Productivity and the Decision to Import and Export: Theory and Evidence*

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Abstract

This paper develops an open economy model with heterogeneous final goods producers who simultaneously choose whether to export their goods and whether to use imported intermediates. The model highlights mechanisms whereby import policies affect aggregate productivity, resource allocation, and industry export activity along both the extensive and intensive margins. Using the theoretical model, we develop and estimate a structural empirical model that incorporates heterogeneity in productivity and shipping costs using Chilean plant-level data for a set of manufacturing industries. The estimated model is consistent with the key features of the data regarding productivity, exporting, and importing. We perform a variety of counterfactual experiments to assess quantitatively the positive and normative effects of barriers to trade in import and export markets. These experiments suggest that there are substantial aggregate productivity and welfare gains due to trade. Furthermore, because of import and export complementarities, policies which inhibit the importation of foreign intermediates can have a large adverse effect on the exportation of final goods.

Keywords: exporting, importing, firm heterogeneity, aggregate productivity, resource allocation

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1 Introduction

This paper develops a stochastic industry model of heterogeneous firms to examine the effects of trade liberalization on resource reallocation, industry productivity, and welfare in the presence of import and export complementarities. We use the theoretical model to develop empirical models which we estimate using Chilean plant-level data for a set of manufacturing industries. The estimated models are then used to perform counterfactual experiments regarding different trading regimes to assess the positive and normative effects of barriers to trade in import and export markets.

Previous empirical work suggests that there is a substantial degree of resource reallocation across firms within an industry following trade liberalization and these shifts in resources contribute to productivity growth. Pavcnik (2002) uses Chilean data and finds such reallocations and productivity effects after trade liberalization in that country. Trefler (2004) estimates these effects in Canadian manufacturing following the U.S.-Canada free trade agreement using plant- and industry-level data and finds significant increases in productivity among both importers and exporters.

Empirical evidence also suggests that relatively more productive firms are more likely to export.[1] In this paper we provide empirical evidence that whether or not a firm is *importing* intermediates for use in production may also be important for explaining differences in plant performance.[2] Our data suggests that firms which both import intermediates and export their output tend to be larger and more productive than firms that are active in either market, but not both. Hence, the impact of trade on resource reallocation across firms which are importing may be as important as shifts across exporting firms.

Melitz (2003), motivated by the empirical findings regarding exporters described above, develops a monopolistic competition model of exporters with different productivities and examines the effect of trade liberalization.[3] To address simultaneously the empirical regularities concern-

[1]See, for example, Aw, Chung, and Roberts (2000), Bernard and Jensen (1999), Bernard, et al. (2003), Clerides, Lack and Tybout (1998), and Eaton, Kortum, and Kramarz (2004a). Other observations on firm level exports include: (a) a majority of firms do not export, (b) most exporters only export a small fraction of their output, and (c) most exporters only export to a small number of countries.

[2]See also Amiti and Konings (2005), Halpern, Korn, and Szeidl (2006), and Kasahara and Rodrigue (2005) for evidence of a positive relationship between importing inputs and productivity. Few empirical studies simultaneously examine both exports and imports at the micro-level. A notable exception is Bernard, Jensen, and Schott (2005) who provide empirical evidence regarding both importers and exporters in the U.S.

[3]Several alternative trade theories with heterogeneous firms have been developed as well. Eaton and Kortum (2002) develop a Ricardian model of trade with firm-level heterogeneity. Eaton, Kortum, and Kramarz (2004b) explore a model that nests both the Richardian framework of Eaton and Kortum and the monopolistic competition approach of Melitz. Helpman, Melitz, and Yeaple (2004) present a monopolistic competition model with

ing importers, we begin by extending his model to incorporate imported intermediate goods. In the model, the use of foreign intermediates increases a firm's productivity (because of increasing returns) but, due to fixed costs of importing, only inherently highly productive firms import intermediates. Thus, a firm's productivity affects its participation decision in international markets (i.e. importing inputs and/or exporting output) and, conversely, this participation decision (i.e. importing inputs) affects its productivity.

In this environment, trade liberalization which lowers restrictions on the importation of intermediates increases aggregate productivity because some inherently productive firms start importing and achieve within-plant productivity gains. This, in turn, leads to a resource reallocation from less productive to more productive importing firms, enhancing the positive aggregate productivity effect. Furthermore, productivity gains from importing intermediates may allow some importers to start exporting, leading to a resource reallocation along the intensive margin. In equilibrium, higher labor demand from new importers and exporters increases the real wage and, as a result, the least productive firms exit from the market. Thus, the model identifies an important mechanism whereby import tariff policy affects aggregate exports and this interaction is essential for understanding the impact of trade policy on aggregate productivity and welfare.[4]

Using the theoretical model, we develop and estimate a structural empirical model of exports and imports using a panel of Chilean plants from a set of manufacturing industries (structural metals, wearing apparel, and plastic products). The data is well-suited for our study as Chile underwent a significant trade liberalization from 1974-1979 but had fairly stable trade policies, and savings, investment, and growth rates during our sample period from 1990-1996. Furthermore, a significant portion of Chilean imports are in chemicals, electrical machinery, and heavy industrial machinery which is consistent with our theoretical focus on imported intermediate inputs.

We consider an extended empirical model that incorporates sunk costs and firm-level heterogeneity in international shipping costs. The inclusion of sunk costs and other features of the model allows us to capture the high degree of persistence in a plant's export and import status apparent in the data. The estimated model also replicates the observed patterns of productivity

heterogeneous firms that focuses on the firm's choice between exports and foreign direct investment. Bernard, Redding, and Schott (2007) develop a model of endowment-driven comparative advantage with heterogeneous firms to examine both across and within industry reallocations in response to trade liberalization.

[4]It should be noted that in standard trade theory, restrictions on imports of final goods will lower exports of final goods so as to maintain balanced trade. In this paper, we are studying a different mechanism whereby import restrictions on intermediates decreases exports of final goods through their negative effect on productivity in the presence of heterogeneous firms and trading costs.

across firms with different import and export status as well as the observed distribution of export and import intensities. It is also consistent with the high degree of trade concentration among a small number of plants in our data. For example, the observation that the top five percent of exporters account for more than forty percent of total exports in the plastic products industry.

For each industry in our study, we find that the estimated mean of the productivity distribution at the steady state is significantly higher than the estimated mean at entry, suggesting that selection through endogenous exit plays an important role in determining industry productivity. Furthermore, the estimated model indicates that firms with high productivity and low shipping costs tend to self-select into exporting and importing. Hence, heterogeneity in both productivity and shipping costs are significant in determining export and import status.

