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DISCRETE PLANT-LOCATION DECISIONS IN AN APPLIED GENERAL-EQUILIBRIUM MODEL OF TRADE LIBERALIZATION

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ABSTRACT

Theoretical and applied work in industrial-organization approaches to international trade typically assume either that there are fixed numbers of firms, or that there is free entry and exit with a continuum of firms. This paper makes a first step toward a more realistic approach in which firms face discrete choices about the numbers and locations of their plants. The model is applied to the North American auto industry in the context of the draft North American Free Trade Agreement. Results include: (1) production appears to be excessively geographically diversified initially; (2) autos are produced in fewer locations as trade barriers are lowered; (3) a "non-monotonicity" case is produced in which a plant is first closed and then reopened as trade barriers are progressively lowered; (4) an example of the misleading nature of marginalist analysis is presented in which plants in Canada and Mexico increase production when locations are fixed but closed down when locations are endogenous and optimized.

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1. Introduction

Perhaps *the* premier development in international trade theory over the last fifteen years has been the industrial-organization literature in which scale economies, imperfect competition, and multinational firms have been added to the more traditional positive theories of trade. The positive literature developed simultaneously with a normative, policy-oriented literature which seeks to understand how these industrial-organization features of economies modify our standard policy prescriptions.

Inherent complexities of increasing-returns technologies and imperfectly-competitive behavior have restricted much of this literature to very simple models with highly restrictive assumptions. The purpose of this paper is to take a relatively modest step in addressing one of the more objectionable simplifying assumption of the trade-IO literature: the nature of entry and exit decisions by firms.

Two approaches to entry and exit decisions have been adopted in the literature. The first is to simply assume that there is no entry or exit. This approach is perhaps best represented by series of papers by Brander and Spencer in the 1980's (e.g., Brander and Spencer (1985), Spencer and Brander (1983)). While important insights emerge concerning duopolistic interaction and the impact of policy on that interaction, this literature misses some of the important dynamic aspects of competition that we have witnessed in industries such as aircraft, computers, and semiconductors. A second approach is to assume that there is a continuum of firms, such that the number of firms can take on any non-integer value. This has the advantage of permitting equilibrium to be found by solving a system of continuous, differentiable, simultaneous equations (a zero profit equation being associated with the variable n, the number of firms). Venables (1985) and Horstmann and Markusen (1986) use this approach in oligopoly models, and it is of course the standard approach in the entire monopolistic-competition literature (e.g., Helpman and Krugman (1985), Helpman (1981). The disadvantage of this approach is that it avoids the lumpiness which it the key aspect of increasing-returns in the first place!

From a policy point of view, we have to worry that we might be getting some very misleading conclusions from either type of model. Following a trade liberalization, for example, "marginalist" considerations might dictate expanding production in Region A, while "global" maximization might dictate closing the plant in Region A.

This paper will build upon our previous work which adds multinational decision making to the existing body of theory, and examines that theory in an applied general-equilibrium model of the North American auto industry (Lopez-de-Silanes, Markusen, and Rutherford (1994a, 1994b), Markusen, Rutherford, and Hunter (1993)). Because of the inherent complexities of integer-programming problems, we make a modest beginning in this paper. Following trade liberalization within North America (motivated by the draft NAFTA agreement), we allow one firm to endogenously choose among 15 alternative plant-location configurations. The other firms retain their existing numbers of and locations for their plants, but endogenously adjust their outputs, markups, and shipment patterns.

Several results emerge from the applied general-equilibrium model. First, we have considerable difficulty in calibrating the model such that the initial plant configuration (plants in all countries) represents an equilibrium. This suggests that production is excessively geographically diversified initially, perhaps due to historical factors involving the forced development of the auto sectors in Canada and Mexico. A calibration in which the mobile firm does optimize by choosing the initial configuration required a significant degree of sunk costs (about 40% of fixed costs must be written off in plant closures) and high transport costs / non-tariff barriers (NTBs) on inactive trade links.

Second, we get the unsurprising result that production becomes more concentrated as trade barriers are lowered. But third, we also observe a more interesting "non-monotonicity" result that a plant may be at first closed and then later reopened as trade barriers are progressively opened. For example, removing only tariffs within North America (NA) leads the mobile firm to shut its US plant, while removing tariffs plus 2/3 of the non-tariff barriers leads the firm to reopen the US plant and shut the Mexican and Canadian plants.

