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Environmental Policy when Market Structure and Plant Locations Are Endogenous[1]

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A two-region, two-firm model is developed in which firms choose the number and the regional locations of their plants. Both firms pollute, and market structure is endogenous to environmental policy. There are increasing returns at the plant level, imperfect competition between the "home" and the "foreign" firm, and transport costs between the two markets. At critical levels of environmental policy variables, small policy changes cause large discrete jumps in a region's pollution and welfare as a firm closes or opens a plant, or shifts production to/from a foreign branch plant. The implications for optimal environmental policy differ significantly from those suggested by traditional Pigouvian marginal analysis.

Existing analyses of environmental policy tend to follow the Pigouvian tradition of examining the effects of taxes, subsidies, and other policy instruments on marginal price and output decisions of firms.[2] Marginal analysis is perfectly appropriate for a world of constant returns to scale and perfect competition. In such a world, one can deal directly with the reduced form of an industry and its continuous and differentiable supply function. Optimal tax and/or regulation

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[2]The early analyses of environmental policy were in a partial equilibrium framework, Pigou [34] and Meade [30] being two classic examples. See Baumol and Oates [3]. General equilibrium models with pollution date back to the 1970s. Førsund [15], Comolli [9], Forster [12, 13], and Yohe [37] consider environmental policy in a one-region general equilibrium framework. General equilibrium models with trade and pollution have been examined by Markusen [22, 23], Pethig [33], Asako [1], Siebert *et al.* [35], McGuire [29], and Merrifield [31]. Pollution may or may not cross international boundaries in these models. For example, in Pethig [33], pollution intensiveness of goods varies, but pollution does not cross boundaries. Environmental policy affects the location of production (domestic or foreign), amount of pollution in each country, and welfare. Pethig shows how gains from trade can be offset by losses from domestic pollution damages. Asako [1], in a slightly different model obtains similar results. Alternatively, Merrifield [31] examines transfrontier pollution (Canada-U.S. regulation of acid deposition). All of these models analyze impacts on the margin and assume pure competition and constant returns to scale.

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formulas can then be derived and expressed in terms of underlying parameters of demand and supply functions. Typically these formulas equate two marginal effects, such as a pollution tax equating a marginal benefit of pollution reduction, to the marginal cost of that reduction.

In an industry with increasing returns to scale, which in turn are generally associated with imperfect competition, such an analysis is at worst inappropriate or at best incomplete. Along with the marginal decisions over continuous variables such as prices and outputs, firms in increasing-returns industries make discrete decisions such as whether or not to serve another region or country by exports or by building a branch plant in that region. Environmental regulation in one region may cause one or more plants in that region to shut down and transfer production to plants in the other region.[3]

Policymakers are quite aware of the possibility that stiff environmental regulations may cause plant closures. Yet most formal policy analysis by economists has continued to pursue the marginal approach, even when imperfect competition is added to the model.[4] In such a marginal analysis, market structure, by which we mean the number and locations of plants, is assumed exogenous.[5]

The purpose of this paper is to readdress environmental issues that have been dealt with before, but in a model that allows firms to enter or exit, and to change the number and location of their plants in response to environmental policies. The model consists of two Regions (A and B) and three goods (X, Y, and Z). A firm incorporated in Region A produces X with increasing returns and a firm in Region B produces Y with the same technology (X and Y may or may not be perfect substitutes). Z is a homogenous good produced in both regions by competitive industries. The production of X and Y generates regional pollution and there are no regional spillovers of pollution. There is no pollution associated with the production of Z.

Each entering firm must incur a firm-specific fixed cost (such as R&D) that is a joint-input across their plants, and a plant-specific fixed cost for each plant it opens. Production occurs with constant marginal cost and there is a transportation cost of shipping output between regions. The decision to serve another region is a discrete choice between the high fixed-cost option of a foreign branch plant or the high variable-cost option of exporting to that market.

[3]There is, to our knowledge, only a small amount of empirical literature on whether plant locations decisions are influenced by environmental policy (Bartik [2] and McConnell and Schwab [28]). McConnell and Schwab [28] use a logit model to explain the location decision for 50 new motor vehicle plants in the U.S. They find "some evidence that, at the margin, firms are deterred from locating plants in the most polluted ozone non-attainment areas."

[4]There is some literature on imperfect competition and pollution control, but what exists is generally partial equilibrium and does not treat the market structure as endogenous. Buchanan [6] examined monopoly and external diseconomies in a partial equilibrium framework. More recent work includes Burrows [7], Besanko [4], Misiolek [32], and Laplante [20, 21].

[5]Note that there is literature (Mathur [27], Gokturk [16], and Forster [14]) on how a firm's location *within a region* is influenced by a pollution tax on the ambient air quality in the region's urban center. The intent of this literature is to derive sufficient conditions on the technology to imply that an increase in the tax will cause the firm to locate further from the urban center. These papers do not consider the optimal tax, nor consider the possibility that an increase in the tax might cause the firm to go out of business or to relocate to another region with a different government. Tietenburg [36] considers optimal pollution taxes when there are many firms and where the spatial distribution of these firms is exogenously given. However, he does briefly consider the possibility that firms might migrate as a function of spatially differentiated tax rates.

General equilibrium is found as the solution to a two-stage game. In stage one, the two firms (X and Y producers) each make a strategy choice over three discrete options: (1) no entry, referred to as the zero-plant strategy; (2) serving both regions from a plant in the home region, referred to as the one-plant strategy; and (3) building plants in both regions, referred to as the two-plant strategy. In stage two, the X and Y firms play a one-shot Cournot output game.[6]

We solve for a subgame perfect equilibrium of this game and show how the equilibrium market structure depends, in part, on environmental policy. In the *positive* analysis of market structure, the policy variable can be interpreted either as (1) a pollution tax when abatement is not possible,[7] or (2) as the increased marginal cost of production due to an environmental restriction (e.g., requiring cleaner fuel) when abatement is possible.[8] The *welfare* consequence of a shift in market structure, however, differ somewhat under the two interpretations, and Section II concentrates on the tax interpretation. A tradable permit system, regulations that fall on fixed costs, and the welfare effects of a regulation falling on marginal costs are discussed in Section IV.

Changes in pollution taxes/regulations change the payoffs to a firm in the second-stage game, which in turn alter the location decision in the first stage at critical values of the policy variable. Changes in market structure have four discrete effects under the tax interpretation: they alter the level of pollution, they change product prices and hence consumer surplus, they change the level of government tax revenue, and they change the profits of the local firm (assumed to enter the local income stream). Some of these four effects generally move in opposite directions. Under the regulatory interpretation of the policy variable, there is no tax revenue, but pollution per unit of output varies with regulation. Again, certain welfare effects move in opposite directions.