To examine the effects of trade policies, we perform a variety of counterfactual experiments that explicitly take into account equilibrium price adjustments. The experiments suggest that the welfare gains in moving from autarky to trade are substantial, with increases in real aggregate income ranging from 3-7 percent. Furthermore, we estimate that industry total factor productivity increases between 14-34 percent when trade is liberalized. Another important finding is that because of importing and exporting complementarities, policies which inhibit the importation of foreign intermediates can have a large adverse effect on the exportation of final goods, causing exports to fall by approximately 25% in each of the industries we study.

Our paper is a contribution to the recent empirical literature which seeks to structually estimate international models with heterogeneous firms using plant-level data in order to examine the quantitative implications of trade policies. For instance, Das, Roberts, and Tybout (2007) use Columbian plant-level data for three manufacturing industries to examine the effects of trade liberalization and export subsidies on exports. Halpern, Koren, and Szeidl (2007) use a panel of Hungarian firms to explore relationships between importing and plant productivity. Using Indonesian data, Rodrigue (2007) estimates a model with foreign direct investment and exporting. Our results complement these papers but with particular focus on the interaction between importing and exporting.

The remainder of the paper is organized as follows. Section 2 presents empirical evidence on the distribution of importers and exporters and their performance using Chilean manufacturing plant-level data. Section 3 presents a theoretical model with import and export complementarities. Section 4 provides details and results of the structural estimation of empirical models based on the theoretical model. Section 5 concludes.

Table 1: Exporters and Importers in Chile for 1990-1996 (% of Total)

	1990	1991	1992	1993	1994	1995	1996	1990-96 ave.
Exporters	8.4	9.7	9.2	9.2	8.6	9.7	8.8	9.1
Importers	12.6	12.1	13.1	12.9	13.5	11.8	12.0	12.6
Ex/Importers	8.2	9.5	10.7	11.8	13.4	12.5	12.6	11.3
Exports by Exporters	48.4	37.8	49.3	44.9	32.6	38.1	40.5	41.6
Exports by Ex/Importers	51.6	62.2	50.7	55.1	67.4	61.9	59.5	58.4
Imports by Importers	34.8	32.1	31.5	27.8	22.0	20.8	26.7	28.0
Imports by Ex/Importers	65.2	67.9	68.5	72.2	78.0	79.2	73.3	72.0
Output by Exporters	17.4	16.7	23.4	18.9	15.2	20.1	17.8	18.5
Output by Importers	16.8	12.9	14.9	15.0	14.1	13.3	14.4	14.5
Output by Ex/Importers	39.1	44.1	40.5	43.8	50.2	46.3	47.5	44.5
No. of Plants	4584	4764	4937	5041	5081	5110	5464	4997

Notes: Exporters refers to plants that export but do not import. Importers refers to plants that import but do not export. Ex/Importers refers to plants that both export and import.

2 Empirical Motivation

In this section we briefly describe Chilean plant-level manufacturing data and provide summary statistics to characterize patterns and trends of plants which may or may not participate in international markets. Section 4.5 describes the data set in further detail.

Table 1 provides several important basic facts about exporters and importers. The fraction of plants that are engaged in trade is relatively small but has increased over time as shown in the first three rows of Table 1. Furthermore, as shown in the fourth through seventh rows of that table, plants that both export and import account for a larger fraction of exports and imports than their counterparts which only export or only import. In addition, the percentage of total output accounted for by firms which were engaged in international trade increased from 73.3% in 1990 to 79.7% in 1996. Plants that both exported and imported became increasingly important in accounting for total output: they constitute only 12.6% of the sample but account for 47.5% of total output in 1996. Overall, this table indicates that plants that engage in both exporting and importing are increasingly common and are important contributors to output and the volume of trade.

Exports and imports are highly concentrated among a small number of plants.[5] Table 2 reports the shares of total exports and imports in the top 1, 5, and 10 percentiles of exporting and importing plants. As indicated in the first two columns, export concentration is very high, with the top 1 percent of exporting plants accounting for 39.8% of total exports; furthermore,

[5] Bernard et al. (2005) find U.S. exports and imports to be concentrated among a very small number of firms.

Table 2: Export and Import Concentration, 1990-1996 average

	Exports		Imports	
	% of Total Exports	% of Ex/Importers	% of Total Imports	% of Ex/Importers
Top 1%	39.8	54.2	25.8	79.6
Top 5%	67.3	66.2	51.3	77.7
Top 10%	80.1	63.2	65.8	72.7

Notes: "Ex/Importers" refers to plants that both export and import while "% of Ex/Importers" refers to the fraction of Ex/Importers in the top 1, 5, and 10% of exporting or importing plants.

Table 3: Distribution of Export and Import Intensities

Export or Import Intensity (percent)	Percentage of Exporting Plants	Percentage of Importing Plants
0-10	51.9	29.2
10-20	9.7	16.9
20-30	5.6	13.9
30-40	4.4	10.0
40-50	4.2	8.1
50-60	4.0	6.8
60-70	4.4	5.8
70-80	5.8	4.0
80-90	5.3	3.0
90-100	3.5	1.3

Notes: Export and import intensities are reported only for exporting and importing plants. The statistics are calculated from all observations in 1990-1996.

a majority of the top 1 percent of exporters are plants that engage in both exporting and importing. Importers show a similar pattern although the degree of concentration is slightly lower than exporters while plants that both export and import play a more important role for the concentration of imports.

We also examine the degree of exporting and importing for plants by reporting the distribution of export and import intensities in Table 3. A plant's export intensity is defined as the ratio of its export sales to total sales while its import intensity is the ratio of expenditures on imported intermediate inputs to total expenditures on intermediate inputs. The table reports the fraction of observations in our sample of exporting or importing plants in each intensity bin. As the table suggests there is a sizable degree of heterogeneity across plants with regard to export and import intensities. The average export intensity is 25% with a standard deviation of .30 while the average import intensity is 29% with a standard deviation of .25.

