ENVIRONMENTAL POLICY WHEN MARKET STRUCTURE AND PLANT LOCATIONS ARE ENDOGENOUS[1]

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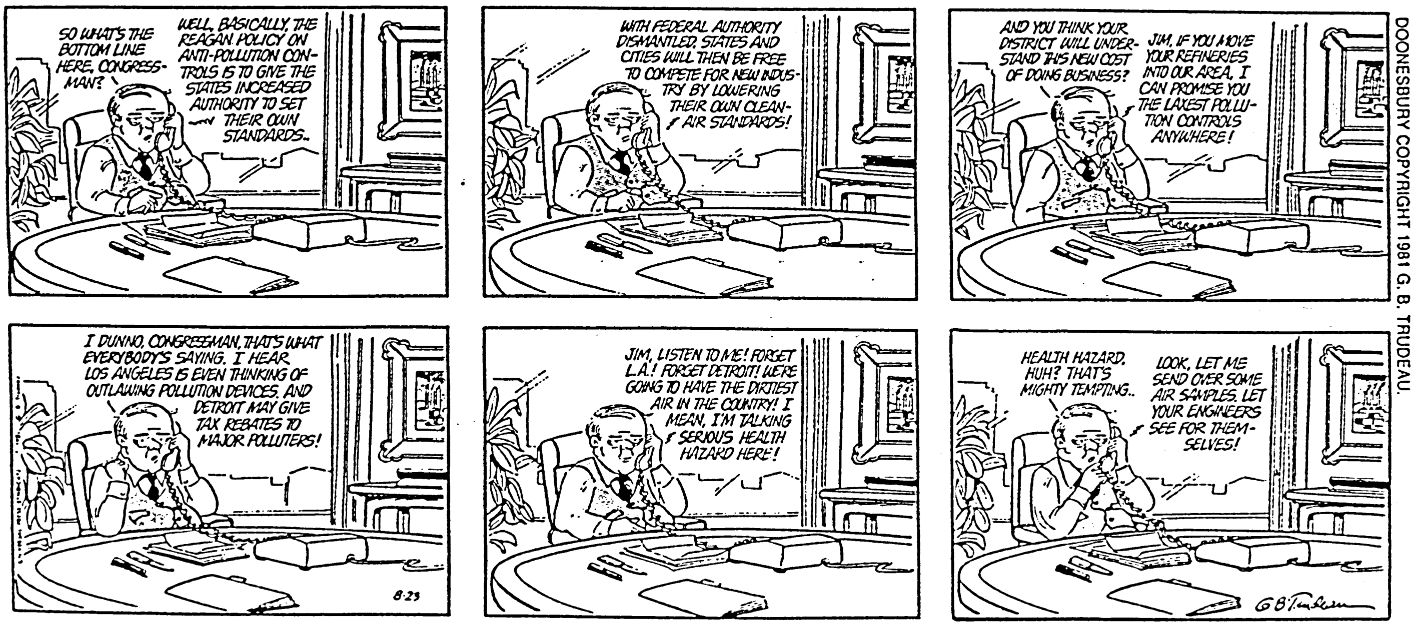

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Abstract

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, in this context, 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. These features imply that 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 for the foreign region from/to the home-region plant to/from a foreign branch plant. The implications for optimal environmental policy differ significantly from those suggested by traditional Pigouvian marginal analysis.

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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] Such analysis is perfectly appropriate for a world of constant returns to scale and perfect competition. In such a world, firms have no particular role to play or alternatively, we can deal directly with the reduced form of an industry and its continuous and differentiable supply function. Optimal tax 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.

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[2]The early analyses of environmental policy were in a partial equilibrium framework; Pigou (1932) and Meade (1952) being two classic examples. General equilibrium models with pollution date back to the 1970s. Commolli (1977), Forster (1977 and 1981), and Yohe (1979) consider environmental policy in a one-region general equilibrium framework. General equilibrium models with trade and pollution have been examined by Markusen (1975a and 1975b), Pethig (1976), Asako (1979), Siebert et al. (1980), McGuire (1982), and Merrifield (1988). Pollution may or may not cross international boundaries in these models. In Pethig (1976), 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 (1979), in a slightly different model obtains similar results. Alternatively, Merrifield (1988) 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.

A small tax aimed at a modest reduction in pollution may dramatically "overshoot" if a plant exits, leading to an excessive reduction in pollution and a decrease in welfare.

Policy makers are quite aware of this problem, and often compete via various tax holidays and grants for new plant locations by firms. Yet most formal policy analysis by economists has continued to pursue the marginal approach, even when imperfect competition is added to the model.[3] In such a marginal analysis, market structure, by which we mean the number and locations of plants, is assumed exogenous to the imposed policy regime.