One feature of the model deserves a brief comment before continuing. Subject to some restrictions, analytical results can be derived specifying market structure

[6]A large number of papers in international trade theory have focused on the second stage of this type of game: Brander and Spencer [5], Dixit [10], Eaton and Grossman [11], Helpman [17], Krugman [19], and Markusen [24, 25] are a few examples. To the best of our knowledge, only Horstmann and Markusen [18] have formally modeled the two-stage game.

[7]Examples of taxes used for environmental policy are: the Netherlands' 1988 tax on fuels, designed to assist in controlling sulfur dioxide and lead emissions, and France's 1990 taxes on air pollution emissions of sulfur dioxide, nitrous oxides, and hydrochloric acid. The Netherlands also imposed in early 1990 a "carbon tax" based on the carbon-dioxide-generating potential per unit energy of different fuels. Many other countries are currently examining the imposition of carbon taxes (including Canada, the United States, and Norway). Pesticide and fertilizer taxes have been imposed in Sweden and are being examined in the state of Washington, British Columbia, and Ontario. Effective in 1990, the U.S. imposed a tax on the ozone-depleting factor for a variety of chlorofluorocarbon and halon chemicals. Environmental taxes have also been a part of CERCLA (the Comprehensive Environmental Response, Compensation and Liability Act of 1980), albeit with an objective of financing the Superfund. These have included taxes on crude oil and 42 different industrial petrochemicals and inorganic compounds.

[8]Other examples of environmental policies which affect marginal costs of production include: the ban on leaded gasoline in Canada—the additive replacing lead is more expensive, adding to refinery costs; and the substitution of bleaching compounds in the pulp and paper industry from dioxin-creating chlorines to alternative inputs. To get a permit to operate a new plant in British Columbia, the more expensive non-chlorine compounds (and process) must be used. To meet pollution requirements, Volvo may be switching to more expensive water-borne rather than oil-based paints. Scrubbers, an essential part of air pollution control regulations for coal-fired electric power plants in the U.S., add both to operating and to capital costs.

as a function of the policy variable. However, the analysis of the welfare effects of market structure shifts proceeds by way of numerical analysis. Market structure makes a discrete change at certain critical values of the environmental and technology parameters. Significant structure is needed to evaluate the combined contributions of conflicting welfare effects at these jumps.

1. A SIMPLE TWO-COUNTRY, TWO-FIRM, THREE-GOOD MODEL WITH POLLUTION

Two regions exist, A and B. Each region is endowed with an identical amount of a homogeneous factor input, L. A homogeneous traded good Z can be produced by each region with its units chosen so that $Z = L_Z$. Z (or L) is the numeraire. There is no pollution associated with the production or consumption of Z.

There is a firm based in Region A that can produce a good X with increasing returns to scale, and there is firm based in Region B that can produce a symmetric substitute good Y.[9] Each firm can either produce in just their own region and export to the other region, have plants in both regions, or not operate. Notionally, let $X^a(Y^a)$ and $X^b(Y^b)$ denote the amount of product $X(Y)$ produced in Regions A and B, respectively. Assume one unit of homogenous pollution is produced in a region for each unit of X or Y produced in that region.[10]

The cost functions for both potential firms (expressed in units of L) are identical where $F \equiv$ firm specific fixed costs, $G \equiv$ plant specific fixed costs, $m \equiv$ constant marginal cost, $s \equiv$ per unit transport costs between the regions, and $t_a \equiv$ the per unit pollution tax in Region A. The firm-specific costs represent joint inputs across plants such as firm-specific knowledge. Multi-plant economies of scale result because the fixed costs of a two-plant firm, $2G + F$, are less than the combined fixed cost of two one-plant firms, $2G + 2F$. Under the regulatory interpretation of the model (discussed in Section IV), t_a is the increased marginal cost of production due to an environmental restriction such as requiring a less polluting but more expensive input.

Demand for the three products is generated by N consumers in each region, where N is assumed to be a large number. All these individuals have identical preferences which can be represented by the same simple quadratic utility function. Specifically, utility for an individual in Region i ($i = a, b$) is

$$U_i = \alpha x_i - (\beta/2)x_i^2 + \alpha y_i - (\beta/2)y_i^2 - \gamma x_i y_i + z_i - \tau(X^i + Y^i), \quad (1)$$

where $x_i(y_i)$ is the amount of good $X(Y)$ consumed by each individual in region i, and $(X^i + Y^i)$ is the total amounts of pollution in region i. The parameter τ reflects the constant marginal disutility from pollution. Each individual views the total production of pollution as exogenous. In the absence of a pollution tax, or regulation, this externality, ceteris paribus, will lead to market failure.[11]

[9] Scale economies are assumed sufficiently large relative to demand such that the two regions can support at most one X and one Y firm. Each of these firms therefore has market power.

[10] Under the tax interpretation of the environmental policy variable, the possibility of abatement (reducing pollution per unit of output) is assumed away.

[11] Note that the system is also distorted by the market power of the X firm and the Y firm.

Assume profits from the X firm (Y firm) and Region A's revenues from the pollution tax are distributed equally amongst the N individuals in Region A. Given this, the individual budget constraints in Region A and B are, respectively,

$$(L + \pi_x + t_a(X^a + Y^a))/N = p_x^a x_a + p_y^a y_a + z_a \tag{2a}$$

$$(L + \pi_y)/N = p_x^b x_b + p_y^b y_b + z_b, \tag{2b}$$

where $p_x^a(p_y^a)$ is the price of good $X(Y)$ in Region A, and π_x and π_y are the profits of the X and Y firms. Focusing on Region A, the inverse aggregate demand functions are found by maximizing (1) ($i = a$) subject to (2a).

$$p_x^a = \alpha - \beta(X_a/N) - \gamma(Y_a/N), \qquad p_y^a = \alpha - \beta(Y_a/N) - \gamma(X_a/N), \tag{3}$$

where $X_a \equiv Nx_a$ and $Y_a \equiv Ny_a$.[12] $x_a(y_a)$ is the demand for $x(y)$ by a representative individual in Region A. The inverse aggregate demand functions for Region B have the same form. Note from (3) that the inverse demand functions do not depend on income and not on tax receipts in particular. We refer to this result again in Section IV when discussing the regulatory interpretation of the policy variable t_a.