We now turn to measures of plant performance and their relationships with export and import status. While the differences in a variety of plant attributes between exporters and non-exporters are well-known (e.g., Bernard and Jensen, 1999), few previous empirical studies have discussed

Table 4: Premia of Exporter and Importer

	Pooled OLS: 1990-1996			Fixed Effects: 1990-1996		
Export/Import Status	Exporters	Importers	Ex/Importers	Exporters	Importers	Ex/Importers
Total Employment	0.889	0.660	1.495	0.101	0.043	0.138
	(0.019)	(0.016)	(0.018)	(0.013)	(0.009)	(0.012)
Total Sales	0.325	0.546	0.756	0.110	0.074	0.158
	(0.018)	(0.013)	(0.016)	(0.013)	(0.010)	(0.013)
Value Added per Worker	0.327	0.490	0.688	0.100	0.053	0.125
	(0.021)	(0.015)	(0.019)	(0.021)	(0.016)	(0.020)
Average Wage	0.210	0.323	0.423	0.055	0.043	0.062
	(0.011)	(0.009)	(0.010)	(0.009)	(0.007)	(0.009)
Non-Production/Total Workers	0.033	0.210	0.345	0.038	0.031	0.056
	(0.014)	(0.011)	(0.012)	(0.014)	(0.011)	(0.015)
Capital per Worker	0.495	0.512	0.866	0.066	0.016	0.134
	(0.026)	(0.019)	(0.024)	(0.016)	(0.012)	(0.017)
No. of Observations		34981			33853	

Notes: Standard errors are in parentheses. "Total Employment" reports the estimates for exporter/importer premia from a regression excluding the logarithm of total employment from the set of regressors. Because they are observed only for one period, 1128 plant observations are dropped from the fixed effects regression.

how plant performance measures depend on import status. Table 4 presents estimated premia in various performance measures according to export and import status. Following Bernard and Jensen (1999), columns 1-3 of this table report export and import premia estimated from a pooled ordinary least squares regression using data from 1990-1996:

$$\ln X_{it} = \alpha_0 + \alpha_1 d_{it}^x (1 - d_{it}^m) + \alpha_2 d_{it}^m (1 - d_{it}^x) + \alpha_3 d_{it}^x d_{it}^m + Z_{it}\beta + \epsilon_{it}, \tag{1}$$

where X_{it} is a vector of plant attributes (employment, sales, labor productivity, wage, non-production worker ratio, and capital per worker). Here, d_{it}^x is a dummy for year t's export status, d_{it}^m is a dummy for year t's import status, Z includes industry dummies at the four-digit ISIC level, year dummies, and total employment to control for size. The export premium, α_1, is the average percentage difference between exporters and non-exporters among plants that do not import foreign intermediates. The import premium, α_2, is the average percentage difference between importers and non-importers among plants that do not export. Finally, α_3 captures the percentage difference between plants that neither export nor import and plants that do both.

The results in Table 4 show that there are substantial differences not only between exporters and non-exporters but also between importers and non-importers. The export premia among non-importers are positive and significant for all characteristics as shown in column 1. The import premia among non-exporters are positive and significant for all characteristics in column 2, suggesting the importance of import status in explaining plant performance even after controlling for export status. Comparing columns 1-2 with column 3, plants that are both exporting and importing tend to be larger and be more productive than plants that are engaged in either exporting or importing but not both.[6]

We also estimate (1) using a fixed effects regression to control for plant specific effects. The results are reported in columns 4-6 of Table 4. They show similar patterns to those based on the pooled OLS in columns 1-3. Notably, all the point estimates for column 6 are larger than those reported in columns 4-5, suggesting that plants that are both exporting and importing are larger and more productive than other plants. The point estimates suggest that the magnitude of the performance gap for various characteristics across different export/import status are substantial.

3 A Model of Exports and Imports

Motivated by the empirical evidence presented above, we now extend the trading environment studied by Melitz (2003) to include importing of intermediates by heterogeneous final goods producers.

3.1 Environment

The world is comprised of $N+1$ identical countries. Within each country there is a set of final goods producers and a set of intermediate goods producers.

3.1.1 Consumers

In each country there is a representative consumer who supplies labour inelastically at level L. The consumer's preferences over consumption of a continuum of final goods are given by $U = \left[\int_{\omega\in\Omega} q(\omega)^{\frac{\sigma-1}{\sigma}} d\omega\right]^{\frac{\sigma}{\sigma-1}}$, where ω is an index over varieties, and $\sigma > 1$ is the elasticity of substitution between varieties. Letting $p(\omega)$ denote the price of variety ω, we can derive optimal consumption of variety ω to be $q(\omega) = Q\left[\frac{p(\omega)}{P}\right]^{-\sigma}$, where P is a price index given by $P = \left[\int_{\omega\in\Omega} p(\omega)^{1-\sigma} d\omega\right]^{1/(1-\sigma)}$ and Q is a consumption index with $Q = U$. Expenditure on variety ω is given by

$$r(\omega) = R\left[\frac{p(\omega)}{P}\right]^{1-\sigma}, \qquad (2)$$

where $R = PQ = \int_{\omega\in\Omega} r(\omega) d\omega$ is aggregate expenditure.

[6] Since export status is positively correlated with import status, the magnitude of the export premia estimated without controlling for import status is likely to be overestimated by capturing the import premia.

3.1.2 Production

We first describe the final goods sector which is characterized by a continuum of monopolistically competitive firms selling horizontally differentiated goods. This sector is our primary focus. Final goods firms sell to domestic consumers and in the trading environment choose whether or not to also export their goods to foreign consumers. In production, final goods producers employ labor, domestically produced intermediates, and choose whether or not to also use imported intermediates.

There is an unbounded measure of ex ante identical potential entrants. Upon entering, an entrant pays a fixed entry cost, f_e. Each new entrant then draws a firm-specific productivity parameter, φ, from a continuous cumulative distribution $G(\varphi)$. A firm's productivity remains at this level throughout its operation. After observing φ, a firm decides whether to immediately exit or stay in the market. All final goods producers must pay a fixed production cost, f, each period to continue in operation. In addition, in each period, a firm is forced to exit with probability ξ.