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 firms must incur a firm-specific fixed cost (such as R&D) that is then a joint-input across their plants, and a plant specific fixed cost for each plant it opens. Production then occurs with constant marginal cost and there is a transportation

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[3]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 (1969) examined monopoly and external diseconomies in a partial equilibrium framework. More recent work includes Burrows (1981), Besanko (1987), Misiolek (1988), and Laplante (1989a, 1989b).

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.

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.[4]

We solve for a subgame perfect equilibrium of this game, and show how the equilibrium market structure depends, in part, on environmental policy. Changes in pollution taxes change the payoffs to a firm in the second stage which in turn alter the location decision in the first stage at critical values of the tax variable. Changes in market structure have four discrete effects: 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.

Two features of the model deserve brief comment before continuing. First, we do not model inter-government rivalry in this first paper: one local government picks a pollution tax with the other government imposing no control. This problem must be

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[4]A large number of papers in international trade theory have focussed on the second stage of this type of game: Brander and Spencer (1985), Dixit (1984), Eaton and Grossman (1986), Helpman (1981), Krugman (1979), and Markusen (1981, 1984) are a few examples. To the best of our knowledge, only Horstmann and Markusen (1991) have formally modelled the two-stage game.

solved in any case as a preliminary step in a more complete model with inter-government rivalry or cooperation, and the present length of the paper requires us to leave this important problem to a later analysis. Second, the analysis of market structure proceeds by way of numerical analysis. While this obviously lacks generality, traditional comparative-statics techniques are of no use here. As just noted, market structure makes a discrete change at certain critical values of the tax and technology parameters. Without a great deal of structure, we cannot tell at what point those jumps will occur, nor can we predict to what new market structure we will shift. The latter question requires knowledge of the numerical values of all off-equilibrium payoffs as we shall demonstrate. Significant structure is also needed to evaluate the combined contributions of conflicting welfare effects. Given the underdeveloped state of the literature on this important topic, we feel the numerical approach is conceptually useful, and that it can point the way to empirical analysis via computable partial or general-equilibrium models.

I. 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 labor 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.[5] 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.[6]

The cost functions for both potential firms (expressed in units of labor) are identical where F ≡ firm specific fixed costs, G ≡ plant specific fixed costs, m ≡ constant marginal cost, s ≡ per unit transport costs between the regions, and t_a and t_b ≡ the per unit pollution tax in Regions A and B. 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.

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 A is

$$(1a)\quad U(x_a, y_a, z_a, (X^a + Y^a)) = \alpha x_a - (\beta/2)(x_a)^2 + \alpha y_a - (\beta/2)(y_a)^2 - \gamma x_a y_a + z_a - \tau(X^a + Y^a)$$

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

[6]The possibility of abatement (allocating labor to reduce pollution without decreasing output) is assumed away for purposes of expositional simplicity. Incorporating abatement in the model with not affect the basic results.

and utility for an individual in Region B is

$$\text{(1b)}\quad U(x_b, y_b, z_b, (X^b + Y^b)) = \alpha x_b - (\beta/2)(x_b)^2 + \alpha y_b - (\beta/2)(y_b)^2 - \gamma x_b y_b + z_b - \tau(X^b + Y^b)$$

where x_a (y_a) is the amount of good X (Y) consumed by each individual in region a, and ($X^a + Y^a$) and ($X^b + Y^b$) are the total amounts of pollution in each region. The parameter τ reflects the constant marginal disutility from pollution. Each individual dislikes pollution but rightly assumes that their consumption, since it is only a negligible proportion of the total, has no effect on total pollution. In the absence of a pollution tax, or regulation, this externality, ceteris paribus, will lead to market failure.[7]

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

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

$$\text{(2b)}\quad (L + \pi_y + t_b(X^b + Y^b))/N = p_x^b x_b + p_y^b y_b + z_b$$

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 (1a) subject to (2a).

$$\text{(3a)}\quad p_x^a = \alpha - \beta(X_a/N) - \gamma(Y_a/N) \qquad \text{and}$$

$$\text{(4a)}\quad p_y^a = \alpha - \beta(Y_a/N) - \gamma(X_a/N).$$

where $X_a \equiv Nx_a^d$ and $Y_a \equiv Ny_a^d$.[8] Where m_a^d, m = x, y, is the demand for m by a

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

[8]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.

representative individual in Region A. The inverse aggregate demand functions for Region B, equations (4a) and (4b)-not reported, have the same form.