General equilibrium is characterized by a situation where: (1) each individual is maximizing his/her utility given exogenous prices, profits, and aggregate pollution; (2) each firm is maximizing its profits given the number of plants operated by the other firm; (3) supply = demand for all three goods in each region; and (4), $L = L_X + L_Y + L_Z$ in both regions. Equilibrium social welfare in Region A is the sum of consumer surplus, profits, tax revenue, the disutility of pollution, and labor income. In a short Appendix, we show that this is given by

$$SW_a = \left[\beta(X_a^2 + Y_a^2)/(2N) + \gamma X_a Y_a/N\right] + \pi_x + \left[(t_a - \tau N)(X^a + Y^a)\right] + L. \tag{4}$$

The first square-bracketed term is consumer's surplus from X and Y (the marginal utility of Z is constant and hence there is no consumer surplus associated with Z), while the other term in square brackets is tax revenue minus the disutility of pollution. The equilibrium social welfare function for Region B is identical except one substitutes π_y for π_x, and production and consumption levels in B for those in A. Section IV discusses the small modification to (4) needed under the regulatory interpretation of t_a.

Equilibrium market structure is determined in a two-step procedure corresponding to a two-stage game. In stage one, X and Y producers make a choice among three options: no production, a plant only in their home region, or a plant in both regions. In stage two, X and Y play a one-shot Cournot game. Moves in each stage are assumed to be simultaneous, and the usual assumptions of full information hold.

The game is solved backward. The maximized value of profits for each firm is determined for the three options listed above, given, in turn, each of the three

[12] Note the distinction between $X_a(Y_a)$ and $X^a(Y^a)$. X_a is the amount of good X consumed in region A and X^a is the amount of good X produced in region A.

options for the other firm. Profit levels for the firms in each of these nine cases are then the payoffs for the game in which the strategy space is the number of plants.[13] The Nash equilibrium (or equilibria) of this game in the number of plants determines the equilibrium market structure for the model.

We illustrate the determination of profits by solving for maximum profits in the simple structure where firm X operates one plant in Region A and firm Y does not operate—structure $(1,0)$.

In the first case, $(1,0)$, $\pi_y^*(1,0) = 0$ and

$$\pi_x(1,0) = [\alpha - \beta(X_a/N)]X_a + [\alpha - \beta(X_b/N)]X_b - mX_a - (m+s)X_b - t_a(X_a + X_b) - F - G. \quad (5)$$

Maximizing, and solving, the profit maximizing levels of sales in the two regions are

$$X_a(1,0) = N(\alpha - m - t_a)/(2\beta) \quad X_b(1,0) = N(\alpha - m - t_a - s)/(2\beta). \quad (6)$$

Substituting Eq. (6) into (5), maximum profits for firm X are

$$\pi_x^*(1,0) = N\left[(\alpha - m - t_a)^2 + (\alpha - m - t_a - s)^2\right]/(4\beta) - F - G. \quad (7)$$

Consider now the structure where both firms operate in both regions—(2, 2):

$$\pi_x(2,2) = [\alpha - \beta(X_a/N) - \gamma(Y_a/N)]X_a + [\alpha - \beta(X_b/N) - \gamma(Y_b/N)]X_b - m(X_a + X_b) - t_aX_a - 2G - F. \quad (8)$$

Using the related expression for π_y, maximizing and solving, the four supply functions are

$$X_a(2,2) = Y_a(2,2) = N(\alpha - m - t_a)/\delta \qquad \delta \equiv (2\beta + \gamma) \quad (9)$$

$$X_b(2,2) = Y_b(2,2) = N(\alpha - m)/\delta. \quad (10)$$

Substituting Eqs. (9) and (10) into Eq. (8) and correspondingly for π_y, maximum profits for the two firms in the (2, 2) case are

$$\pi_i^*(2,2) = N\left[(\alpha - m - t_a)^2 + (\alpha - m)^2\right]\Big/(\beta/\delta^2) - (F + 2G) \qquad i = (x, y). \quad (11)$$

While tedious, maximum profits for all of the other structures can be worked out in similar fashion. Note that while welfare is a decreasing function of τ, profit levels and equilibrium market structure are not a function of τ.

[13]The nine cases are (0, 0), (1, 0), (0, 1), (2, 0), (0, 2), (2, 1), (1, 2), (1, 1) and (2, 2), where the number in the first (second) position is the number of plants operated by the $X(Y)$ producer. (2, 0) denotes, for example, a market structure in which the X producer has plants in both regions, and Y does not enter. In order to limit the dimensionality of the problem to nine cases, we assume that the $X(Y)$ firm cannot have a single plant in Region $B(A)$: A firm must have a plant in its home region (or none at all). Without this restriction there would be a total of 16 possible cases.

TABLE I
Equilibrium Market Structure and Plant Location in Four Different Simple Games

	Number of Plants for Firm Y		
Firm X	2 Plants	1 Plant	0 Plants
Game 1. $G = 5{,}000$ and $F = 30{,}000$: Nash equilibrium (2, 2), denoted by *			
2	(960, 960)*	(2,700, −300)	(24,000, 0)
1	(−300, 2,700)	(1440, 1440)	(21,500, 0)
0	(0, 24,000)	(0, 21,500)	(0, 0)
Game 2. $G = 6{,}000$ and $F = 29{,}000$: Nash equilibria (2, 0) or (0, 2)			
2	(−40.0, −40.0)	(1,700, −300)	(23,000, 0)*
1	(−300, 1,700)	(1,440, 1,440)	(21,500, 0)
0	(0, 23,000)*	(0, 21,500)	(0, 0)
Game 3. $G = 7{,}000$ and $F = 28{,}000$: Nash equilibria (1, 2), (2, 0) or (0, 2)			
2	(−1,040, −1,040)	(700, −300)	(22,000, 0)*
1	(−300, 700)	(1,440, 1,440)*	(21,500, 0)
0	(0, 22,000)*	(0, 21,500)	(0, 0)
Game 4. $G = 7{,}000$ and $F = 27{,}000$: Nash equilibrium (1, 1)			
2	(−40.0, −40.0)	(1,700, 700)	(23,000, 0)
1	(700, 1,700)	(2,440, 2,440)*	(22,500, 0)
0	(0, 23,000)	(0, 22,500)	(0, 0)

Note. Parameter values: $\alpha = 16$, $\beta = 2$, $\gamma = 1$, $m = 0$, $s = 2$, $\tau = 0.0035$, $N = 1000$, $L = 50{,}000$, and $t_a = t_b = 0$. The first (second) number of each pair is the maximum profits for the $X(Y)$ firm in that structure.