In the open economy, firms must also pay fixed costs associated with importing intermediates and exporting their product in any period that they choose to be active in those markets. Before making their import and export decisions, firms draw a firm-specific shock to the fixed cost of importing. This shock is denoted ϵ and is identically and independently distributed across firms and across time with a continuous cumulative distribution $H(\epsilon)$ defined over $[\underline{\epsilon}, \bar{\epsilon}]$ with zero mean. The total fixed cost per import market for a firm which is importing but not exporting equals $f_m + \epsilon > 0$. A firm that is exporting but not importing incurs a non-stochastic cost of $f_x > 0$ each period for each export market. Finally, a firm that is both exporting and importing incurs a fixed cost equal to $\zeta(f_x + f_m + \epsilon)$ for each market, where $0 < \zeta \leq 1$ determines the degree of complementarity in fixed costs between exporting and importing.[7]

We let $d^x \in \{0, 1\}$ denote a firm's export decision where $d^x = 0$ implies that a firm does not export their good and let $d^m \in \{0, 1\}$ denote a firm's import decision where $d^m = 0$ implies that a firm does not use imported intermediates. Finally, let $d = (d^x, d^m)$ denote a final good producer's export/import status. With this notation, we can write the total per-period fixed

[7]We impose lower bounds on the values for f_x and $f_m + \bar{\epsilon}$ and upper bounds on $f_m + \underline{\epsilon}$ which guarantee that there is a positive measure of firms in each export/import category in the open economy equilibrium. These restrictions are similar to the condition imposed by Melitz (2003) which ensures that his economy is characterized by partitioning of firms by export status. These derivations as well as full derivations of the theoretical results discussed below are presented in a supplementary appendix which is available upon request.

cost of a firm that chooses d and draws ϵ as

$$F(d,\epsilon) = f + N\zeta^{d^x d^m}[d^x f_x + d^m(f_m + \epsilon)]$$

The technology for a firm with inherent productivity level φ and import status d^m is given by:

$$q(\varphi, d^m) = \varphi l^\alpha \left[\int_0^1 x_o(j)^{\frac{\gamma-1}{\gamma}} dj + d^m \int_0^N x(j)^{\frac{\gamma-1}{\gamma}} dj\right]^{\frac{(1-\alpha)\gamma}{\gamma-1}},$$

where l is labor input, $x_o(j)$ is input of domestically-produced intermediate variety j, $x(j)$ is input of imported intermediate variety j, $0 < \alpha < 1$ is the labor share, and $\gamma > 1$ is the elasticity of substitution between any two intermediate inputs.

Note that this production function incorporates increasing returns to variety in intermediate inputs using an approach similar to that used in many applications in macroeconomics, growth, and international economics.[8] As is well-known, this feature of the production function implies that firms which use a wider variety of intermediates (here, through importing), will have higher total factor productivity. Thus, our environment is consistent with the empirical evidence presented in Section Two and in Amiti and Konings (2005), Halpern, Koren, and Szeidl (2006), and Kasahara and Rodrigue (2005) which suggest that the use of foreign intermediate goods is associated with higher plant productivity.[9]

In the intermediate goods industry, there is a continuum of firms producing differentiated goods. The measure of varieties produced within a country is fixed at one.[10] Anyone can access the blueprints of the intermediate production technology for all varieties and there is free entry. Firms have identical linear technologies in labor input with marginal product equal to one. These conditions imply that domestic intermediates sold in the domestic market will all have price equal to the wage which we normalize to one. We allow for iceberg importing costs so $\tau_m > 1$ units of an intermediate good must be shipped abroad for 1 unit to arrive.

[8] See, for example, Devereux, Head, and Lapham (1996a, 1996b), Ethier (1982), Grossman and Helpman (1991), and Romer (1987).

[9] An alternative approach would be to incorporate vertically differentiated inputs with foreign inputs of higher quality to generate a positive relationship between importing and plant productivity. Halpern, Koren, and Szeidl (2006) use Hungarian plant data and find that approximately two-thirds of the increase in plant productivity due to importing is attributable to an increase in the variety of intermediates used in production while the remaining one-third is due to an increase in quality. For ease of exposition and tractability, we focus on the former effect.

[10] Thus, we are abstracting from the effects of trade on the measure of intermediates produced within a country. Our environment does, however, capture the effects of trade on the measure of varieties of final goods produced within a country and on the measure of varieties of final goods available to consumers in a country. We take this approach so as to focus on the effects of trade on the final good sector and to provide estimation of the baseline model of Melitz (2003) in Section Four. Incorporating an endogenous measure of intermediate varieties is an interesting avenue for future work but is beyond the scope of this paper.

In the symmetric equilibrium, inputs of all domestic intermediates will be equal so $x_o(j) = x_o$ for all j. The cost minimization problem of a final goods producer implies that employment of any imported variety will equal $x(j) = x = \tau_m^{-\gamma} x_o$ for all j. Thus expenditure on imported intermediates and total intermediates respectively are given by

$$X^m = N\tau_m^{1-\gamma} x_o \qquad\qquad X = (1 + N\tau_m^{1-\gamma})x_o \tag{3}$$

Finally, production can be written as

$$q(\varphi, d^m) = a(\varphi, d^m) l^\alpha [x_o + d^m N\tau_m x]^{1-\alpha}, \tag{4}$$

where

$$a(\varphi, d^m) \equiv \varphi \lambda^{d^m}, \tag{5}$$

with $\lambda \equiv (1 + N\tau_m^{1-\gamma})^{\frac{1-\alpha}{\gamma-1}} > 1$. We will refer to this term as a firm's total factor productivity.[11] Note that $a(\varphi, 1) > a(\varphi, 0)$ so, as discussed above, a firm which imports intermediates will have higher total factor productivity than if it does not import because of the increasing returns to variety.

The form of preferences implies that final goods producers will price at a constant markup equal to $\frac{\sigma}{\sigma-1}$ over marginal cost. Hence, using the final goods technology and recalling that all intermediates are priced at the wage which equals one, we have the following pricing rule for final goods sold in the home market for a producer with productivity φ and import status d^m:

$$p^h(\varphi, d^m) = \left(\frac{\sigma}{\sigma - 1}\right)\left(\frac{1}{\Gamma a(\varphi, d^m)}\right),$$

where $\Gamma \equiv \alpha^\alpha (1-\alpha)^{1-\alpha}$. As in Melitz (2003), we also assume that there are iceberg exporting costs for final goods so that $\tau_x > 1$ units of goods has to be shipped abroad for 1 unit to arrive at its destination. The pricing rule for final goods sold in the foreign market is then given by $p^f(\varphi, d^m) = \tau_x p^h(\varphi, d^m)$.

The total revenue of a final good producer depends on inherent productivity and export/import status. From (2), revenue from domestic sales can be written as $r^h(\varphi, d^m) = R\left(\frac{\sigma-1}{\sigma} P\Gamma a(\varphi, d^m)\right)^{\sigma-1}$ while revenue from foreign sales per country of export is given by

$$r^f(\varphi, d) = d^x \tau_x^{1-\sigma} r^h(\varphi, d^m). \tag{6}$$

[11] Note that l is a firm's labour input and $x_o + d^m N\tau_m x$ is a firm's gross input of intermediate inputs so $a(\varphi, d^m)$ is a residual measure of productivity.