General Equilibrium for the two regions is characterized by a situation where: (1) each individual is maximizing their utility given exogenous prices and profits; (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

(5a) $SW_a = [\beta(X_a^2 + Y_a^2)/(2N) + \gamma X_a Y_a/N] + \pi_x + [(t_a - \tau N)(X^a + Y^a)] + L.$

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, equation (5b)-not reported, is identical except one substitutes π_y for π_x, t_b for t_a, and production and consumption levels in B for those in 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 backwards. The maximized value of profits for each firm is determined for each of the three options listed above, given, in turn, each of the three options for the other firm. Profit levels for each of 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.[9] 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 for two different market structures; first for the simple structure where firm X only operates a plant in Region A and firm Y does not operate - structure (1,0), and then the structure where both firms operate plants in both regions - (2,2). After we have used these two structures to illustrate the determination of profits, we demonstrate, with example games, the determination of the equilibrium market structure.

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

$$(6)\quad \pi_x(1,0) = [\alpha - \beta(X_a/N)]X_a + [\alpha - \beta(X_b/N)]X_b - mX_a - (m + s)X_b - t_a(X_a + X_b) - F - G.$$

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

$$(7)\quad X_a^s(1,0) = N(\alpha - m - t_a)/2\beta \qquad \text{and}$$

$$(8)\quad X_b^s(1,0) = N(\alpha - m - t_a - s)/2\beta$$

Substituting equations (7) and (8) into equation (6), maximum profits for firm X in the (1,0) case are

[9] 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 in region A (B). 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.

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

Consider now the structure where both firms operate in both regions - (2,2). With this structure, there are no shipping costs and no distinction between production and consumption in a region. If each firm operates two plants

(10) $\pi_x(2,2) = [\alpha - \beta(X_a/N) - \gamma(Y_a/N)]X_a + [\alpha - \beta(X_b/N) - \gamma(Y_b/N)]X_b$

$- m(X_a + X_b) - 2G - F - t_aX_a - t_bX_b$ and

(11) $\pi_y(2,2) = [\alpha - \beta(Y_a/N) - \gamma(X_a/N)]Y_a + [\alpha - \beta(Y_b/N) - \gamma(X_b/N)]Y_b$

$- m(Y_a + Y_b) - 2G - F - t_aY_a - t_bY_b$

Maximizing and solving, the four supply functions are

(12) $X_a^s(2,2) = Y_a^s(2,2) = N(\alpha - m - t_a)/(2\beta + \gamma)$ and

(13) $X_b^s(2,2) = Y_b^s(2,2) = N(\alpha - m - t_b)/(2\beta + \gamma)$.

Substituting equations (12) and (13) into equations (10) and (11) maximum profits for the two firms in the (2,2) case are

(14) $\pi_x^*(2,2) = \pi_y^*(2,2) = -(F + 2G) + N\beta[(\alpha - m - t_a)^2 + (\alpha - m - t_b)^2]$

$/(4\beta 2 + 4\beta\gamma + \gamma 2)$.

While tedious, maximum profits for all of the other structure can be worked out in similar fashion.

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 ($\gamma = \beta/2$), marginal cost is zero ($m = 0$) and unit transport costs, s, are 2. The assumed parameter values are $\alpha = 16$, $\beta = 2$, $\gamma = 1$, $\tau = .0035$, $N = 1000$ and $L = 50{,}000$.[10] There is nothing special about the specific values chosen for the parameter values. Note that while welfare is a decreasing function of τ, profit levels and equilibrium market structure are not a function of τ. To isolate on the endogeneity of market structure independent of pollution taxes, initially pollution taxes are set to zero.[11] Table 1 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, the multi-plant market structure is the unique equilibrium. In game 2, high total fixed cost yield a situation where there are two symmetric equilibria, with only a single two-plant firm operating. In game three, 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.

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[10]L must be chosen sufficiently large so that the production of Z in each region is nonnegative.

[11]The impact of pollution taxes on plant location and market structure is the subject of the next section.

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.

Different parameterizations of the model thus yield different initial market structures in an environment of zero pollution taxes. In the following section, we will focus on a the parameterization of the model in game 1, where both firms are multi-plant producers in the initial situation, in order to illustrate the effects of progessively increasing the pollution tax.