The maximum profits for both firms in each of the nine structures are the payoffs in the second stage of the game. The Nash equilibrium (equilibria) is (are) that (those) market structure(s) such that given the number of plants operated by firm X, firm Y cannot increase it profits by changing its number of plants; and given the number of plants operated by Y, firm X cannot increase its profits by changing its number of plants.

To gain some insights into how different plant locations and market structures can originate, consider four simple example games. All that varies from one game to the other is the magnitudes of F and G (firm- and plant-specific fixed costs). In each game, X and Y are assumed to be imperfect substitutes ($\gamma = \beta/2$), and marginal cost is zero ($m = 0$). Other parameter values are shown at the top of Table I. These values are chosen to demonstrate how an interesting and empirically relevant sequence of market structure can be generated by varying fixed costs (scale economies).[14]

To isolate on the endogeneity of market structure independent of pollution taxes, initially pollution taxes in Region A are set to zero (pollution taxes in Region B already equal zero). Table I reports the profits and equilibrium market structure for the four games. The first (second) number of each pair is the maximum profits for the $X(Y)$ firm in that structure. The Nash equilibrium is denoted with an asterisk.

Roughly speaking, the games are ordered by decreasing F and increasing G, holding the transport cost s constant. In game 1 with the highest F and lowest G,

[14]The (2, 2) market structure, for example, is the case of "mutually invading multinationals" as it is known in the international trade literature. Chemicals and pharmaceuticals are two such industries which also pollute. (1, 1) is an exporting duopoly, a market structure which has been heavily analyzed in the "new" trade literature. Steel, and pulp and paper, are two such industries which also pollute.

the multi-plant market structure is the unique equilibrium. In Game 2, an increase in G with an equal decrease in F yield two symmetric equilibria, with only a single two-plant firm operating one plant in each region. In Game 3, there are three possible equilibria. In Game 4 with a low F but high G, the unique equilibria is a duopoly between single-plant firms, each firm exporting to the other firm's home market.

The general result is that a multi-plant market structure is more likely with a high F and low G, while a single-plant (for each firm) outcome is more likely with a low F and high G for the given value of s. This is an intuitive result: firms are likely to serve the other market by exports when the fixed costs of a new plant are high relative to the unit transport costs. General cases are found in Horstmann and Markusen [18].[15]

II. THE IMPACT OF A UNILATERAL POLLUTION TAX (OR A REGULATION RAISING MARGINAL COST) ON EQUILIBRIUM PLANT LOCATION AND MARKET STRUCTURE

Suppose that Region A imposes a unilateral pollution tax $t_a > 0$ while Region B has no tax ($t_b = 0$). Alternatively, t_a could be the additional marginal cost of an emission restriction, perhaps due to the added costs of cleaner fuel. A number of possible sequences of market structures, as a function of t_a, are possible. Rather than present a taxonomy, we choose to present two interesting possibilities: (i) The initial market structure is mutually invading multinationals $(2, 2)$, corresponding to a technology with high firm-specific costs, high transport costs, and low plant-specific costs (e.g., Game 1 of Table I). (ii) The initial market structure is exporting duopoly $(1, 1)$, corresponding to a technology with high plant-specific costs, low firm-specific costs, and low transport costs (e.g., Game 4 of Table I). Consider the following three assumptions where t_{a1}, and t_{a2}, denote specific values of t_a.

Assumption 1 (*High transport costs and high firm-specific costs, low plant-specific costs*).

(A) The initial equilibrium market structure is $(2, 2)$ at $t_a = 0$.

(B) At $t_a = t_{a1} > 0$ such that $\pi_x(2,2) = \pi_y(2,2) = 0$, $\pi_y(2,1) < 0$.[16]

(C) At $t_a = t_{a2} > t_{a1}$ such that $\pi_y(2,1) = 0$, $\pi_x(2,1) > 0$.[17]

RESULT 1. *Given Assumptions* 1A *through* 1C, *the sequence of market structures as a function of Region A's tax is given schematically by Fig.* 1.

[15]Extensive empirical evidence strongly supports this association between the importance of firm-specific costs and the multinationality of an industry. (See, for example, Caves [8].)

[16]Given a sufficiently large F, only a small t_a is needed to reduce $\pi_x(2,2) = \pi_y(2,2)$ to zero. If G is small and s is large, Y cannot then earn positive profits by dropping its plant in Region A (saving G and t_a) and exporting to A (incurring s) from its single plant in B.

[17]Again, under a sufficiently large F and s, the value of t_a that will set $\pi_y(2,1) = 0$ will be small relative to s. In market structure $(2, 1)$ Y does not pay t_a or a second G, but does pay s and vice versa for X. If G and t_{a2} are small relative to s, then assumption (1C) will be supported.

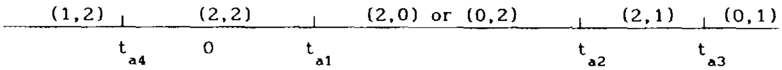

FIG. 1. Assumptions 1A through 1C yield this sequence of market structures as a function of Region A's tax rate.

Proof. Consider first raising t_a from zero. The properties of the model imply that $\pi_y(2,1)$ must increase and $\pi_y(2,2)$ must decrease with an increase in t_a. It follows from (1B) that for $t_a < t_{a1}$, we must have $\pi_y(2,1) < 0$. Assumption 1B thus implies that the Y producer cannot do better by serving Region A from a single plant over the region $0 < t_a < t_{a1}$. If this is true, given the symmetry in the model, the X producer cannot do better by serving Region B from its home plant in A (X would incur more tax *and* transport costs). (2, 2) is therefore the equilibrium over the interval $0 < t_a < t_{a1}$.

Just beyond $t_a = t_{a1}$, one firm must exit completely. Profits for both firms in the (2, 2) market structure are negative. Assumption 1B implies that the transport cost is sufficiently high that the Y Producer cannot make profits by deviating to one plant. The symmetry of the model then implies that the X producer would do even worse by deviating to one plant. Thus one firm must exit. For some values of $t_a > t_{a1}$, the equilibrium must be either (2, 0) or (0, 2). In order to avoid a taxonomy of all possible cases, we assume that the equilibrium is (2, 0) (the home government will not allow its firm to go out of business) but we report welfare values for a (0, 2) outcome in a later figure.

Further increases in t_a reduce the output of X's plant in Region A and, of course, X has no interest in deviating to a single plant in Region A. This reduction in the output of X^a increases the demand for Y. Assumption 1C implies that the Y producer will eventually find it profitable to reenter the market with a single plant serving both A and B. We denote this critical tax level by t_{a2}. Assumption 1C also implies that the profits of the home firm remain positive when Y enters with a single plant (and, again X will not deviate to a single plant), so the new equilibrium at $t_a = t_{a2}$ will be (2, 1).