Hence, total revenue for a firm with productivity φ and export/import status d is given by $r(\varphi, d) = r^h(\varphi, d^m) + N r^f(\varphi, d)$ or

$$r(\varphi, d) = (1 + d^x N \tau_x^{1-\sigma}) r^h(\varphi, d^m). \tag{7}$$

Thus, using equations (5) and (7), we can determine revenue for a firm with productivity φ and export/import status d relative to a firm with the same productivity who is neither exporting nor importing:

$$r(\varphi, d) = b_x^{d^x} b_m^{d^m} r(\varphi, 0, 0), \tag{8}$$

where $b_x \equiv 1 + N\tau_x^{1-\sigma}$ and $b_m \equiv \lambda^{\sigma-1}$. Turning to profits, we see that the pricing rule of firms implies that profits of a final good producer with inherent productivity φ, export/import status d, and fixed import cost shock ϵ can be written as

$$\pi(\varphi, d, \epsilon) = \frac{r(\varphi, d)}{\sigma} - F(d, \epsilon) \tag{9}$$

In what follows, we explore the equilibria of four economies: the closed economy and three trading economies. Let autarkic equilibrium variables be denoted with a subscript A. We denote equilibrium variables in the full trading equilibrium with a subscript T. Our partial trading economy with $\zeta = b_m = 1$ is equivalent to the open economy studied by Melitz (2003) with trade in final goods but no trade in intermediates and we denote this economy with an X subscript. We also consider an economy with trade in intermediate goods but no trade in final goods and denote this economy with an M subscript.

The equilibrium price index and aggregate revenue in economy $S \in \{A, T, X, M\}$ are denoted P_S and R_S respectively. Evaluating equations (7) and (9) at these equilibrium values allows us to determine equilibrium revenue and profit functions for a final goods producer in each economy.

3.2 Exit, Export, and Import Decisions

3.2.1 Exit Decision

We focus on stationary equilibria in which aggregate variables remain constant over time. Each firm's value function in economy $S \in \{A, T, X, M\}$ is given by the maximum of the exiting value, which is assumed to be zero, and the present value of total sum of expected profits as:

$$V_S(\varphi) = max\left\{0, \sum_{t=0}^{\infty}(1-\xi)^t E_{\epsilon_t}\left(\max_{d_t \in \{0,1\}^2} \pi_S(\varphi, d_t, \epsilon_t)\right)\right\} = max\left\{0, E_{\epsilon}\left(\max_{d \in \{0,1\}^2} \frac{\pi_S(\varphi, d, \epsilon)}{\xi}\right)\right\},$$

where the second equality follows because ϵ is independently distributed over time. Now since profits are strictly increasing in φ, there exists a cutoff productivity, φ_S^* such that a firm will exit if $\varphi < \varphi_S^*$ where φ_S^* is characterized by $E_\epsilon \left(max_{d \in \{0,1\}^2} \frac{\pi_S(\varphi_S^*, d, \epsilon)}{\xi} \right) = 0$. Using methods similar to those employed by Melitz (2003) we can show that the cutoff productivities for each economy exist, are unique, and satisfy $r_S(\varphi_S^*, 0, 0) = \sigma f$. This also implies that the revenue of a firm can be written as

$$r_S(\varphi, d) = b_x^{d^x} b_m^{d^m} \left(\frac{\varphi}{\varphi_S^*} \right)^{\sigma - 1} \sigma f. \tag{10}$$

3.2.2 Export and Import Decisions

For the full trading economy, we now consider the export and import decisions for firms which choose not to exit. Define the following function of inherent productivity:

$$\Phi(\varphi) \equiv \left(\frac{\varphi}{\varphi_T^*} \right)^{\sigma - 1} \left(\frac{f}{N} \right).$$

For convenience, we can reference firms of different productivity levels by Φ where the dependence on φ is understood. We refer to this variable as relative productivity. Using equations (9) and (10), we can write profits in terms of Φ:

$$\hat{\pi}(\Phi, d, \epsilon) = b_x^{d^x} b_m^{d^m} N \sigma \Phi - F(d, \epsilon).$$

To obtain the export and import decision rules as a function of a firm's productivity and fixed import cost, we define the following variables. Let $\Phi_x(d^m, \epsilon)$ be implicitly defined by $\hat{\pi}(\Phi_x(d^m, \epsilon), 1, d^m, \epsilon) = \hat{\pi}(\Phi_x(d^m, \epsilon), 0, d^m, \epsilon)$ or

$$\Phi_x(d^m, \epsilon) = \frac{\zeta^{d^m} f_x + d^m(\zeta^{d^m} - 1)(f_m + \epsilon)}{b_m^{d^m}(b_x - 1)}. \tag{11}$$

So a firm with import status d^m, fixed import cost shock ϵ, and relative productivity $\Phi_x(d^m, \epsilon)$ will be indifferent between exporting and not exporting. Similarly, we have

$$\Phi_m(d^x, \epsilon) = \frac{\zeta^{d^x}(f_m + \epsilon) + d^x(\zeta^{d^x} - 1) f_x}{b_x^{d^x}(b_m - 1)} \tag{12}$$

where a firm with d^x, ϵ, and relative productivity $\Phi_m(d^x, \epsilon)$ will be indifferent between importing and not importing. Finally, let

$$\Phi_{xm}(\epsilon) = \frac{\zeta(f_x + f_m + \epsilon)}{(b_x b_m - 1)}. \tag{13}$$

So a firm with fixed import cost shock ϵ, and relative productivity $\Phi_{xm}(\epsilon)$ will be indifferent between participating in both exporting and importing markets and not participating in either market.

We can graph each of the variables defined in equations (11)–(13) as a function of fixed import costs, $f_m + \epsilon$, to determine firms' export and import choices. Figure 1 graphs these cutoff functions for the case with no complementarities in fixed costs, i.e. $\zeta = 1$. Note that $\Phi(\varphi_T^*) = \frac{f}{N}$ so active firms are those with $\Phi \geq \frac{f}{N}$. As the figure demonstrates, the space is partitioned into four areas (with boundaries given by the dark solid lines) according to firms' export and import choices. Firms with relatively low productivity and low fixed cost of importing will choose to import but not export. Firms with relatively low productivity and higher fixed cost of importing will choose to neither import nor export. Firms with relatively high productivity and high fixed cost of importing will choose to export but not import. Finally, firms with relatively high productivity will choose to both import and export.