The fourth result should be of some general importance for the trade-industrial-organization literature. We demonstrate the possibility that "marginalist" analysis may incorrectly predict the signs of production changes in the various countries relative to the global solution in which the firm can open and close plants. When plant locations are fixed, the firm's optimal response to trade liberalization is to increase production in Mexico and Canada and decrease production in the US and Rest of World (ROW). When the firm is allowed to reconfigure, it shuts the plants in Mexico and Canada and expands production in the US and ROW. Comparisons of marginal costs can be misleading in that they do not take into account the discrete capital cost savings of plant closures.

2. The General-Equilibrium Model

There are four regions in the model (CAN, MEX, USA, ROW). Each region produces a homogeneous composite commodity from "labor" (L) and a sector-specific factor "resources" (R). Labor is actually an aggregate of labor, capital, and intermediates so it bears no empirical relationship to actual labor; i.e., "labor" is just a convenient label. The production functions for Y in region i are given by

$$Y_i = G_i(L_{iy}, R_i) = L_{iy}^{\alpha} R_i^{1-\alpha} \tag{1}$$

Production of X (autos), requires a fixed cost in units of labor F and a constant marginal cost in units of labor c. The labor required by the *j*th firm in the *X* sector in region i is given by

$$L_{ix}^{j} = c_i^j X_i^j + F_i^j \tag{2}$$

Total labor requirements for the *X* sector in region i are simply:

$$L_{ix} = \sum_j L_{ix}^j = \sum_j (c_i^j X_i^j + F_i^j) \tag{3}$$

Equation (4) gives the labor supply adding up constraint in which L_{it} denotes the labor used in transportation services (discussed below) and L_i is the aggregate endowment:

$$L_i = L_{iy} + L_{ix} + L_{it} \tag{4}$$

Consumers in each region have utility functions defined over consumption of autos and the composite commodity. p_i^j denotes the price of auto j in terms of the composite good in region *i*. No auto producer accounts for more than 0.6% of GDP in any region, and so we make two simplifying assumptions about producer behavior. First, auto producers maximize profits using the composite commodity as numeraire (over 97% of GDP). Second, auto producers view total income as fixed. Both assumptions are standard in the literature, which is not to argue that they are always appropriate. Producers thus face an inverse demand function $p_i^j(C_i)$ in region i where C_i is a vector of consumption of the different types of autos in region i. p_i^j is measured in terms of Y and income is perceived as parametric in this function. We also assume that the auto producers do not perceive market power in factor markets. However, factor price changes are taken into account in the discrete optimization problem.

There are two types of firms in the model, denoted US and FOR, where the former is the aggregate of the US "big three" (GM, Ford, Chrysler) and the latter is the aggregate of the foreign (Japanese plus Volkswagen and Volvo) firms operating plants in North America. In this paper, we split off 1/3 of the US composite as a separate firm, roughly the market share of Ford. We will refer to this firm as "Jupiter", and the remaining 2/3 of the US aggregate as "Other". The model will thus have three firms: Jupiter, Other, and Foreign. Only Jupiter will be allowed to change the numbers and locations of plants, but all firms optimally adjust outputs, markups, and shipments.

Let w denote the wage rate in terms of the composite good Y. The elasticity of scale (ε) in auto production for firm j in region i is given by the ratio of the average (AC) to the marginal (MC) cost of producing X. ε is a *variable* which decreases with plant scale.

$$\epsilon_i^j \equiv \frac{AC_i^j}{MC_i^j} = \frac{w_i(c_i^j + F_i^j/X_i^j)}{w_i c_i^j} = 1 + \frac{F_i^j}{c_i^j X_i^j} \qquad (5)$$

Engineering estimates (Toder 1976) and direct estimates provided to us by the auto industry, along with data on outputs by model type and by firm (Motor Vehicle Manufacturers Association, 1990), allow us to estimate initial values of ε_i^j. We also have reasonably good data giving the relative price of cars to the composite price index in the three North American countries (Carstens and Escalante, 1987).[1] We unfortunately do not have data on

[1]We assume that Jupiter and Other cars sell for the same price in each country. Foreign cars are assumed to cost 10% more than Jupiters and Others in North America and vice versa in ROW. The latter assumption is necessary in order that calibrated transport costs are non-negative. Each producer

marginal cost (engineering studies produce average cost curves).