Increases in t_a beyond t_{a2} continue to reduce the profits of the X producer and increase the profits of the Y producer. Eventually we will reach a value of $t_a = t_{a3}$ such that $\pi_x(2,1) = 0$. The X producer cannot increase his profits by deviating to one plant, and so must exit. The equilibrium for all tax rates $t_a > t_{a3}$ is (0, 1).

Finally, consider reducing t_a below zero, subsidizing the production of X and Y in A. This increases profits from producing in A, so Y will not want to deviate from its initial two plants. But at some point, the subsidy and the reduction in plant-specific costs will outweigh the transport cost, and the X producer will shut his plant in B. We denote the critical value of the tax (subsidy) as $t_{a4} < 0$. The new equilibrium will become (1, 2). This completes the derivation of the sequence of equilibria given by Result 1.

This sequence of equilibria can, in turn, translate into a number of qualitatively different welfare graphs due to conflicting welfare effects. For example, in the transition from (2, 1) to (0, 1) Region A experiences a loss of product X and an increase in p_y, but the level of pollution falls. Further, welfare effects depend on whether or not t_a is a tax or the additional marginal cost of an emissions

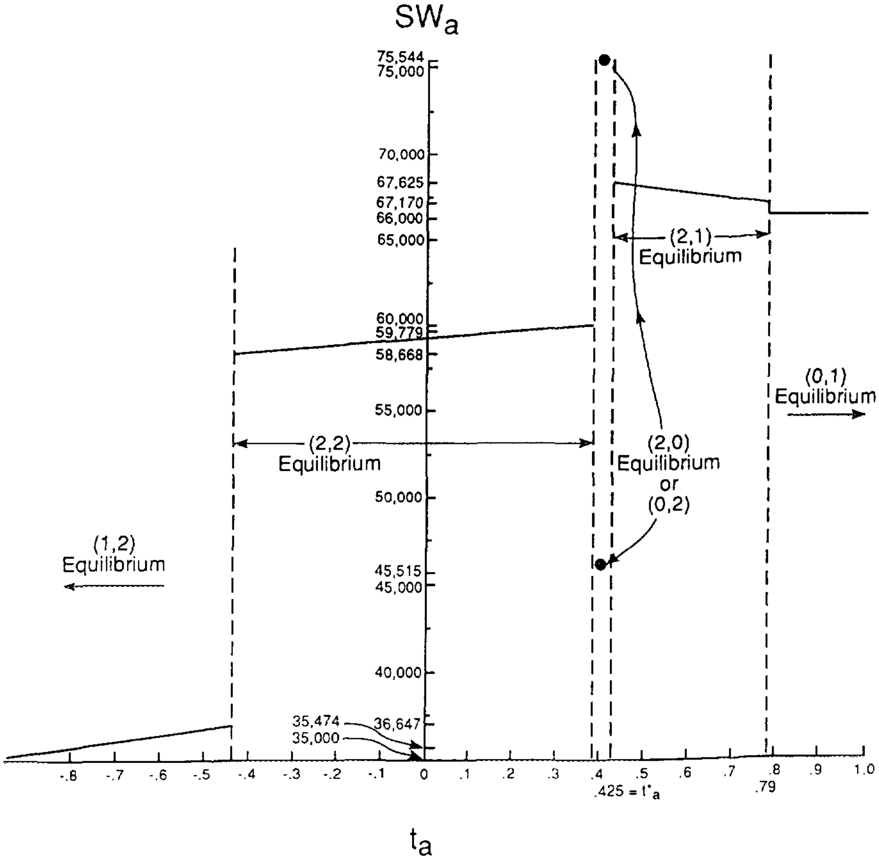

FIG. 2. Equilibrium social welfare in Region A as a function of t_a. Parameter values: $F = 30{,}000$; $G = 5{,}000$; $\tau = 0.0035$; $\alpha = 16$; $\beta = 2$; $\gamma = 1$; $m = 0$; $s = 2$; $N = 1{,}000$; $L = 50{,}000$; $t_b = 0$.

restriction as noted earlier. In what follows we assume that t_a is a tax. An emission restriction will be discussed in a subsequent section.

Two outcomes corresponding to different values of τ, the marginal disutility of pollution, are shown in Figs. 2 and 3. In both cases, the initial parameterization of the model corresponds to that of Game 1 in Table I, and the sequence of market structures corresponds to that of Result 1. Figure 2 assumes a relatively low $\tau = 0.0035$. Region A's equilibrium level of social welfare is 59,280 in the absence of a pollution tax. This welfare level is generated by a market structure of (2, 2). For small tax levels, $0 \leq t_a \leq 0.39999$, social welfare gradually increases as the tax is increased and market structure remains at (2, 2). The small increase in welfare is a reflection of the fact that the positive contributions of decreased pollution and increased tax revenue are largely offset by a loss of consumer surplus from the consumption of X and Y (the prices of X and Y increase) and by a loss in the profits of the domestic firm. At a tax rate of $t_a = 0.4$, the market structure switches to either (2, 0) or (0, 2). Since X and Y are symmetric substitutes, the only difference between the two market structures is in the profits of the domestic X producer. In market structure (2, 0), the increased profits of the local firm outweigh the loss of consumer surplus coming from both the loss of Y and from the increased monopoly price of X. In market structure (0, 2) we have only the latter two effects and no profits for the X producer, so welfare takes a discrete drop.