We can also demonstrate the effect of complementarities in the fixed costs of importing and exporting. Recall that a decrease in ζ represents an increase in complementarities. Examination of equations (11)-(13) shows that a decrease in ζ will shift down and decrease the slopes of $\Phi_m(1, \cdot)$, $\Phi_x(1, \cdot)$, and $\Phi_{xm}(\cdot)$. As can be seen from Figure 2, each of these changes would serve to increase the measure of firms choosing to both export and import and decrease the measure of firms in each of the other three areas. The shaded area in the figure indicates the firms which became active in *both* exporting and importing who were either active in only one market or in neither market in the absence of complementarities of fixed costs. This is intuitive as an increase in the complementarities should increase the fraction of firms which choose to engage in both activities.

3.3 Autarkic and Trading Equilibria

All variables in the stationary equilibrium for each economy can be determined once we determine the cutoff variable for operation, φ_S^*. We now seek to characterize the equations which determine these cutoff variables.

Let $\nu_S(\varphi_S^*, d)$ denote the equilibrium fraction of firms that have export/import status equal to d in economy $S \in \{A, T, X, M\}$. Let average profits within each group of firms according to export/import status be denoted $\tilde{\pi}_S(\varphi_S^*, d)$. Then, average overall profit, $\bar{\pi}_S$, can be expressed as

$$\bar{\pi}_S = \sum_{d \in \{0,1\}^2} \nu_S(\varphi_S^*, d) \tilde{\pi}_S(\varphi_S^*, d). \tag{14}$$

This equation, corresponding to the "zero cutoff profit condition" in Melitz (2003), provides an equilibrium relationship between average overall profit, $\bar{\pi}_S$, and the cutoff productivity, φ_S^*.

The second equilibrium equation is given by the free-entry condition which guarantees that the ex-ante value of an entrant must be equal zero:

$$(1 - G(\varphi_S^*)) \left(\frac{\bar{\pi}_S}{\xi} \right) - f_e = 0. \tag{15}$$

Solving these two equations (14)-(15) for the two unknowns $\bar{\pi}_S$ and φ_S^*, allows us to uniquely determine the equilibrium cutoff productivity in each economy.

3.4 Effects of Trade

We first examine the effects of trade on the decision to operate. Using methods similar to those employed by Melitz (2003), we can demonstrate that either type of trade increases the cutoff productivity for operation, i.e. $\varphi_A^* < \varphi_X^* < \varphi_T^*$ and $\varphi_A^* < \varphi_M^* < \varphi_T^*$. Thus opening trade in either final goods or intermediates or both causes firms with lower inherent productivity to exit. In the economy with no importing, this result is identical to that identified by Melitz (2003) where the exportation of final goods induces a reallocation of labour from less productive firms to more productive firms. We find that allowing firms to import intermediates leads to even more exit of less productive firms.

We also find that when the economy moves from autarky to full trade, market shares are shifted away from firms which do not engage in trade (low productivity firms) to firms which both export and import (high productivity firms). This reallocation of market shares from less productive to more productive firms when an economy opens for full trade increases a productivity average measured using firms revenue shares as weights. This effect was identified by Melitz (2003) in the economy with no importing of intermediates. If the economy also opens to intermediates imports this effect is strengthened because of additional resource reallocation *and* a direct increase in productivity from the use of additional intermediates.

An additional interesting result is that if the returns to importing intermediates, b_m, are large enough, then a firm which chooses to export but not import in the open economy will also lose market share. This is because a firm which chooses to only export is at a disadvantage relative to its domestic and foreign competitors who are importing intermediates and such a firm may lose market share when the economy opens to full trade. For similar reasons, when the returns to exporting, b_x, are large enough, then a firm which chooses to import but not export in the open economy will also lose market share.

It is also easy to show that the mass of operating firms must fall when an economy opens to either type of trade. This is similar to the findings of Melitz (2003) and is an example of a *selection effect* as discussed in the trade literature with increasing returns and free entry (see, for example, Krugman, 1979). Our environment identifies an additional mechanism arising from the presence of imported intermediates that strengthens this selection effect.

We are also interested in the normative effects of trade and, as in Melitz (2003) use the equilibrium aggregate price index in each equilibrium to obtain a welfare measure: $W_S = \frac{1}{P_S}$. In moving from autarky to an economy with trade in final goods, consumer welfare is impacted by two effects. The number of varieties available to the consumer changes and aggregate productivity increases. In the trading economy with no trade in final goods but trade in intermediates, consumer welfare is only affected by the latter effect and trade in intermediates impacts positively on welfare. In the economies with trade in final goods, the number of varieties available to the consumer in the open economies may be higher or lower than the number of varieties available to the consumer in autarky. If the number of varieties available to the consumer is higher in trade, then welfare is also enhanced by this effect but if it falls then welfare is negatively impacted. However, as in Melitz (2003), we can show the increase in welfare from the productivity gain dominates and welfare is higher in any of the trading economies than in autarky and full trade generates higher welfare than partial trade, i.e. $W_A < W_X < W_T$ and $W_A < W_M < W_T$.

3.5 Restrictions on Trade in Intermediate Goods

We now briefly examine the effects of a restriction on the importation of intermediates on aggregate productivity and export activity. We already argued above that prohibiting the importation of intermediates will have a negative effect on average productivity and welfare. We may also interpret an increase in the transportation costs associated with shipping intermediates, τ_m, as an increase in barriers to trade in those goods and can show that this would also decrease average productivity and welfare.

Furthermore, allowing intermediate imports will allow a larger fraction of firms to enter the export market. This is because the use of imported intermediates increases the productivity of firms through the increasing returns to variety in production. Thus, a restriction on imports decreases export activity and hence, import protection acts as export destruction. Figure 3 demonstrates this effect when imported intermediates are prohibited for the case where there are no fixed cost complementarities. The shaded area in that figure shows the fraction of exporting firms which stop exporting when imports are prohibited, and, hence the export destruction due to import protection. Of course, in the presence of fixed cost complementarities, export destruction due to restrictions on trade in intermediate goods is even more pronounced.

4 Structural Estimation

4.1 The Environment

In this section, we develop an empirical model based on the theoretical model presented in the previous section. The empirical model retains the basic structure of the theoretical model but extends the theoretical model in the following three dimensions.