II. The Impact of a Unilateral Pollution Tax on Equilibrium Plant Location and Market Structure

As often expressed by regional politicians, plant location and market structure are a function of environmental regulation. Consider the imposition of a unilateral pollution tax in Region A ($t_a > 0$, $t_b = 0$). The equilibrium market structure will be a function of the magnitude of the tax. This is most clearly seen with an example. Consider again game 1 from Table 1. In that game, where G = 5,000, F = 30,000 and $t_a = t_b = 0$, the equilibrium has each firm producing in each region. Now consider how things would change if a positive pollution tax was unilaterally imposed in Region A. The results of four such games (games 5 - 8) are reported in Table 2. Each is identical to game 1 except $t_a = .2$ in game 5, $t_a = .4$ in game 6, $t_a = .6$ in game 7 and $t_a = .8$ in game 7.

Increasing the tax from 0 to .2 has no impact on equilibrium market structure, it remains at (2,2), but the level of pollution is reduced as firms reduce output in Region A. The effect of this small tax is thus correctly given by the traditional marginalist approach.

Imposing a tax of .4 (game 6), however, shifts the equilibrium to either a (2,0) or a (0,2) equilibrium: one firm shuts down and the remaining firm maintains plants in both regions. The tax thus reduces profits such that there is no market configuration where both firm can make positive profits. The surviving firm will always find it more profitable to produce in Region B what it sells in Region B where it is not subject to environmental taxation. Pollution in Region A is reduced for two reasons. First, the tax discourages output in the usual way, and second, output is further reduced because the market is now served by a monopolist, rather than the initial duopolists. (These two effects can be seen by comparing equation (7) with two times equation (12)).

A of t_a of .6 (game 7) results in a (2,1) equilibrium where the X firm operates in both regions and the Y firm just produces in its untaxed home market, exporting to Region A. The effect of the increase in t_a from .4 to .6 is to reduce the equilibrium value of the X producer's output in Region A for any level of Y sales in that region. This reduction in supply increases the demand price for Y sufficiently that the Y producer can now profitably export to Region A. There is a further reduction in pollution over the case of $t_a = .4$ because the positive imports of Y into A generate no pollution in Region A but lead X to cut back production in Region A.

A t_a of .8 (game 8) generates a (0,1) equilibrium; i.e., the tax is sufficiently high to drive the X firm out of business and to keep the Y firm from operating in Region A.

There is no pollution generated in Region A in this last case.

As a final point, we note in game 9 that a (1,2) equilibrium can result if Region A subsidizes rather than taxes pollution. The X producer now finds it profitable to concentrate production for both markets in Region A. Production in A by the X and Y producers for sale in Region A are higher than in the zero-tax base case, but there is also production in A of X for sale in Region B, so total pollution must be higher than in the base case.

We thus have the result that increases in the pollution tax do indeed reduce pollution, but welfare also depends on consumer surplus, the home firm's profits, and tax revenue. All of these change discretely with a change in market structure, and may have welfare effects opposite to the change in pollution.

III. The Optimal Unilateral Pollution Tax in Region A When Market Structure is Endogenous

Assume that the government of region A wants to choose that t_a that will maximize social welfare in Region A. Refer to this tax rate, t_a^*, as the optimal unilateral pollution tax.[12] For simplicity, assume that region b does not tax pollution.[13] The

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[12]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 <u>both</u> the pollution distortion and the excess market-power distortion. Nor should one expect it to, as a single instrument cannot, in general, simultaneously correct two separate distortions.

[13]It is straightforward to generalize to situations where t_b is positive but independent of t_a. Situations where the pollution tax rates in the two countries are simultaneously determined as the outcome of a game between the governments of the two regions is a significant extension. One might also consider bilateral agreements.

optimal tax, t_a^*, is determined numerically, for a given set of parameter values, by plotting equilibrium social welfare in Region A, SW_a, as a function of t_a. Each point is determined by determining the equilibrium output levels, consumption levels and profits for that tax rate. These are then substituted into equation (5a) to determine the equilibrium level of social welfare that is associated with that tax rate. The optimal pollution tax is that tax rate that maximizes equilibrium social welfare in Region A. Note that an analytical solution for the optimal tax does not exist.

For illustration and discussion, the optimal pollution tax, t_a^*, is determined for three different cases: F = 30,000, G = 5,000 and τ = .0035 (Game 1 and Games 5 - 9); F = 30,000, G = 5,000 and τ = .0042; and F = 27,000 G = 7,000 and τ = .0035 (game 4).[14] Equilibrium social welfare in Region A is plotted as a function of t_a in Graph 1 for F = 30,000, G = 5,000 and τ = .0035; in Graph 2 for F = 30,000, G = 5,000 and τ = .0042; and in graph 3 for F = 27,000, G = 7,000 and τ = .0035. The equilibrium market structure for each tax rate is identified on each graph.

