718) provides an example to help chemical firms compute the tax on imports of non-ODC taxed chemicals. In this example, .75 pounds of benzene are reacted with .28 pounds of ethylene to produce one pound of ethylbenzene, so the tax rate on ethylbenzene is $.75 * \tau_{benzene} + .28 * \tau_{ethylene}$. The Cumulative Bulletin explains that this calculation corresponds to the Friedel-Crafts alkylation process, which is the predominant means of producing ethylbenzene.

foreign wages, w^D and w^F, may differ, but there is an integrated world market for the intermediate good, which has a unit price of e. Initially, both domestic and foreign firms provide this good to the domestic market, so $p^D = p^F$.

The total cost function for domestic producers is $c^D(Q^D, e, w^D)$, where Q^D is the quantity of domestic output, and the analogous cost function for foreign producers is $c^F(Q^F, e, w^F)$. If foreign and domestic producers are perfectly competitive, then in the pre-tax equilibrium,

$$c^D_Q(Q^D,e,w^D) = p^D = p^F = c^F_Q(Q^F,e,w^F). \qquad (1)$$

A specific tax of θ is levied on domestic consumption of the intermediate good raises the domestic price to $e + \theta$, under the assumption that the world price of the intermediate good is not affected by the domestic tax. The change in the price of the domestically produced good is therefore

$$dp^D = c^D_{Qe}(Q^D,e,w^D)*\theta. \qquad (2)$$

Since the derivative of the cost function with respect to the input price for the intermediate good equals the demand for the intermediate good, conditional on output level Q^D, equation (2) could be re-written as $dp^D = (\partial E/\partial Q^D)*\theta$, where $\partial E/\partial Q^D$ is the change in the quantity of E required to increase output (Q^D) by a single unit. To preserve the competitive positions of domestic and foreign firms, imports must bear a tax τ such that $\tau = dp^D = (\partial E/\partial Q^D)*\theta$.

Regulations that set the import tax equal to the amount of input needed to produce the final good under the predominant means of domestic production implicitly assume that production exhibits constant returns. In this case, marginal and average input requirements coincide, and the change in domestic producer prices associated with a given tax can be estimated from the input-output coefficient relating E to Q^D.[3]

To raise the marginal cost of foreign and domestic producers by the same amount, the tax on imported final goods must be based on the importance of the intermediate good in domestic production.[4] Current tax regulations that allow importers to pay taxes equal to the actual amount of intermediate good used in production, subject to documentation, therefore may not raise marginal costs of foreign and domestic producers by the same amount. Importers will presumably take advantage of their option to provide specific documentation only when their inputs of the taxed intermediate goods are below the average level of inputs for domestic producers. Of course, if the government's objective is to reduce global environmental externalities, then shifting production from high-externality domestic firms toward less-polluting foreign producers may be attractive.

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[3]The IRS Cumulative Bulletin 1989-1 is explicit in stating that "for purposes of computing the rate of tax for a taxable substance, the term 'conversion factor' means the number of tons of each taxable chemical consumed in the manufacture of one ton of the taxable substance..." (p. 717).

[4]The tax that achieves import neutrality is closely related to the tariff that provides zero "effective protection" to an industry; see Corden (1987).

3. Import Neutrality with Joint Production

In the last section, the intermediate good was fully consumed in producing the final good. This made it straightforward to measure the quantity of the intermediate good that is embodied in the final good. When several final goods are produced jointly from an intermediate good, however, such assignment is difficult. Joint production processes are extremely common in some of the industries that produce taxed goods; petroleum refining and petrochemicals are examples that are discussed below.[5] This section illustrates the problems of taxing imported final goods with a simple example of a joint production technology.

We assume that two goods, q_1 and q_2, are jointly produced according to the following production functions:

$$q_1 = \min[\frac{L_1}{\delta_1}, \frac{E}{h_1}] \tag{3}$$

and

$$q_2 = \min[\frac{L_2}{\delta_2}, \frac{E}{h_2}]. \tag{4}$$

Labor input must be dedicated to the production of one good or the other, but the intermediate good input is "public" in the sense that over some ranges of output, production of one good can be increased without raising intermediate good inputs. The production technology described in (3) and (4) exhibits constant marginal costs

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[5]Leffler (1979) and Burdick and Leffler (1990) provide readable introductions to the technology of the petroleum refining and petrochemical industries, respectively.

of producing goods 1 and 2.