The relationships among prices (known data), markups (m_i^j), and marginal costs (unknowns) are

$$p_i^j = (1 + m_i^j)\, c_i^j \tag{6}$$

A variety of modelling decisions must be made with respect to initial calibration. Following our earlier work, we assume a situation of zero profits initially, and indeed make the assumption that entry and exit produce an initial situation in which each plant just breaks even. For each plant for each firm the sum of markup revenues must then be equal to fixed costs (note that with declining average cost, no firm would build more than one plant in a country). Let t_{ik} denote the ad valorem tariff on cars shipped from region i to region k. Let τ_{ik}^j denote the specific transport cost (in units of labor) from region i to region k. The τ_{ik}^j can also be interpreted as unobserved non-tariff barriers. X_{ik}^j gives the shipments of firm j from i to k. The benchmark zero-profit condition is given in matrix form by

$$\left[(1 + t_{ik})(c_i + \tau_{ik}^j)X_{ik}^j\right] \begin{bmatrix} m_c^j \\ m_u^j \\ m_m^j \\ m_r^j \end{bmatrix} = \begin{bmatrix} F_c^j \\ F_u^j \\ F_m^j \\ F_r^j \end{bmatrix} \tag{7}$$

$$(i,k) \in c,u,m,r, \qquad j \in (Jupiter, Other, Foreign)$$

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initially has the same relative prices of cars across the three NA countries.

Joint maximization by multinationals across plants in different countries implies that the firms equate delivered marginal costs from all sources to market k. If k is served by supplies from market i, we have $c_k^j = (1+t_{ik})(c_i^j + \tau_{ik})$. This allows us to write (7) as

$$\left[c_k X_{ik}^j\right] \begin{bmatrix} m_c^j \\ m_u^j \\ m_m^j \\ m_r^j \end{bmatrix} = \begin{bmatrix} F_c^j \\ F_u^j \\ F_m^j \\ F_r^j \end{bmatrix} \qquad (8)$$

The equations (5), (6), and (8) constitute a system of 36 equations in 36 unknowns. Data include e_i^j, X_i^j, X_{ik}^j, p_i^j, i,k = {CAN, MEX, USA, ROW}, j = {Jupiter, Other, Foreign}. The 36 unknowns are m_i^j, c_i^j, and F_i^j (three variables for three firm for four regions). Our preliminary calibration program solves this square system to obtain the values of these 36 unknowns. Solution values for c_i^j and m_i^j are reported in Table 2.

Our assumptions on pricing behavior follow our earlier work (Markusen, Rutherford, Hunter (1993), Lopez-de-Silanes, Markusen, Rutherford (1994a,b)). We basically assume Cournot behavior, but use a calibrated "conjecture" parameter Ω to reconcile the Cournot formula with the calibrated markup given by the procedure just discussed. The Cournot markup formula for firm j in market i is given by $p_i^j(1 + s_i^j/\sigma_i^j) = c_i^j$ where s is the firm's market share and σ is the Marshallian price elasticity of demand (a negative number). Given that we have solved for the m_i^j, we then work backwards using the Cournot formula to calibrate Ω.

$$1 + \Omega_i^j(s_i^j/\sigma_i^j) = \frac{1}{1+m_i^j} \tag{9}$$

We assume that Y and X are Cobb-Douglas substitutes, and (in the simulations reported in this paper) that the elasticity of substitution among auto types is 5.0. The derivation of the Marshallian elasticities σ_i^j is presented in our two earlier papers and will not be shown here. All the other variable in (9) are known at this point. The conjecture parameter is thus calculated by rearranging (9):

$$\Omega_i^j = -\frac{(\sigma_i^j/s_i^j)m_i^j}{1+m_i^j} \tag{10}$$

Solution values for the Ω_i^j are reported in Table 2. These parameters are held constant in the simulations, but the markups themselves vary endogenously as the firms' market shares change. Smaller market shares increase the perceived elasticity of demand and hence lower markups.

Having solved for markups and marginal costs then allows us to calculate transport costs (non-tariff barriers) on the active trade links.

$$\tau_{ik}^{j} = \frac{p_k^j}{(1+t_{ik})(1+m_k^j)} - c_i \tag{11}$$

Transport costs on inactive trade links are set sufficiently high such that the existing configuration of plants represents an equilibrium, a problem discussed below.