Examining the outcome for the first set of parameter values, F = 30,000, G = 5,000 and τ = .0035 (Graph 1), 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, $0 \leq t_a \leq .39999$), 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 are largely offset by a loss of consumer surplus from the consumption of

[14]All other parameters, except for t_a, remain at their original levels as specified in Table 1.

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 $t_a = .4$, the market structure switches to either firm (2,0) or (0,2) as was shown in game 6. 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 increased profits for the X producer, so welfare takes a discrete drop.

A further increase in t_a to .425 leads to the market structure (2,1) for the reasons discussed in connection with game 7. Welfare is higher than in the (2,2) market structure due to a combination of several conflicting effects. Pollution is lower as we indicated in the previous section since Y is imported, and profits of the local firm are higher (for a given tax rate) since X now competes in Region A with higher-cost imports. But there is a discrete loss of consumer surplus (the price of Y jumps up) and tax revenue 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 $t_a = .79$, the local firm exits, 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 A desires a determistic outcome (i,e, it avoids the (2,0), (0,2) indeterminancy) we thus have $t_a = .425$ as the optimal tax.

Case 2 and graph 2 examines what happens if the disutility from pollution is increased. Again assume that F = 30,000 and G = 5,000 but now assume that τ = .0042 - a twenty percent increase in the disutility from pollution. 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 .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 ($t_a^* \geq .79$). The optimal market structure requires that firm X does not operate, and that firm Y just operates in region b - (0,1). Increasing t_a beyond .79 does not change anything.

The third case investigates the impact of changing fixed costs. Assume F = 27,000, G = 7,000 and τ = .0035 (Graph 3), in this case, the initial equilibrium market structure is (1,1) as shown in game 4. As the tax is increased from zero, social welfare decreases as a gradual rate as long as the market structure remains fixed. This case of an exporting duopoly has been analyzed by Brander and Spencer 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 .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). 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 case 1 (graph 1), 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).

IV. The Cost of Ignoring The Endogeneity of Market Structure in the Determination of an Optimal Pollution Tax

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 level being the equilibrium level 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.

Consider the three cases discussed above. If F = 30,000, G = 5,000, and τ = .0035 (graph 1), 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 $t_a = 3.5$.[15] 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 graph 1 - firm X will be driven out of business and firm Y will close its

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

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 .425.

Consider now case 2 where F = 30,000 and G = 5,000 but τ = .0042 rather than .0035 (graph 2). 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, she will conclude that the optimal tax is 4.2 and she anticipates that it will generate a welfare level of 58,320. 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 $t_a \geq .79$ will drive pollution to zero; its optimal amount when τ is .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 the third case where F = 27,000, G = 7,000 and τ = .0035 (graph 3); 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 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.[16] 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

[16]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.

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 .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 τ = .0035 (we have not analyzed this case previously). In this case, 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.

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. 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. Neither the simplicity of the model or the specific parameter values chosen in the example games detract from these two important points. As is prevalent in the trade and imperfect competition literature, few general qualitative predictions result. The difficulty is that a general analytical approach does not reveal when jumps in market structure occur, nor can it tell us to which new market structure we shift. Among other things, market structure depends on the numerical payoffs from off-equilibrium strategies. In game 1 of Table 1, for example, the market structure (1,1) is Pareto superior to the Nash equilibrium market structure (2,2), but (1,1) cannot be an equilibrium because the off-equilibrium payoff to either firm of opening a second plant given its rival has a single plant would cause it to defect from (1,1). Given these difficulties and the under-developed nature of this literature, we thus feel that the numerical approach is valuable at this point. Also note that the traditional marginal approach only yields optimal tax <u>formulae</u>, generally expressed in terms of inverse elasticities, but cannot tell the numerical <u>value</u> of the optimal taxes. Actual empirical and policy implementation of both approaches thus suggests the need for numerical analysis via calibrated partial or general-equilibrium models.

The model could be extended in a number of interesting directions. Rather than assuming an exogenous pollution tax in region B, one could greatly increase the richness of the model by modelling 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. The payoff for this game would be determined by the game between the two firms.

One might also consider bilateral agreements, a topic much on the mind of many countries including Canada, the U.S. and those in the European Economic Community.

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APPENDIX

The purpose of this appendix is to give the derivation of the social welfare function in (5a). Multiplying the utility function in (1a) by N and noting that $x_a = X_a/N$ and $y_a = Y_a/N$, aggregate utility or welare is given by

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

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

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

Using (3a) and (4a) for p_x^a and p_y^a, the last two terms in (A2) are

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

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

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

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

Cancelling and collecting terms yields (5a).