First, we incorporate not only per-period fixed costs but also one-time sunk costs associated with exporting and importing. This is primarily motivated by empirical evidence on the existence of sunk costs of exporting and importing.[12] Furthermore, incorporating sunk costs of exporting and importing substantially improves the model's ability to replicate the observed transition patterns for export and import status.

Second, as reported in Section 2, heterogeneity in export and import intensities is one of the key features of plant-level data. Our theoretical model, however, implies no differences in export and import intensities across firms. To explain why different plants choose different export/import intensities in the context of the model, we allow for heterogeneity in transportation costs of exporting and importing.[13] Incorporating heterogeneous transportation costs provides a plausible self-selection mechanism regarding export/import decisions: plants with low transportation costs self-select into exporting and importing. Our assumptions on heterogeneous transportation costs are similar to those on heterogeneous productivity. Namely, we assume that plant-specific transportation costs, τ_x and τ_m, are drawn upon entry and are constant after the initial draw. Thus, a plant's type is characterized by a vector $\eta \equiv (\varphi, \tau_x, \tau_m)'$ in the empirical model.

Third, we introduce stochastic fixed costs of exporting and importing and cost shocks associated with exiting. These cost shocks represent unobserved state variables that are not explicitly

[12] See Roberts and Tybout (1998), Bernard and Jensen (2002), and Das, Roberts, and Tybout (2007) for evidence of sunks cost of exporting and Kasahara and Rodrigue (2005) for sunk costs of importing.

[13] Heterogeneity in export and import intensities may also be because plants differ in the number of trading partners as Eaton, Kortum, and Kramarz (2004a) find in French data. Unfortunately, due to data limitations, we are unable to determine with which countries a plant is trading.

incorporated into the model's specification in terms of observables.[14] With these shocks, the empirical model does not have closed-form characterizations of firms' decisions, complicating the estimation.

Extending the framework developed by Rust (1987), we consider a *nested logit* dynamic programming model in which the set of alternatives are partitioned into subsets, or nests, as follows.[15] First, a firm draws a cost shock associated with the exiting decision $\chi \in \{0, 1\}$, denoted by $\epsilon_t^{\chi} \equiv (\epsilon_t^{\chi}(0), \epsilon_t^{\chi}(1))$. Here, $\chi = 0$ implies that a firm exits while $\chi = 1$ implies that a firm continues to operate. We assume that ϵ_t^{χ} is independent of alternatives and is randomly drawn from the extreme-value distribution with scale parameter ϱ^{χ}.

If a firm decides to stay, it then draws stochastic fixed costs associated with its export/import decision. These are similar to the random fixed cost of importing in the theoretical model but here we allow for a stochastic cost for every status. We partition the set of alternative export/import choices into two subsets: $D_0 \equiv \{(0, 0)\}$ and $D_1 \equiv \{(1, 0), (0, 1), (1, 1)\}$. The cost shocks associated with the decision to trade or not trade, denoted by $\epsilon_t^D(D)$ for $D \in \{D_0, D_1\}$, are randomly drawn from the extreme-value distribution with scale parameter ϱ^D. Let $\epsilon_t^D \equiv (\epsilon_t^D(D_0), \epsilon_t^D(D_1))'$. If a firm decides to engage in trade by choosing $D = D_1$, it then draws additional choice-dependent cost shocks associated with its export and import decisions. These are denoted $\epsilon_t^d(d)$ for $d \in D_1$ and are drawn from the extreme-value distribution with scale parameter ϱ^d. Let $\epsilon_t^d \equiv (\epsilon_t^d(1, 0), \epsilon_t^d(0, 1), \epsilon_t^d(1, 1))'$.

A firm's net profit depends on the value of the firm-specific vector $\eta = (\varphi, \tau_x, \tau_m)'$ as well as on its past and current export/import status (d_{t-1}, d_t):

$$\pi(\eta, d_{t-1}, d_t) = \frac{r(\eta, d_t)}{\sigma} - F(d_t, d_{t-1}),$$

where $r(\eta, d_t)/\sigma$ is gross profit while $F(d_t, d_{t-1})$ is the sum of the per-period fixed costs and the one-time sunk costs of exporting and importing.

The Bellman's equations which characterize the optimization problem for an incumbent firm

[14] Adding these shocks is also necessary to explain certain observations in the data. For example, in the absence of exiting cost shocks, the theoretical model predicts that all firms with productivity below the cutoff level will exit. This, however, is inconsistent with the existence of many small firms in our data.

[15] A nested logit model allows for richer substitution patterns across alternatives than does a standard multinomial logit model. See, for example, Ben-Akiva and Lerman (1985).

of type η and past export/import status d_{t-1} are written as follows:

$$
\begin{aligned}
V(\eta, d_{t-1}) &= \int \max\{\epsilon^{\chi}(0), W(\eta, d_{t-1}) + \epsilon^{\chi}(1)\} dH^{\chi}(\epsilon^{\chi}), && (16)\\
W(\eta, d_{t-1}) &= \int \max\{J(\eta, d_{t-1}, D_0) + \epsilon^{D}(D_0), J(\eta, d_{t-1}, D_1) + \epsilon^{D}(D_1)\} dH^{D}(\epsilon^{D}), && (17)\\
J(\eta, d_{t-1}, D) &= \begin{cases} \pi(\eta, d_{t-1}, (0,0)) + \beta(1-\xi)V(\eta, (0,0)), & \text{for } D = D_0, \\ \int \left(\max_{d' \in D_1} \pi(\eta, d_{t-1}, d') + \beta(1-\xi)V(\eta, d') + \epsilon^{d}(d')\right) dH^{d}(\epsilon^{d}) & \text{for } D = D_1, \end{cases} && (18)
\end{aligned}
$$

where H^{χ}, H^{D}, and H^{d} represent the cumulative distribution functions of ϵ^{χ}, ϵ^{D}, and ϵ^{d}, respectively, and $\beta \in (0,1)$ is the discount factor.

To clarify these modifications, we describe the timing of the shocks and the decisions of an incumbent. At the beginning of every period, a firm with value $V(\eta, d_{t-1})$ first draws the idiosyncratic cost shocks associated with exiting decisions, ϵ^{χ}, and decides whether to exit or continue to operate. If the firm decides to exit, it receives the terminal value of $\epsilon^{\chi}(0)$. If the firm decides to operate with the continuation value of $W(\eta, d_{t-1})$, it then draws the cost shocks associated with trading decisions, ϵ^{D}, and decides whether it will engage in trading activities. This trading decision is described in the right hand side of equation (17), where $J(\eta, d_{t-1}, D)$ denotes the continuation value under a trading choice $D \in \{D_0, D_1\}$. If the firm decides to trade, it draws the cost shocks associated with exporting and importing, ϵ^{d}, and makes export and import decisions. The firm then faces a possibility of a large negative shock that causes it to exit with probability ξ. If the firm remains in the market, production and trading occurs.