A final calibration step involves setting the general-equilibrium cost of drawing labor into the auto sector. The wage rate (more correctly the marginal cost of the composite factor "labor") in terms of Y in a country is given by the marginal product of labor in the production of Y.

$$w = \alpha \left[\frac{R}{L_y} \right]^{1-\alpha} \tag{12}$$

Using (1) and (4), the elasticity of the wage rate with respect to labor demand in the X sector (holding transport demand constant) is then given by

$$\frac{L_x}{w}\frac{\partial w}{\partial L_x} = -\frac{L_x}{L_y}\frac{L_y}{w}\frac{\partial w}{\partial L_y} = \frac{L_x}{L_y}\frac{\alpha(1-\alpha)L_y^{\alpha-2}R^{1-\alpha}}{\alpha\, L_y^{\alpha-2}R^{1-\alpha}} \tag{13}$$

This simplifies to

$$\frac{L_x}{w}\frac{\partial w}{\partial L_x} = \frac{L_x}{L_y}(1-\alpha) = \frac{L_x}{L_y}\theta \equiv \omega \tag{14}$$

where θ is the value share of resources in Y output, and ω denotes the wage elasticity of X sector labor demand. ω is a general equilibrium elasticity, that tells how much the "wage" or more appropriately marginal cost (wc) in the X sector, must rise as output expands. A higher value of ω will tend to choke off expansion of the X sector (or reduce contraction) in a country following trade liberalization. ω is unfortunately a major empirical unknown. This parameter depends in part on the time-frame of the analysis as well as on the structural characteristics of the individual national economies. In a more detailed model, such as that of Kehoe and Serra-Puche (1983), labor market imperfections might be taken into account in order to produce a consistent representation of this elasticity.

We choose units so that $w = 1$ in the benchmark. Using (3) and recalling that Y is Cobb-Douglas, (14) can be rewritten as

$$\omega_i = \theta_i \frac{\sum_j (c_i^j X_i^j + F_i^j)}{(1-\theta_i) Y_i} \tag{15}$$

which gives us θ as a function of the other variables:

$$\theta_i = \frac{\omega_i Y_i}{\sum_j (c_i^j X_i^j + F_i^j) + \omega_i Y_i} \tag{16}$$

In our calibrating procedure, Y_i, X_i^j, X_{ik}^j, p_i^j, ω_i, and σ_i^j given as input data, and F_i^j, c_i^j, and m_i^j are then calculated in the calibration procedure just described. Equation (16) then allows us to infer θ_i which is then used to calibrate the *Y* sector production function and the region's factor endowments. The θ_i are held constant in the counter-factuals, while ω varies slightly with the size of the X sectors.

Following this calibration procedure, we then checked that the initial configuration of plants for Jupiter (plants in all four countries) was indeed an equilibrium. There are 15 possible plant configurations, not counting exiting entirely, and these are shown in Table 3. For modest levels of transport costs (NTBs) on inactive trade links we were somewhat surprised to discover that maintaining plants in all countries generated the *minimum* profits over all 15 configuration. This is in part due to our assumption of zero profits initially: with delivered marginal costs equalized on active trade links, profits are increased by the savings in fixed costs obtained by shutting at least one plant.

In order to ensure that the existing configuration is an equilibrium, we had to add a sunk-cost element to fixed costs, and raise the values of ω and τ on inactive trade links to fairly high levels. By sunk costs, we mean that only a percentage of the value of a firm's fixed costs can be recovered when a plant is closed. Further discussion is postponed until the next section.

3. Benchmark Data and Parameters

Table 1 gives some of the data and parameter values that we have chosen. Y gives the output of the composite sector in each country in billions of US dollars in 1990. Two sets of parameter values are reported in this paper, which we will refer to as Case 1 and Case 2. The ω for Cases 1 and 2 are reports as ELS1 and ELS2 (for elasticity of labor supply) respectively. PXU and PXF denote the benchmark prices for US (identical for Jupiter and Other) and Foreign manufactures respectively. ESU and ESF give the values of ϵ for the US and Foreign firms respectively. SVK1 and SVK2 stand for the scrap value of capital in the two cases; a value of 0.6, for example, indicates that if a plant is close the firm recovers 60% of its fixed costs.