Figure 2 summarizes the supply behavior of a price-taking firm facing the production function given by (2) and (3). If the price of either good 1 or good 2 is below the marginal cost of the labor required to produce it, δ_1w and δ_2w, respectively, the firm will not produce this good. Even when p_1 and p_2 both exceed the marginal labor cost required for production, however, the firm may not supply any output, since it must also cover the cost of intermediate good inputs. The break-even condition for the firm to produce <u>both</u> goods is:

$$\frac{p_1}{h_1}+\frac{p_2}{h_2}=e+[\frac{\delta_1}{h_1}+\frac{\delta_2}{h_2}]*w. \qquad (5)$$

This expression equates the marginal cost of jointly producing $1/h_1$ units of good 1 and $1/h_2$ units of good 2 to the marginal revenue from selling these goods. The relative quantities of goods 1 and 2 in this expression are set by their relative intermediate good input requirements, which dictate that a firm producing both goods will set $q_2 = (h_1/h_2)*q_1$.

If $h_2 = 0$, there is no joint production and the intermediate good content of good one is $\alpha_1 = h_1$, since producing one unit of good one requires h_1 units of E. If h_1 and h_2 are both non-zero, however, what is the intermediate good intensity of good one? Since one unit of intermediate input E produces $1/h_1$ units of good one and $1/h_2$ units of good two, the intermediate good intensities of goods one and two, α_1 and α_2, must satisfy:

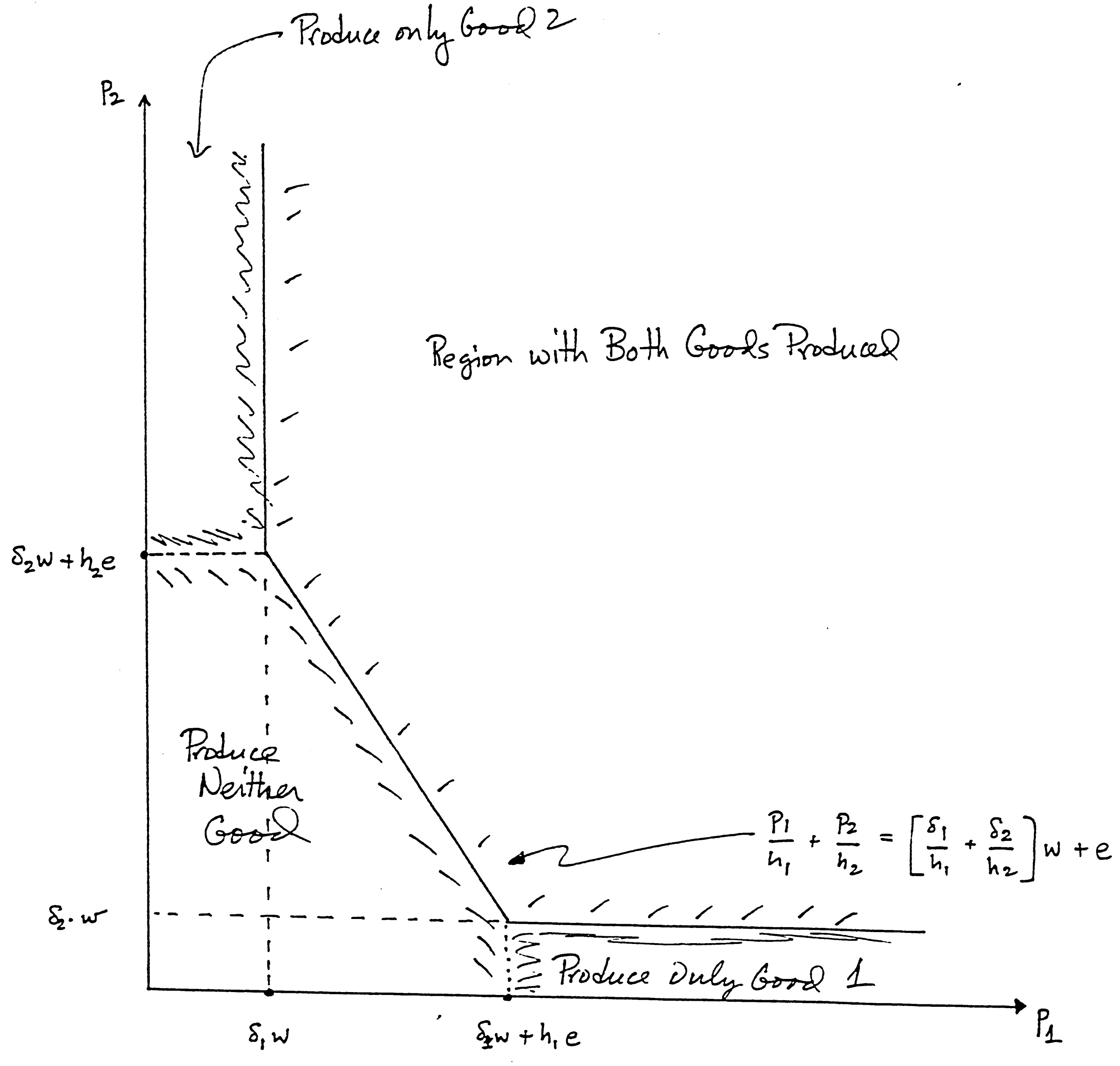

Figure 2: Production Decisions For Firm Facing Linear Joint Technology

$$\frac{\alpha_1}{h_1}+\frac{\alpha_2}{h_2}=1. \qquad (6)$$

While this condition ensures that $\alpha_1 < h_1$, so that the intermediate good intensity of good 1 is strictly less than the amount of the intermediate good needed to produce one unit of good 1, it does not provide a precise value for α_1.

Analyzing how producer prices respond to a change in the cost of intermediate goods requires assumptions about the elasticity of demand for goods 1 and 2, as well as the elasticity of supply of labor. We consider the case in which good one is traded in international markets, while good two is a production by-product that is sold in the domestic market. We further assume that labor is elastically supplied at a fixed wage, w, and that the demand for good 2 is perfectly elastic in each nation. Foreign and domestic firms therefore face the same price for good one, but they may face different prices, p_{2F} and p_2, respectively, for their output of good two.

These assumptions imply that a tax on the intermediate good will be fully reflected in the price of good 1.[6] Holding w and p_2 fixed, we differentiate (6) with respect to e and find $dp_1 = h_1*(de/d\theta)*\theta$. When $de/d\theta = 1$, the tax on imports of good one that raises marginal costs by the same amount for domestic and foreign producers is $\tau = h_1*\theta$. But we know from above that the share of the intermediate

[6]The question we consider is a standard tax incidence problem: how will an increase in the price of the intermediate good be reflected in the prices of the two final goods and wage rate? Our assumptions that the wage is fixed, and that the demand for good two is infinitely elastic at a given price, determine the outcome that all of the price adjustment occurs in the price of good one. Relaxing these assumptions would lead to some adjustment in other prices as well.

good embodied in good one is $\alpha_1 < h_1$. Thus a tax on imports based on the intermediate good intensity of good one, defined as the increase in the inputs of E that are needed to produce one more unit of good one, will raise marginal costs for foreign producers by less than the cost increase for domestic producers. This result obtains when both foreign and domestic producers employ the same technology, and could even obtain in some cases when foreign producers use more intermediate input per unit of output than domestic producers. This finding suggests that intermediate good intensity may not be an appropriate standard for choosing border tax adjustments associated with domestic environmental taxes.[7]

4. The Government Objective Function and Import-Neutrality

The previous discussion takes the government's objective of raising the marginal costs of domestic and foreign producers by the same amount as given. In this section, we show that the optimal tax chosen by a social planner who is equally concerned with externalities generated abroad and at home will exhibit this property.