A further increase in t_a to 0.425 leads to the market structure (2, 1) for the reasons discussed: reduced production of X in A increases the demand for Y to the point where the Y producer reenters the market with a single plant, exporting to A. Welfare is higher than in the (2, 2) market structure due to a combination of several conflicting effects. Pollution is lower, as we indicated above, because Y is imported. Profits of the local firm are higher (for a given tax rate) since X now competes in Region A with higher cost imports. There is a discrete loss of consumer surplus (the price of Y jumps up) and tax revenue decreases at the switch in market structure. Further increases in t_a reduce welfare, suggesting that further reductions in pollution and increases in tax revenue are outweighed by the loss of consumer surplus and profits. At the tax rate of $t_a = 0.79$, the local firm (X) exist, and Region A suffers a discrete loss of both consumer surplus and profits that outweighs the decrease in pollution to zero. If we assume that Region

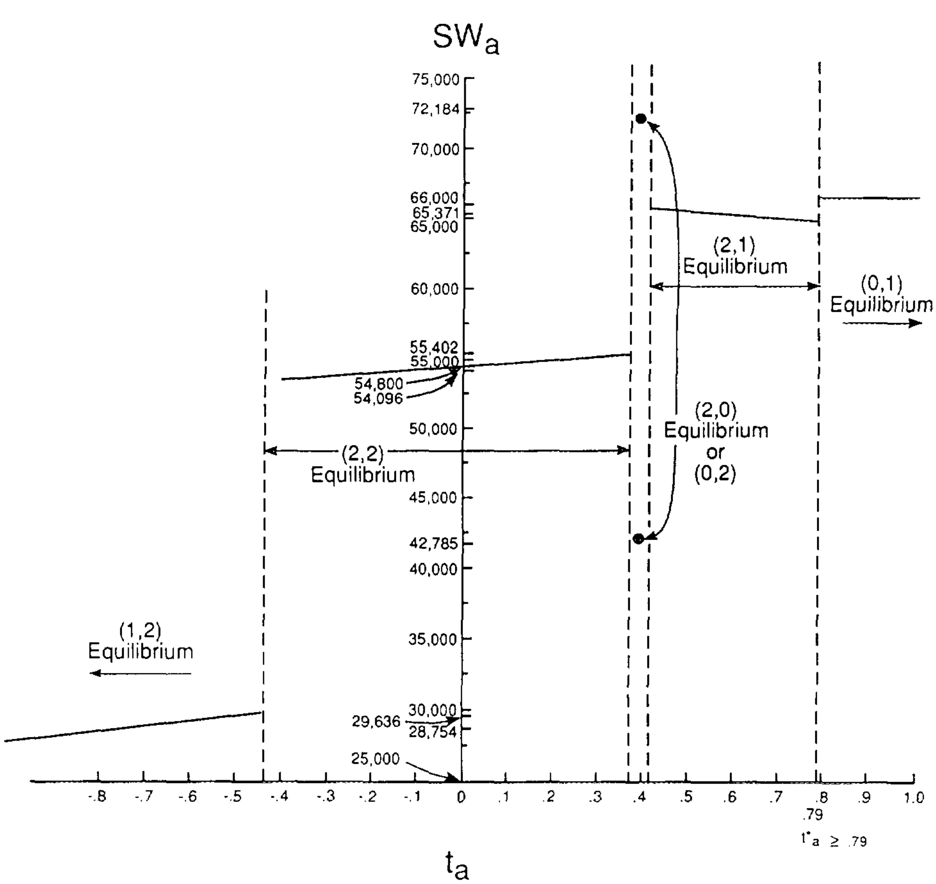

FIG. 3. Equilibrium social welfare in Region A as a function of t_a. Parameter values: $F = 30{,}000$; $G = 5{,}000$; $\tau = 0.0042$; $\alpha = 16$; $\beta = 2$; $\gamma = 1$; $m = 0$; $s = 2$; $N = 1{,}000$; $L = 50{,}000$; $t_b = 0$.

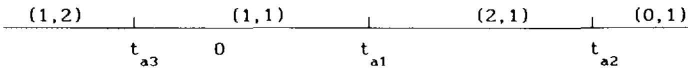

FIG. 4. Assumptions 2A and 2B yield this sequence of market structures as a function of Region A's tax rate.

A cannot engineer outcome $(2,0)$ (i.e., it cannot avoid the $(2,0),(0,2)$ indeterminancy) we thus have $t_a = 0.425$ as the optimal tax.[18]

Figure 3 examines what happens if the disutility from pollution is increased by 20% (the sequence of market structures is independent of τ as noted above). In this case, given the greater welfare loss from pollution, it is optimal to impose a tax that drives all the polluters from Region A. A tax of 0.79 is sufficient to do this and there is no cost to imposing a higher tax; i.e., with this higher level of disutility from pollution, the optimal t_a is not unique ($t_a^* \geq 0.79$). The optimal market structure requires that firm X does not operate, and that firm Y operates in Region B—$(0,1)$. Increasing t_a beyond 0.79 does not change anything.

We now examine one of a number of possible sequences of market structures as functions of t_a given an initial market structure of $(1,1)$. The assumptions are as follows:

Assumption 2 (*High plant-specific costs, low firm-specific costs and transport costs*).

(A) The initial market structure is $(1,1)$ at $t_a = 0$, implying $\pi_x(1,1) > \pi_x(2,1)$ at $t_a = 0$.

(B) There exists a $t_a = t_{a1} > 0$ such that $\pi_x(1,1) = \pi_x(2,1) > 0$, and $\pi_y(2,1) > 0$.[19]

RESULT 2. *Given Assumptions* 2A *and* 2B, *the sequence of market structures as a function of Region A's tax is given schematically by Fig.* 4.

Proof. Consider first raising t_a from zero. The X producer will not wish to deviate initially to two plants and the Y producer will never wish to open a plant in A. Neither firm will wish to exit given that profits are still positive. As t_a increases, the properties of the model imply that $\pi_x(1,1)$ falls faster than $\pi_x(2,1)$ because all of the firm's production is taxed in the former market structure. At the level $t_a = t_{a1}$, the tax has reached the level where X is now just indifferent to supplying B by building a branch plant, thereby incurring a fixed cost G but saving transport costs and the pollution tax in A. By Assumption 2B, profits of the Y producer are

[18]Note that this tax affects both production and pollution levels in Region A. This tax rate is therefore "best" given that there is only one producer of X and one producer of Y. Given the market power of the two firms, t_a will not, in general, eliminate the inefficiency caused by *both* the pollution distortion and the market-power distortion. Nor should we expect it to, as a single instrument cannot, in general, simultaneously correct two separate distortions.

[19]Assumptions 2A and 2B must hold as s and F approach zero. Consider the case where $s = 0$. $(1,1)$ must be the market structure if profits are positive. $\pi_y(1,1) = \pi_y(2,1)$ since X's marginal cost of supplying Region B is the same in either case, and hence both firms' supplies in B are the same under either $(1,1)$ or $(2,1)$. But $\pi_y(1,1) > \pi_x(1,1)$ since Y pays no tax. At t_{a1}, we therefore have $\pi_y(2,1) = \pi_y(1,1) > \pi_x(1,1) = \pi_x(2,1)$. Finally, $\pi_x(2,1) > 0$ at t_{a1} provided that fixed costs are not too large.

positive at the (2, 1) market structure, so (2, 1) becomes the new market structure at $t_a = t_{a1}$.