We see from Table 1 that the values of SVK are fairly low and the values of ELS fairly high (1.0 means that if the whole industry doubles in size, the cost of labor in terms of the composite commodity would double). These values were sufficient to produce a model in which the initial diversified plant structure for Jupiter is the optimum configuration. Note also that there is a fairly small difference between the parameterizations in the two cases, with SVK being different and ELS being different for Canada. Yet the two cases produce different results as we shall see. This sensitivity is yet another reason to not take the results too literally at this stage.

Table 1 then gives the benchmark protection rates between countries. We see that protection within North America is low initially, which is part of the explanation why we had to use large values of ELS and small values of SVK in order calibrate the model to reproduce the initial configuration as an equilibrium.

Table 1 also gives the benchmark trade pattern for autos in billions of US dollars. It is hard to know exactly how these invoice values are arrived at (e.g., marginal versus average costs). We assume that they are proportional to the numbers of cars produced and shipped.

Table 2 gives some of the parameters obtained from the calibration procedure described in the previous section. c_i^j and m_i^j are obtained from the solution to the square system (5), (6), and (8). The Ω_i^j are then given by (10), and the θ_i by (16). $\Omega = 1$ implies that behavior is Cournot; values of Ω smaller than one indicate that the market is more competitive (markups are smaller) than Cournot and vice versa for values larger than one. Results in Table 2 suggest that smaller markets are less competitive.

Case 2 has a higher value of ω (ELS) for Canada and a higher scrap value of capital (SVK) for plants in all countries. The former assumption makes it more costly to expand production in Canada relative to Case 1, while the latter assumption makes it more profitable to close plants relative to Case 1. Case 2 has considerably higher transport costs (NTBs) on inactive trade links as indicated in Table 2. This ensures ensure that the initial diversified plant configuration generated the highest profits in the benchmark; i.e., the higher SVK in Case 2 generates an incentive to close plants that must be offset by higher NTBs on inactive trade links. Of course, there are many configurations of input data consistent with the benchmark equilibrium. These are only two.

Table 3 list the 15 possible plant location scenarios for Jupiter, beginning with the initial benchmark situation of full diversification (plants in all four regions).

Table 1: Data and Selected Parameters

Benchmark Statistics by Region

	Y	ELS1	ELS2	PXU	PXF	ESU	ESF	SVK1	SVK2
CAN	443	0.9	1.1	1.21	1.331	1.2	1.2	0.55	0.60
USA	4709	1.5	1.5	1.10	1.21	1.1	1.1	0.55	0.60
MEX	128	0.9	0.9	1.54	1.694	1.75	1.75	0.55	0.60
ROW	11527	1.5	1.5	1.21	1.10	1.1	1.1	0.55	0.60

Benchmark Protection (Tariff Rates)

(a_{ij} = protection in j against imports from i)

	CAN	USA	MEX	ROW
CAN	0	0	0.20	0.05
USA	0	0	0.20	0.05
MEX	0.095	0.038	0	0.05
ROW	0.095	0.038	0.33	0

Benchmark trade (billions of dollars - net trade)

(a_{ij} = exports from i to j)

	USA	MEX	CAN	ROW
US .USA	123.180			4.562
US .MEX	1.644	4.341		
US .CAN	10.063		10.194	
US .ROW				74.030
FOR.USA	25.980			
FOR.MEX	0.457	2.894		0.290
FOR.CAN			4.352	
FOR.ROW	39.172		1.067	326.162

Table 2: Calibrated Parameters

		CAN	MEX	USA	ROW
c_i^j	Jupiter	0.936	0.776	1.000	1.100
	Other	0.936	0.776	1.000	1.100
	Foreign	1.109	0.886	1.100	1.101
m_i^j	Jupiter	0.292	0.985	0.100	0.100
	Other	0.292	0.985	0.100	0.100
	Foreign	0.200	0.913	0.100	0.098
Ω_i^j	Jupiter	0.781	2.737	0.263	0.397
	Other	0.533	1.895	0.178	0.330
	Foreign	0.419	1.755	0.217	0.117
θ_i	(case 1)	0.933	0.893	0.976	0.972
θ_i	(case 2)	0.945	0.893	0.976	0.972

Transport/NTB cost in case 2 as a multiple of case 1.