We illustrate this by modifying the joint production function of the last section to allow for diminishing returns to labor input. Outputs q_1 and q_2 are therefore jointly produced according to:

---

[7]Braeutigam (1980) explains that in regulatory contexts, a number of arbitrary rules have been used to solve similar problems of joint cost attribution. The parameters α_1 and α_2 might be set by the relative physical weights of the two outputs, or by their relative market values, or by the relative variable costs that can be attributed to each of these products. Yet only under restrictive conditions will any of these rules yield welfare-maximizing prices for the various regulated goods.

$$q_1^D = \min[f(L_1^D), \frac{E^D}{h_1}] \tag{7}$$

and

$$q_2^D = \min[g(L_2^D), \frac{E^D}{h_2}]. \tag{8}$$

As before, good 1 is both produced domestically and imported, while good 2 is not tradable. E^D denotes domestic consumption of the intermediate good. We assume the social planner maximizes the utility of a representative consumer who has an additively-separable utility function in goods 1, 2, labor supplied, and the externality associated with consumption of E both at home (E^D) and abroad (E^F):

$$W = U(q_1^D + q_1^F) + V(q_2^D) - p_1^F * q_1^F - L_1^D - L_2^D - e * E^D - \beta * (E^D + E^F) \tag{9}$$

We have normalized the domestic wage to unity, and use q_1^F to denote imports of good 1, which cost p_1^F per unit. The parameter β denotes the reduction in utility for each unit of E consumed, whether at home or abroad. The problem of choosing the optimal tax on the foreign good is now equivalent to choosing q_1^F, and in so doing, the social planner recognizes the effect of producing good 1 abroad on the level of energy consumption abroad (E^F), and the associated level of externalities generated.

We assume that foreign production takes place under conditions of constant marginal cost, which simplifies the problem, and that the production functions for q_1^F and q_2^F are respectively $q_1^F = \min[L_1^F, E^F/h_1]$ and $q_2^F = \min[L_2^F, E^F/h_2]$. With a fixed wage abroad and infinitely elastic demand for good 2, which fixes p_2^F, the break-even condition derived in the last section requires that

$$p_1^F = h_1 * e - \frac{h_1}{h_2} * p_2^F. \tag{10}$$

In addition, as we derived in the last section, $dE^F/dq_1^F = h_1$. Thus we can replace E^F in equation (9) with $h_1 * q_1^F$. This fact, along with the relationship $E^D = h_1 * f(L_1^D)$, allows us to rewrite the representative consumer's utility function as:

$$W = U(f(L^D_1)+q_1^F)+V(q_2^D)-p_1^F*q_1^F-L_1^D-g^{-1}[q_2^D]-e*h_1*f(L^D_1)-\beta*(h_1*f(L^D_1)+h_1*q_1^F). \tag{11}$$

The government's control variables are domestic labor input, the quantity of good one imported, and the quantity of good two produced domestically. The first order condition for the optimal choice of q_1^F is:

$$U' = p_1^F+\beta*h_1. \tag{12}$$

This condition implies that the optimal tax that the social planner would levy on imports of good 1 equals $\beta * h_1$. This is the utility cost of the externality associated with consumption of E times the quantity of E consumed in producing another unit of q_1^F. Inspection of (9) shows that the Pigouvian tax on domestic consumption of E is also β. Thus the optimal tax on imported goods, $\tau = h_1 * \beta$, is precisely the optimal tax on domestic intermediate good use, β, times the marginal effect of imports of good 1 on foreign consumption of E.

5. Potential Applications: Petroleum Refining and Petrochemicals

The stylized examples of linear production technologies in the preceding sections illustrate the problems of taxing imported finished goods, yet they do not address the practical importance of these problems. Two of the industries that are best described by our stylized analysis are petroleum refining and petrochemical production. This section briefly outlines the production processes in these industries, and notes the similarities, as well as differences, with our modelling above.

Crude oil and most refined petroleum products are traded in active global markets. In 1991, the United States imported 5.78 million barrels per day of crude oil, and 1.79 million barrels of refined petroleum products (Annual Energy Review (1991, p. 123)). Crude oil is an intermediate input in the production of refined petroleum products, so nearly one quarter of U.S. petroleum imports are "finished goods" for purposes of our analysis. The United States imports a wide range of refined products.