TABLE 1: EQUILIBRIUM MARKET STRUCTURE AND PLANT LOCATION IN FOUR DIFFERENT SIMPLE GAMES

Parameter Values: $\alpha = 16$, $\beta = 2$, $\gamma = 1$, $m = 0$, $s = 2$, $\tau = .0035$, $N = 1000$, $L = 50{,}000$, and $t_a = t_b = 0$.

<u>GAME 1</u>: G = 5,000 and F = 30,000: Nash Equilibrium (2,2), denoted by *

		Region B		
		2 Plants	1 Plant	0 Plants
	2	(960, 960)*	(2,700, -300)	(24,000, 0)
Region A	1	(-300, 2,700)	(1440, 1440)	(21,500, 0)
	0	(0, 24,000)	(0, 21,500)	(0, 0)

<u>GAME 2</u>: G = 6,000 and F = 29,000: Nash Equilibria (2,0) or (0,2)

		Region B		
		2 Plants	1 Plant	0 Plants
	2	(-40.0, -40.0)	(1,700, -300)	(23,000, 0)*
Region A	1	(-300, 1,700)	(1,440, 1,440)	(21,500, 0)
	0	(0, 23,000)*	(0, 21,500)	(0, 0)

<u>GAME 3</u>: G = 7,000 and F = 28,000: Nash Equilibria (1,1), (2,0) or (0,2)

		Region B		
		2 Plants	1 Plant	0 Plants
	2	(-1,040, -1,040)	(700, -300)	(22,000, 0)*
Region A	1	(-300, 700)	(1,440, 1,440)*	(21,500, 0)
	0	(0, 22,000)*	(0, 21,500)	(0, 0)

<u>GAME 4</u>: G = 7,000 and F = 27,000: Nash Equilibrium (1,1)

			Region B	
			2 Plants	1 Plant0 Plants
	2	(-40.0, -40.0)	(1,700, 700)	(23,000, 0)
Region A	1	(700, 1,700)	(2,440, 2,440)*	(22,500, 0)
	0	(0, 23,000)	(0, 22,500)	(0, 0)

TABLE 2: THE IMPACT OF A UNILATERAL POLLUTION TAX IN REGION A ON EQUILIBRIUM PLANT LOCATION AND MARKET STRUCTURE

Parameter Values: $\alpha = 16$, $\beta = 2$, $\gamma = 1$, $m = 0$, $s = 2$, $\tau = .0035$, $N = 1000$, $L = 50{,}000$, and $t_b \doteq 0$.

<u>GAME 5</u>: $G = 5{,}000$, $F = 30{,}000$ and $t_a = .2$: Nash Equilibrium (2,2), denoted by *

		Region B		
		2 Plants	1 Plant	0 Plants
Region A	2	(450, 450)*	(2,000, -155)	(23,205, 0)
	1	(-1370, 2,370)	(175, 1765)	(20,010, 0)
	0	(0, 23,205)	(0, 21,500)	(0, 0)

<u>GAME 6</u>: $G = 5{,}000$, $F = 30{,}000$ and $t_a = .4$: Nash Equilibrium (2,0) or (0,2)

		Region B		
		2 Plants	1 Plant	0 Plants
Region A	2	(-50, -50)	(1300, -10)	(22,420, 0)*
	1	(-2420, 2,050)	(-1070, 2,090)	(18,540, 0)
	0	(0, 22,420)*	(0, 21,500)	(0, 0)

<u>GAME 7</u>: $G = 5{,}000$, $F = 30{,}000$ and $t_a = .6$: Nash Equilibrium (2,1)

		Region B		
		2 Plants	1 Plant	0 Plants
Region A	2	(-550, -550)	(620, 130)*	(21,645, 0)
	1	(-3460, 1730)	(-2290, 2410)	(17,090, 0)
	0	(0, 21,645)	(0, 21,500)	(0, 0)

(Table 2 continued next page)