CAN to MEX: 2, USA to MEX: 2, USA to CAN: 1.333

Table 3: Alternative Plant-Location Scenarios

	CAN	MEX	USA	ROW
S1	1	1	1	1
S2	1		1	1
S3		1	1	1
S4	1	1		1
S5	1	1	1	
S6	1	1		
S7		1	1	
S8		1		1
S9	1		1	
S10	1			1
S11			1	1
S12	1			
S13		1		
S14			1	
S15				1

4. Simulation Results

Tables four and five give the results of trade liberalization for Cases (parameterizations) 1 and 2 respectively. The *Ranking* column gives the six most profitable configurations beginning with the most profitable denoted by 1. The letters C, M, U, and R in the *Plant Configuration* column indicate an active plants in the countries listed; for example M - U would indicate plants only in Mexico and the USA. The *Profits* column indicates whether profits are 0, positive, or negative for that configuration. In both Tables 4 and 5, the parameters have been set such that the initial situation (S1) generates higher profits for Jupiter than any other configuration.

For Case 1 shown in Table 4, Jupiter's second-best option in the benchmark is to close its plant in Canada, but this yields negative profits as indicated by the (-) in the profits column. Elimination of tariffs alone within North America make it profitable for Jupiter to close its Mexican plant. This is likely due to the fact that Mexico has the highest initial protection within North America (Table 1). All other location scenarios, including the benchmark, now result in negative profits.

Table 4 then presents results for the elimination of tariffs along with a 1/3 reduction in the calibrated transport costs / NTBs. Now it is profitable for Jupiter to close its Canadian plant along with its Mexican plant. C-U-R now becomes second best, although it does generate positive profits for the firm. A USA-only configuration is third best, also yielding positive profits as does C-U. Reducing NTBs to 2/3 of their original value (the last panel of Table 4) does not change the optimal configuration, but does raise the USA only option to second place.

Table 4: Case 1

Benchmark

Ranking	Plant Configuration	Profits
1 (S1)	C - M - U - R	0
2 (S3)	M - U - R	-
3 (S5)	C - M - U	-
4 (S4)	C - M - R	-
5 (S7)	M - U	-
6 (S2)	C - U - R	-

Eliminate Tariffs with North America

Ranking	Plant Configuration	Profits
1 (S2)	C - U - R	+
2 (S1)	C - M - U - R	-
3 (S3)	M - U - R	-
4 (S11)	U - R	-
5 (S9)	C - U	-
6 (S4)	C - M - R	-

Reduce Transport Cost / NTBs within North America by 1/3

Ranking	Plant Configuration	Profits
1 (S11)	U - R	+
2 (S2)	C - U - R	+
3 (S14)	U	+
4 (S9)	C - U	+
5 (S3)	M - U - R	-
6 (S4)	C - M - R	-

Reduce Transport Cost / NTBs within North America by 2/3

Ranking	Plant Configuration	Profits
1 (S11)	U - R	+
2 (S14)	U	+
3 (S2)	C - U - R	+
4 (S4)	C - M - R	+
5 (S9)	C - U	+
6 (S3)	M - U - R	+

Table 5 presents the same calculations, but with a higher value of ω for Canada and slightly higher scrap-value of capital in all countries (0.60 instead of 0.55). The elimination of tariffs alone makes it profitable for Jupiter to close its US plant in this case, and the initial diversified configuration yields negative profits as it did in Case 1. Reducing transport cost / NTBs by 1/3 in addition to eliminating tariffs does not change the optimal configuration in Table 5, but it does make other configurations profitable (not including the initial diversified configuration S1). Reducing transport costs / NTBs by 2/3 leads to a switch back to producing in the USA, and eliminating the Mexican and Canadian plants as in Case 1.

Case 2 thus produces an interesting "non-monotonicity" result. As barriers are first lowered, the USA plant is closed. As barriers are lowered further, the USA plant is "reopened" and the Mexican and Canadian plants are closed. This result is partly explained by the initial pattern of protection and the initial calibrated NTB values. The calibrated values of the transport cost /NTBs are highest on the initially inactive trade links such as USA to Mexico and USA to Canada. Thus lowering only tariffs does not make it profitable to serve Canada and Mexico from a USA plant. Lowering the NTB barriers does in turn create a tendency to concentrate production in the largest country. These same general comments apply to Case 1.