Further increases in t_a beyond $t_a = t_{a1}$ result in a decrease in profits for X and an increase in profits for Y. At some critical value $t_a = t_{a2}$, the X producer exits from the market (recall that X cannot produce only in B). Y will not deviate to two plants, so (0, 1) becomes the market structure for $t_a > t_{a2}$. Finally, consider negative values of t_a. X will not wish to deviate from one plant, but at some critical value $t_a = t_{a3}$, Y will find that the subsidy and the savings on transport costs will outweigh the plant-specific cost, and will open a plant in A. (1, 2) then becomes the market structure for $t_a < t_{a3}$.

Figure 5 gives a numerical example of the welfare effects of t_a given initial parameters corresponding to those of Game 4 in Table I. As the tax is increased from zero, social welfare decreases at a gradual rate as long as the market structure remains fixed. This case of an exporting duopoly has been analyzed by Brander and Spencer [5] among others. What happens (with Cournot behavior) is that the tax puts the domestic firm at a competitive disadvantage such that the loss of its profits reduces welfare. In the case we consider here, this profit effect obviously dominates the positive effect of the reduction in pollution.

When t_a reaches 0.275, the equilibrium market structure switches to (2, 1) and welfare in Region A jumps to its maximum value. The shift by the local firm of its production for Region B to Region B causes a discrete fall in pollution with no adverse consequences for consumer surplus or profits (at the point of switch).

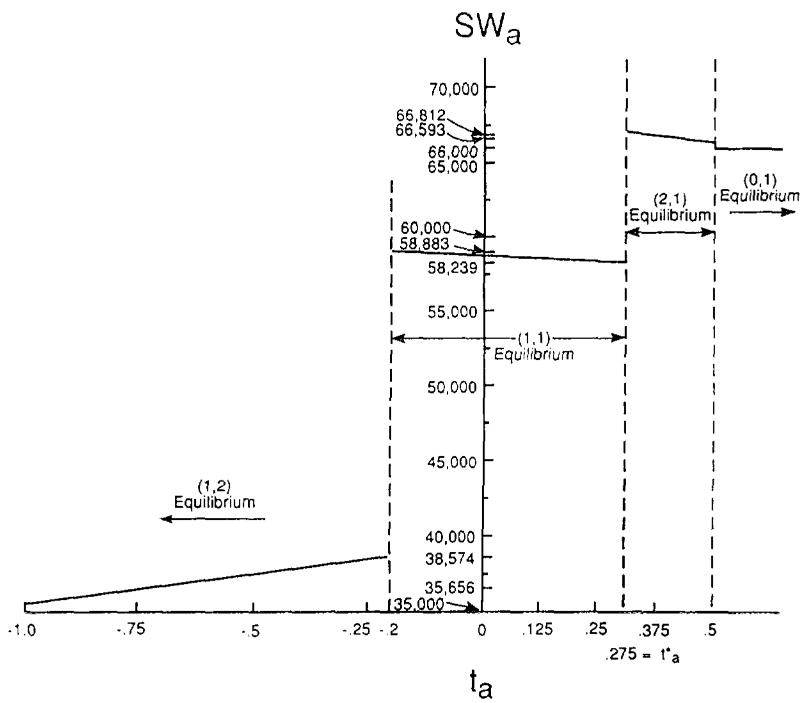

FIG. 5. Equilibrium social welfare in region A as a function of t_a. Parameter values: F = 27,000; G = 7,000; τ = 0.0035; α = 16; β = 2; γ = 1; m = 0; s = 2; N = 1,000; L = 50,000; t_b = 0.

There is a fall in tax revenue, but this is obviously outweighed by the discrete drop in pollution. Further increases in the tax reduce welfare for reasons identical to those discussed in Fig. 2, and as in that case, here the optimal value of the tax is that which is just sufficient to cause the jump in market structure to (2, 1).

III. THE COST OF IGNORING THE ENDOGENEITY OF MARKET STRUCTURE IN THE DETERMINATION OF AN "OPTIMAL" (SECOND-BEST) TAX[20]

Consider how costly it is to ignore the endogeneity of market structure when determining pollution taxes. Assume, as has much of the literature, that the market structure existing in the absence of a pollution tax will not change due to the imposition of such a tax. The exogenous structure is the equilibrium associated with $t_a = 0$. In the context of our model, if one pretends that this market structure is exogenous, one can determine the "optimal exogenous" tax by plotting equilibrium social welfare as a function of t_a, *holding* market structure at its zero tax level. However, this tax rate will not be optimal and will usually result in a suboptimal level of social welfare.

In Fig. 2, the equilibrium market structure when there is no tax is (2, 2). If the regulator incorrectly assumes that the market structure will remain (2, 2) independent of the tax, he or she will determine that the best that can be done is to set $t_a = 3.5$.[21] The regulator anticipates that this tax rate will generate a social welfare level of 61,730. He or she will be wrong. If t_a is set equal to 3.5, equilibrium market structure will switch to (0, 1) as shown in Fig. 2—firm X will be driven out of business and firm Y will close its plant in Region A. Equilibrium social welfare will be 66,000, not 61,730. While the outcome is better than expected, it is still less than the welfare level that could have been achieved, 67,625, if the tax had been set at its optimal rate of 0.425.

Consider now Fig. 3. In this case, the equilibrium market structure in the absence of the tax is again (2, 2). If the regulator incorrectly assumes that market structure will remain at (2, 2) independent of the tax rate, he or she will conclude that the optimal tax is 4.2 and anticipates that a welfare level of 58,320 will result. What a tax of 4.2 will do is generate a (0, 1) equilibrium and a welfare level of 66,000. In this case, there is no cost to ignoring the endogeneity of market structure because imposing any $t_a \geq 0.79$ will drive pollution to zero; its optimal amount when τ is 0.0042.

In the two cases considered so far, imposing the "optimal exogenous" tax was better than doing nothing at all ($t_a = 0$), but this is not always the case. Consider Fig. 5. The equilibrium market structure when there is no tax is (1, 1) and the corresponding welfare level is 58,556. If the policy maker incorrectly assumes that

[20]Recall that there are two distortions: pollution and market power. The single tax here can only be optimal in a second-best sense, since in general it cannot correct both distortions and produce a full social optimum. Since the pollution tax tends to increase the market power distortion (i.e., we reduce further the output of a good that is already underproduced), there is some presumption that the second-best tax may be smaller than a first-best pollution tax when another policy instrument is available to correct the market power distortion.