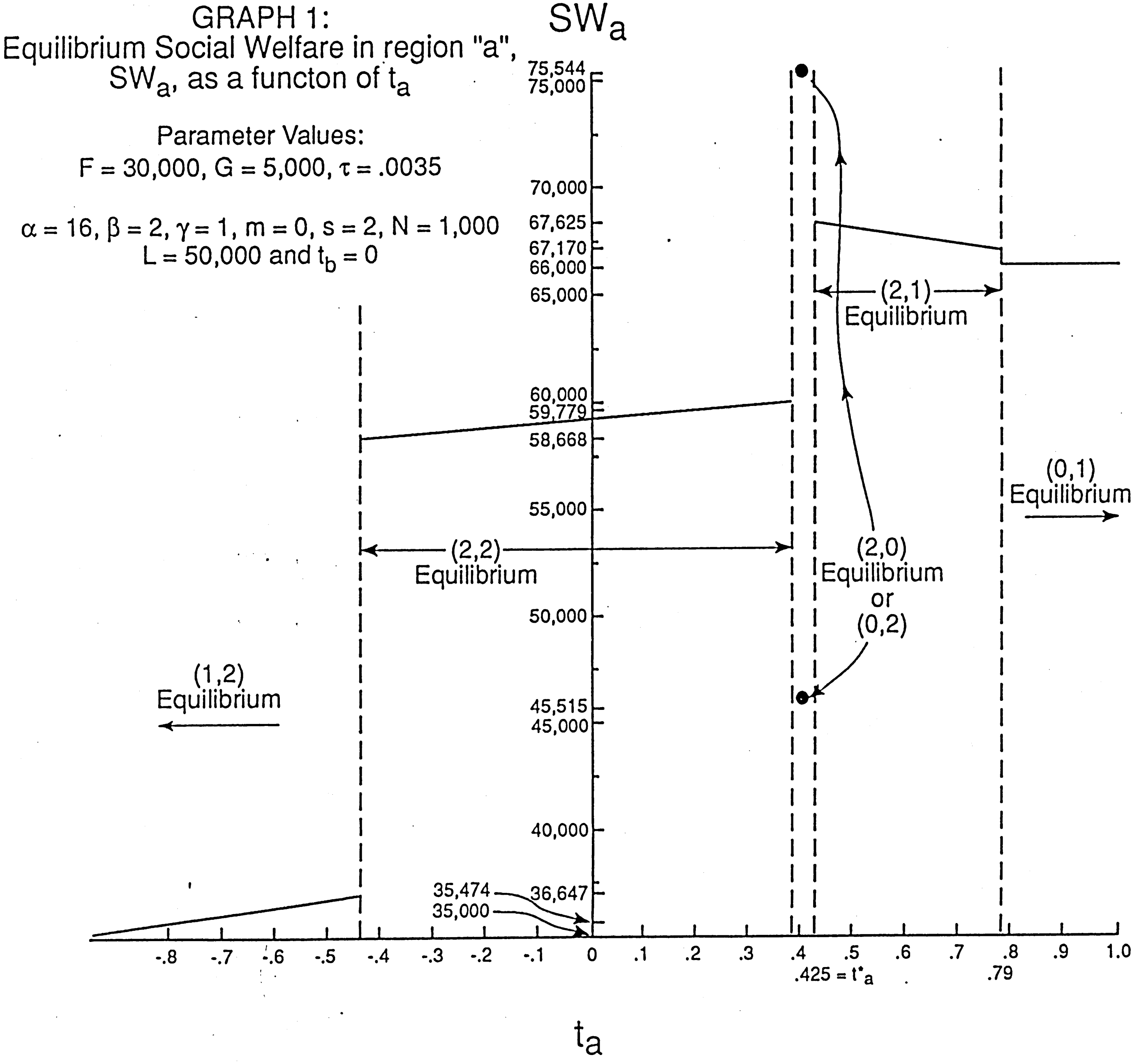
Continuation of Table 2

GAME 8: $G = 5{,}000$, $F = 30{,}000$ and $t_a = .8$: Nash Equilibrium (0,1)

		Region B		
		2 Plants	1 Plant	0 Plants
	2	(-1040, -1040)	(-50, 280)	(20,880, 0)
Region A	1	(-4480, 1420)	(-3490, 2740)	(15,660, 0)
	0	(0, 20,880)	(0, 21,500)*	(0, 0)

GAME 9: $G = 5{,}000$, $F = 30{,}000$ and $t_a = -.6$: Nash Equilibrium (1,2)

		Region B		
		2 Plants	1 Plant	0 Plants
	2	(2525, 2525)	(4890, -720)	(26,445, 0)
Region A	1	(3025, 3740)*	(5390, 490)	(26,090, 0)
	0	(0, 26,445)	(0, 21,500)	(0, 0)