Refining is the production process that transforms crude oil into a range of petroleum products. The critical feature of crude oil, explained for example in Leffler (1979), is that it is a complex mixture of many hydrocarbons. The refining process separates these different components, and in some cases also initiates chemical reactions that transform some component hydrocarbons into others. Refining is a textbook example of a joint production process. The refining process produces gasoline, kerosene, distillate oil, residual fuel oil, asphalt, and a range of other petroleum products. Although the characteristics of the crude oil input and the specification of the refinery process can affect the relative amounts of the various outputs that are produced from a barrel of crude oil, it is essentially impossible to produce only a single product from crude oil input. For example, even though most U.S. refineries are designed to maximize gasoline output per barrel of crude oil input, gasoline accounts for less than half of refinery output.

The difficulty of determining the share of intermediate inputs, such as crude oil, in outputs, such as gasoline, is illustrated in Table 2. The table shows the output mix of refineries in various regions. There are substantial differences in gasoline's share in refinery output between the United States (46%) and all other regions (20% in Asia, 18% in Africa and the former Soviet Union). The share of residual fuel oil is correspondingly much higher in other countries than in the United States. The parameter h_i in our preceding analysis, the amount of a given input that is needed to produce a unit of the final good, thus would vary for gasoline-crude oil across nations. Table 3 presents some evidence on the source of these differences, describing the technological characteristics of the refining industry in different countries. This table shows the nature of the refinery capacity in the United States and the five countries from which the U.S. imported the largest volume of petroleum products in 1991.[8]

The processes in Table 3 are presented in approximately increasing order of sophistication, with vacuum distillation and thermal methods the least sophisticated, and catalytic hydro-treating and hydro-reforming the most complex. There are

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[8]In 1991, imports from Saudi Arabia were 1.80 million barrles per day, Canada, 1.03, Venezuala, 1.01, Mexico, .80, and Nigeria, .70; see Annual Energy Review (1991, p.125).

significant differences in the set of processes used in different countries. Venezuala, for example, relies more heavily on non-catalytic refinery methods, distillation and other thermal methods, than the U.S. or any of the other nations shown. Catalytic reforming, a process that is designed to increase the output of high-octane gasoline from a given input of crude oil, is relatively more common in Mexico than elsewhere. These technological differences further suggest that there may be differences between the U.S. and the nations from which we import petroleum products in the input-output coefficients for these products.

A key issue in applying our analytical framework to the market for refined petroleum concerns the assumption that some products are traded in world markets, while others are not. Leffler (1979) discusses the "bottom of the barrel," the products such as asphalt, road oil, and coke that are left over after the production of higher-value products such as gasoline. These products, while tradable, are relatively low value and therefore tend not to be transported. The United States, for example, imported only 2,000 barrels per day of petroleum coke in 1992, compared with domestic production of 596,000 barrels.[9] The fact that these products are nevertheless tradable suggests that the simple framework developed above may need to be modified before analyzing these markets.

Better examples of tradable and non-tradable joint products can be found in the petrochemical industry. This industry is a downstream segment of the refining industry, which produces a range of synthetic hydrocarbons used in plastics, resins,

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[9]American Petroleum Institute (1993), Table 18d.

and a wide range of other manufactured products. Burdick and Leffler (1990) describe many of the principal products of this industry, and the chemical processes by which they are produced. Joint production is ubiquitous in this industry.

To illustrate the difficulty posed by joint production, consider the case of benzene, one of the products taxed under the U.S. Superfund tax. There are several ways to obtain benzene, all involving joint production. For example, ethylene and propylene are produced by "cracking" naphtha in an olefin plant, yielding benzene as a byproduct. More than 20% of the U.S. supply of benzene now results from this production process (Burdick and Leffler, 1990, p. 32). While benzene is actively traded, ethylene is not; it is similar to the untraded good in our analysis above.[10] Reuben and Burstall (1973) write that

> ...like propylene and the butenes, ethylene is a gas and it is inconvenient to transport. It is normally used near its point of production... One unexpected consequence of [this] ... is that very little [ethylene] is bought or sold except at secret contract prices, and it is difficult to know at what price it changes hands in large quantities. (p.197)

Ethylene in turn is used as an intermediate good in the production of various polyethylene compounds as well as ethylene oxide, ethylene gycol, ethyl benzene, and ethyl alcohol.