Several general points emerge from the simulations. First, note from Tables 4 and 5 that trade liberalization is profitable for Jupiter, *given that no other firm can change its configuration*. This is presumably the results of the capture of scale economies (reduction in fixed costs) from eliminating one or more plants.

Table 5: Case 2

Benchmark

Ranking	Plant Configuration	Profits
1 (S1)	C - M - U - R	0
2 (S4)	C - M - R	-
3 (S3)	M - U - R	-
4 (S5)	C - M - U	-
5 (S7)	M - U	-
6 (S2)	C - U - R	-

Eliminate Tariffs with North America

Ranking	Plant Configuration	Profits
1 (S4)	C - M - R	+
2 (S1)	C - M - U - R	-
3 (S3)	M - U - R	-
4 (S2)	C - U - R	-
5 (S11)	U - R	-
6 (S5)	C - M - U	-

Reduce Transport Cost / NTBs within North America by 1/3

Ranking	Plant Configuration	Profits
1 (S4)	C - M - R	+
2 (S11)	U - R	+
3 (S2)	C - U -R	+
4 (S14)	U	+
5 (S3)	M - U - R	-
6 (S9)	C - U	-

Reduce Transport Cost / NTBs within North America by 2/3

Ranking	Plant Configuration	Profits
1 (S11)	U - R	+
2 (S14)	U	+
3 (S4)	C - M - R	+
4 (S2)	C - U - R	+
5 (S9)	C - U	+
6 (S3)	M - U - R	+

Second, the initial diversified production structure is *always unprofitable for all three firms* under any degree of liberalization. This is presumably the "pro-competitive effect" of trade liberalization that has been much discussed in the trade literature (e.g., Markusen, 1981). Each firm individually has an incentive to expand overall production (although reducing production in some countries) since, in some sense, "overall" delivered marginal costs of supplying the various markets have decreased. However, the expansion by all firms depresses prices and generates negative profits.

Third, when Jupiter changes plant configuration in response to a given degree of liberalization, this *always increases* the profits of the other two firms. The reason for this is that, when Jupiter stops producing in one market, it serves that market by higher marginal-cost imports. Under the Cournot-type behavior assumed in the model, Jupiter will then supply less to that market for any given level of its competitors' supplies than when it produced within the region. This has a favorable impact on the profits of Other and Foreign.

Table 6 presents a set of calculations that help make one of the principal points of the paper. The benchmark levels of production for Jupiter in each country are normalized to 1.0. The left-hand column of numbers gives the production levels for Jupiter in the four regions following liberalization (tariffs eliminated plus NTBs reduced by 2/3) under the assumption that Jupiter's plant configuration remains fixed at S1 (plants in all four regions). We see that in both Cases 1 and 2 that Jupiter increases production in Canada and Mexico and reduces production in USA and ROW. The

Table 6: Fixed versus Endogenous Location Decisions

Production by Jupiter with Tariffs Eliminated and NTBs Reduced by 2/3
(benchmark normalized to 1.0)

	Fixed (Benchmark) Locations		Optimal Locations (U and R)	
Case 1:	CAN	1.305	CAN	0.0
	MEX	1.724	MEX	0.0
	USA	0.971	USA	1.140
	ROW	0.910	ROW	1.044
Case 2:	CAN	1.295	CAN	0.0
	MEX	1.725	MEX	0.0
	USA	0.971	USA	1.134
	ROW	0.912	ROW	1.039

right-hand numbers give the corresponding results when Jupiter is allowed to optimally adjust its plant configuration to S11 (plants in USA and ROW). We see starkly contrasting results. Now Jupiter increases production in USA and ROW and eliminates production entirely in Mexico and Row.

Table 6 emphasizes rather dramatically the possibly misleading nature of marginal analysis. With exogenously fixed locations, profits are maximized by allocating production across plants such that delivered marginal costs are equalized (subject to inequality constraints: some markets might be served by a single plant). These marginalist considerations dictate that, when trade is liberalized, more of the US market is served by production from low marginal cost plants in Canada and Mexico. Furthermore, increasing marginal costs in general equilibrium work against a solution in which production is concentrated in one country.