GRAPH 1:
Equilibrium Social Welfare in region "a", SW$_a$, as a functon of t_a

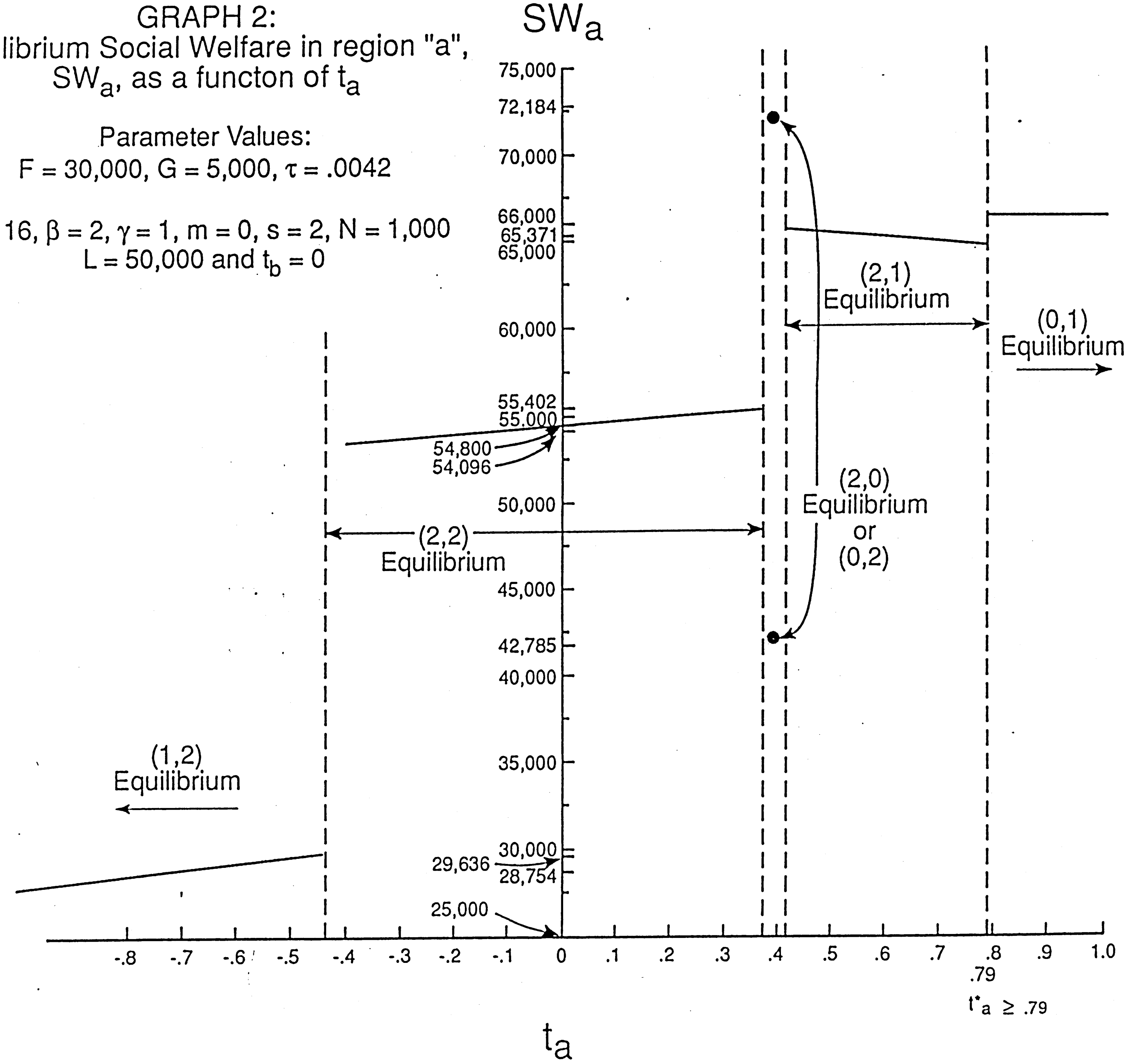
Parameter Values:
F = 30,000, G = 5,000, τ = .0035

$\alpha = 16$, $\beta = 2$, $\gamma = 1$, m = 0, s = 2, N = 1,000
L = 50,000 and $t_b = 0$

GRAPH 2:
Equilibrium Social Welfare in region "a", SW_a, as a functon of t_a

Parameter Values:
F = 30,000, G = 5,000, τ = .0042

α = 16, β = 2, γ = 1, m = 0, s = 2, N = 1,000
L = 50,000 and t_b = 0



GRAPH 3:
Equilibrium Social Welfare in region "a", SW_a, as a functon of t_a

Parameter Values:
$F = 27{,}000$, $G = 7{,}000$, $\tau = .0035$

$\alpha = 16$, $\beta = 2$, $\gamma = 1$, $m = 0$, $s = 2$, $N = 1{,}000$
$L = 50{,}000$ and $t_b = 0$