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[10]Waddams (1973) provides further support for the difficulty of transporting some petrochemical products in his discussion (p. 296) of ethylene production in the U.S. and Europe. He describes the greater reliance on naphtha as an input to the cracking process in Europe, and the greater prevalence of joint products from this method rather than the ethane-based methods of ethylene production more common in the United States. He also indicates that the rate of growth in demand for ethylene's joint products <u>in Europe</u> is a key factor affecting the economics of the naphtha-based process.

A U.S. producer of both benzene and ethylene would be taxed on both products (see Figure 1). A foreign producer supplying benzene to the U.S. market, however, would not face a comparable tax on ethylene output. This could imply a smaller increase in the marginal production cost for foreign than domestic producers.

6. Conclusion and Future Directions

This paper examines a problem that arises in many aspects of international tax policy: how should tax rates be set to avoid providing a competitive advantage to either domestic or foreign producers? We show that standard prescriptions based on the case of exhaustive production, when all inputs are consumed in producing a single final good, do not carry over to the more complex case of joint production. Moreover, we argue that the very notion of the embodied intermediate good content of a joint product is poorly defined, even though this is the concept that typically underlies actual attempts to design tax policies.

This paper does not provide a constructive suggestion on how to set appropriate border taxes in general. Rather, our simple examples highlight that the tax rate that raises marginal costs for foreign and domestic producers by the same amount will depend on conditions in the markets for each of the joint products, as well as conditions in the markets for other factors that are used to produce the joint products. Simple, general rules for border tax adjustment are not available.

The issues considered in this paper arise in a variety of public policy contexts that involve subsidization or regulation of joint production, and not just in tax design.

Subsidizing one of several joint products, or regulating one product, may reduce the equilibrium price that producers can charge for the other joint products. For example, unintended subsidies to the production of carbon dioxide are apparently one consequence of U.S. government subsidies to ethanol.

The administrative difficulties that arise in taxing internationally-traded joint products are inherent to multijurisdictional tax systems. International coordination of tax policies, which can ensure that all joint products face similar tax burdens, provides one method of reducing these difficulties.

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Table 1: U.S. Imputation of Ozone Depleting Chemical Content of Imports

Product	Imputed ODC Weight	1993 Tax Burden
Household Freezers	2.40 lbs.	$8.04
Computer Keyboards	0.07	0.20
Telephones, Value > $11	0.10	0.27
VCRs	0.06	0.16
Foam Chairs	0.30	1.01
Passenger Cars with Air Conditioning	4.00	13.07

Source: U.S. Code of Federal Regulations, 26 CFR 52.4682.3, pp. 24-27.

Table 2: Refinery Output Mix, by Region, 1990

	Gasoline	Distillate	Residual	Other
United States	45.9%	19.3%	6.3%	28.6%
Canada	35.3	26.7	8.4	29.6
Mexico, Central & South America	24.0	25.2	28.1	22.7
Western Europe	24.7	31.7	18.9	24.7
Middle East	14.1	28.9	33.6	23.4
Africa	18.0	27.7	29.6	24.7
Asia	20.0	29.5	24.6	25.8
Eastern Europe & Former Soviet Union	18.3	24.4	33.5	23.8

Source: American Petroleum Institute, 1993, Basic Petroleum Data Book volume XIII, Number 3 (September), and authors' calculations.

Table 3: Refinery Capacity by Type and Country, 1993

	U.S.	Saudi Arabia	Canada	Venezuela	Mexico	Nigeria
Vacuum Distillation	24.0	31.1	26.1	45.7	30.7	32.2
Thermal Operations	6.5	5.3	4.2	10.8	2.6	0.0
Catalytic Cracking	18.8	6.4	15.0	19.1	10.4	21.4
Catalytic Reforming	13.0	13.4	14.0	0.8	30.7	18.1
Catalytic Hydrocracking	4.4	5.6	8.1	0.0	0.9	0.0
Catalytic Hydro-Reforming	7.7	3.3	1.3	0.0	12.1	0.0
Catalytic Hydro-Treating	25.4	35.0	31.2	23.6	12.6	28.3

Source: Oil and Gas Journal Data Book 1993, pp.206-7, and authors' calculations.