When we allow plant configurations to change, the firm is interested in minimizing total costs, and equality of delivered marginal costs is only an optimality condition if "global" maximization dictates keeping plants active. We can think of the firm's decision as a two-part process. In the first part, the firm chooses its optimal number and location of plants, taking into account the discrete savings in fixed costs from having fewer plants. In the second stage, the firm optimizes according to marginalist rules for the *given* plant configuration. The problem is solved backwards (as indeed our computer algorithm does), finding the maximized profit for each configuration and then picking the optimal configuration. The numbers in Table 6 reveal that, when we endogenize the first stage of the decision problem, we may arrived at quite different results than those suggested by looking at only the second stage of the problem.

5. Puzzles, Problems, and Caveats

This paper attempts to take a first step at endogenizing discrete location choices by firms. The analysis is motivated by the assertion that the two existing streams of literature are misleading or incomplete insofar as they avoid the discreetness aspect that is at the heart of increasing-returns technologies. The "duopoly" literature with fixed numbers of firms avoids the problem altogether while the "free entry/exit" literature fudges the problem by allowing for a continuum (non-integer number) of plants or firms. We believe that the paper makes a good case for endogenizing the discrete-choice of plant numbers and locations. The results of Table 6 in particular illustrate the dangers of using marginalist rules with increasing-returns technologies.

Rather than repeat the principal findings of the paper here, we instead close by raising a number of problems and qualifications. First, the need to assume a low (though perhaps not unrealistic) figure for capital scrap value, a high elasticity of the "wage" (marginal cost) with respect to industry labor demand, and very high "transport costs" (unspecified NTBs) on inactive trade links in order to make the initial plant configuration optimal is interesting. Subject to the limitations of the model, it suggests that production is excessively geographically diversified initially. There are all sorts of reasons beyond the scope of the model as to why this makes sense. Historically, high non-tariff barriers in Canada and Mexico have generated auto industries in those countries that may never have developed in a free-trade environment. Political considerations may lead firms to distribute production more widely than would be optimal from a very narrow profit-maximizing point of view. The model also fails to capture the fact that firms produce many models of cars and that the large US market can support many plants of efficient scale. Introducing more models, each produced most efficiently in a single plant, would probably lead us away from the tendency to reduce the number of production locations.

A second caveat is to remind ourselves of the "partial-equilibrium" nature of the solution presented here. Although we have pushed the problem back one step by allowing one firm to change the number and location of its plants, there is no attempt to find a "general-equilibrium" solution in which all firms are allowed to make such choices. We will eventually take a more ambitious approach in which we find the Nash equilibrium of the game in which all firms pick a plant configuration in the first stage and then play the (conjecture-modified) Cournot game in the second stage that we have described here. With two firms making such choices, we will have to calculate 225 general-equilibrium solutions instead of 15, and then employ a procedure for searching for a Nash equilibrium developed by Rutherford. The present model has 175 dimensions, and calculating the 15 scenarios requires about 5 minutes on a 486 machine. Thus the two-endogenous-firm model would require almost 75 minutes per run, not counting the algorithm to find Nash equilibria. Three firms endogenous requires the calculation of 3375 solutions. Despite the recent promising developments in discrete mathematics and integer programming (see Scarf, 1990), it appears that this brute-force strategy is the only avenue of attach at the present time.

A somewhat defensive comment may be in order concerning numerical modelling. We acknowledge, even emphasize, the limitations of numerical simulation analysis. However, it is generic to the analysis of discrete choice problems that little progress can be made on a strictly analytic level. In a general algebraic model, we cannot know the critical values of parameters at which a firm will make a discrete jump to a new plant configuration, nor can we predict to what new configuration the firm will move. For example, we might expect that trade liberalization might lead a firm to close one of its three North American plants, but we cannot predict what plant(s) might be closed, nor at what level of liberalization this will occur. Subject to its obvious limitations, numerical modelling can analyze these questions.

As a final comment, we wish to emphasize that the results presented in this paper should not be used as a guide to analyzing NAFTA or as a prediction of its effects on the auto industry. The paper illustrates a technique and argues for the importance of introducing discrete choice into trade-industrial-organization models. The need to use of somewhat "unrealistic" parameter values to calibrate the model to reproduce the status quo as the optimal choice and the great sensitivity of the results to small changes in parameter values (e.g., the small difference in the parameterizations of cases 1 and 2) should be sufficient to discourage a literal application of the results.

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