[21]This value was determined by finding that value of t_a that maximizes SW_a holding market structure constant at (2, 2).

the market structure will remain (1, 1) independent of the tax, he or she will determine that the best that can be done is to set $t_a = -1.5$ and anticipates that this tax rate will achieve a welfare level of 61,292.[22] The "optimal exogenous" tax is negative for the reasons developed in the strategic trade-policy literature discussed above: Artificially holding market structure at (1, 1), the increased rents for the local firm outweigh the increased pollution and loss of tax revenue. However market structure does not remain at (1, 1), a tax rate of -1.5 shifts the equilibrium to (1, 2) and generates an equilibrium welfare level of 33,483. Imposing the "optimal exogenous" tax results in a 57% decrease in social welfare relative to doing nothing at all. As noted above, if the policy maker had taken the endogeneity of market structure into account she would have imposed a tax of 0.275 and achieved a welfare level of 66,812.

A second example of when it is better to not tax the pollution than to impose the "optimal exogenous" tax is if $F = 30{,}000$, $G = 1{,}000$, and $\tau = 0.0035$ (we have not analyzed this case previously). In this case of very low plant-specific fixed costs, the equilibrium market structure in the absence of the tax is (2, 2) and generates a welfare level of 67,280. If the policy maker incorrectly assumes that the market structure will remain at (2, 2), independent of the tax rate, she will impose a tax of 3.5 with the expectation that it will generate a welfare level of 69,730. Rather it will generate a welfare level 66,000 and a (0, 1) equilibrium. The optimal tax in this case is 1.7 and generates a welfare level of 73,914, a 10% increase over the no tax case.

IV. ADAPTING THE MODELING FRAMEWORK TO REGULATIONS, PERMITS

As we noted earlier, much of the model can be adapted to consider a variety of regulatory constraints. We mentioned several times that t_a can be interpreted as the added marginal cost of production in Region A due to a regulatory constraint, such as one on the quality of inputs, or indeed any abatement technology that falls exclusively on marginal costs. Because demand is independent of tax revenue, the *positive* analysis of market structure is exactly the same as in the tax interpretation, and Results 1 and 2 apply equally well. However, the welfare implications of these sequences of market structures are somewhat different. Referring back to (4), there is no tax revenue term under the regulatory interpretation. On the other hand, the pollution per unit of output is lower when the marginal-cost abatement technology is used.

In order to illustrate the close relationship between the two interpretations, suppose that we choose units such that an abatement technology that raises marginal costs by t_a per unit of output results in a reduction of exactly t_a units of pollution per unit of output. Then (4) continues to give the exact formula for social welfare. The term that is tax revenue, $t_a(X^a + Y^a)$, now becomes simply the (utility) increase from the abatement activity. Of course, negative values of t_a have little meaning under the regulatory interpretation.

[22] When the equilibrium is constrained to remain at (1, 1), SW_a is a decreasing function of t_a. A tax rate of -1.5 is the smallest tax rate consistent with nonnegative profits in the Y industry, a necessary condition for a (1, 1) equilibrium.

Adapting the model to deal with tradable emissions permits is a bit less straightforward due to the imperfect competition (e.g., the monopoly firm would bid zero for the permits and the permits would simply become a binding output restriction). But suppose that we simply take a partial-equilibrium interpretation of the model, and assume that the X and Y producers are only small sectors in a large, competitive economy where many industries pollute. Assume further that X and Y are price-takers in a competitive market for permits, and that abatement is not possible as in our tax interpretation of the model. In this case, t_a becomes the price of a permit per unit of output, and the positive analysis of market structure proceeds as before.

Our analysis also points the way for an analysis of an abatement technology that falls on fixed costs. We can see from the results of Table I that we will likely get interesting sequences of market structures as G changes much as we do here (general results about market structure as a function of G and F are found in Horstmann and Markusen [18]). If the regulation raises G in Region A, for example, we could construct a case where the sequence of market structures is $(2,2), (2,1), (0,1)$. Welfare diagrams similar to those of Figs. 2 and 3 would then follow.

V. CONCLUSIONS AND EXTENSIONS

The model presented in this paper is a first attempt at linking pollution policy with a model of endogenous plant location and industrial structure. This topic is currently one of the principal concerns in the formulation of (in particular opposition to) the U.S.–Mexico free-trade agreement. The model demonstrates, in a simple framework, that plant location and market structure can be a function of environmental policy. The model also demonstrates that the cost can be quite high if environmental policy ignores this endogeneity. We also argue that the modeling framework is general enough to encompass tax policies, permit systems, regulations that fall on marginal costs, and regulations that fall on fixed costs.

The model is in the process of being extended (Markusen et al. [26]). Rather than assuming an exogenous pollution tax in Region B, the extension models the simultaneous determination of the pollution tax rates in the two regions as the outcome of a game between the governments of the two regions. Bilateral agreements are also considered, a topic much on the mind of many countries including Canada, Mexico, the U.S., and those in the European Economic Community.

APPENDIX

The purpose of this Appendix is to give the derivation of the social welfare function in (4). Multiplying the utility function in (1) by N and noting that $x_a = X_a/N$ and $y_a = Y_a/N$, aggregate utility or welfare is given by

$$SW_a = NU_a = \alpha X_a - (\beta/2)X_a^2/N + \alpha Y_a - (\beta/2)Y_a^2/N - \gamma X_a Y_a + Z_a - \tau N(X^a + Y^a). \tag{A1}$$

Multiplying (2a) through by N gives the aggregate budget constraint, which we can rearrange as

$$Z_a = L + \pi_x + t_a(X^a + Y^a) - p_x^a X_a - p_y^a Y_a. \tag{A2}$$

Using (3) for p_x^a and p_y^a, the last two terms in (A2) are

$$p_x^a X_a = \alpha X_a - \beta(X_a^2/N) - \gamma Y_a X_a/N \tag{A3}$$

$$p_y^a Y_a = \alpha Y_a - \beta(Y_a^2/N) - \gamma Y_a X_a/N. \tag{A4}$$

Substitute (A3) and (A4) into (A2). Then substitute the right-hand side of (A2) for Z_a in (A1). SW_a is now given by

$$\begin{aligned} SW_a = {} & \alpha X_a - (\beta/2)X_a^2/N + \alpha Y_a - (\beta/2)Y_a^2/N - \gamma Y_a X_a/N \\ & - \alpha X_a + \beta(X_a^2/N) + \gamma X_a Y_a/N \\ & - \alpha Y_a + \beta(Y_a^2/N) + \gamma Y_a X_a/N \\ & + L + \pi_a + (t - \tau N)(X^a + Y^a). \end{aligned} \tag{A5}$$

Canceling and collecting terms yields (4).

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