With the solution to the functional equations (16)-(18), and using the properties of the extreme-value distributed random variables (see, for example, Ben-Akiva and Lerman, 1985), the conditional choice probabilities of exiting and export/import decisions are derived as follows. First, taking into account the exogenous exiting probability of ξ, the probabilities of staying ($\chi_t = 1$) and exiting ($\chi_t = 0$) are given by:

$$
P(\chi_t = 1 | \eta, d_{t-1}) = (1-\xi) \frac{\exp(W(\eta, d_{t-1})/\varrho^{\chi})}{\exp(0) + \exp(W(\eta, d_{t-1})/\varrho^{\chi})}, \tag{19}
$$

and $P(\chi_t = 0 | \eta, d_{t-1}) = 1 - P(\chi_t = 1 | \eta, d_{t-1})$. *Conditional on* $\chi = 1$ (i.e., continuing to operate), the choice probabilities of $d \in \{0,1\}^2$ are given by:

$$
P(d_t | \eta, d_{t-1}, \chi = 1) = \begin{cases} P(D_0 | \eta, d_{t-1}, \chi = 1) & \text{for } d_t \in D_0, \\ P(D_1 | \eta, d_{t-1}, \chi = 1) P(d_t | \eta, d_{t-1}, \chi = 1, D = D_1), & \text{for } d_t \in D_1, \end{cases} \tag{20}
$$

where

$$
\begin{aligned}
P(D|\eta, d_{t-1}, \chi = 1) &= \frac{\exp(J(\eta, d_{t-1}, D)/\varrho^D)}{\sum_{D' \in \{D_0, D_1\}} \exp(J(\eta, d_{t-1}, D')/\varrho^D)}, \\
P(d_t|\eta, d_{t-1}, \chi = 1, D = D_1) &= \frac{\exp([\pi(\eta, d_{t-1}, d_t) + \beta(1-\xi)V(\eta, d_t)]/\varrho^d)}{\sum_{d' \in D_1} \exp([\pi(\eta, d_{t-1}, d') + \beta(1-\xi)V(\eta, d')]/\varrho^d)}.
\end{aligned}
$$

These choice probabilities follow the familiar nested logit formula (c.f., McFadden, 1978).[16]

We assume that the logarithm of plant-specific productivity, $\ln \varphi$, is drawn upon entry from $N(0, \sigma_\varphi^2)$. Regarding, the plant-specific transportation costs, we define the following functions for notational convenience:

$$
z_x \equiv \ln(N\tau_x^{1-\sigma}), \qquad z_m \equiv \ln(N\tau_m^{1-\gamma}). \tag{21}
$$

We assume that, conditional on $\ln \varphi$, the random variables z_x and z_m are independent of each other and are drawn at the time of entry from normal distributions with the means μ_x and μ_m and variances σ_x^2 and σ_m^2, respectively. We denote the density function of $\eta = (\varphi, \tau_x, \tau_m)$ at the initial draw by $g_\eta(\eta)$.

We focus on a stationary equilibrium in which the joint distribution of (η, d) is constant over time. In such an equilibrium, free entry implies that the expected value of an entering firm must equal the fixed entry cost f_e:

$$
\int V(\eta, d_{t-1} = (0,0)) g_\eta(\eta) d\eta = f_e, \tag{22}
$$

where $V(.)$ is given by equation (16).

We denote the stationary distribution of (η, d) among incumbents by $\mu^*(\eta, d)$. Stationarity requires that the number of exiting firms equals the number of *successful* new entrants so that

$$
\underbrace{M \int \sum_{d' \in D} P(\chi = 0|\eta', d') \mu^*(\eta', d') d\eta'}_{\text{exits}} = \underbrace{M_e \int P(\chi = 1|\eta, d_{t-1} = (0,0)) g_\eta(\eta') d\eta'}_{\text{entrants}}, \tag{23}
$$

[16] There are important differences, however, between static nested logit models and the dynamic model we consider here. First, in static models, the property of *independence from irrelevant alternatives* (IIA) holds within each nest but the IIA property no longer holds even within a nest in dynamic models because the continuation value depends on the attributes of other alternatives outside of the nest (c.f., Rust, 1994). Second, while a static model typically has a closed-form specification in parameters (e.g., linear-in-parameters), the conditional choice probabilities (19)-(20) do not have a closed-form expression in parameters; instead, their evaluations require the solution to the functional equations (16)-(18). It is computationally intensive, therefore, to evaluate the conditional choice probabilities in our dynamic model although the extreme-value specification substantially simplifies the computation by avoiding the need for multi-dimensional numerical integrations in (16)-(18).

where M is a total mass of incumbents and M_e is a total mass of firms that attempt to enter into the market.

Now the evolution of the probability measure among incumbents has to take account of both the transition of states among survivors and entry/exit processes. The probability that a firm with state (η, d_{t-1}) continues in operation at t with state d_t is given by:

$$P(d_t, \chi_t = 1|\eta, d_{t-1}) = P(d_t|\eta, d_{t-1}, \chi_t = 1)P(\chi_t = 1|\eta, d_{t-1}).$$

In the stationarity equilibrium, the measure of firms with state (η, d) does not change over time:

$$M\mu^*(\eta, d) = M\sum_{d'\in D} P(d, \chi = 1|\eta, d')\mu^*(\eta, d') + M_e P(d, \chi = 1|\eta, d_{t-1} = (0,0))g_\eta(\eta) \quad \text{for all } (\eta, d). \tag{24}$$

The first term on the right hand side is the measure of survivors from the last period with state (η, d) while the second term represents the measure of new entrants with state (η, d). Note that new entrants have no past export/import experience so $d_{t-1} = (0,0)$ for those plants. The stationary distribution is numerically computed as the fixed point of (24) under the restriction of (23).

4.2 The Likelihood Function

Total revenue, export intensity, and import intensity are assumed to be measured with error. We also allow for labor augmented technological change at an annual rate of α_t. Modifying the revenue functions and the intermediate demand functions to include measurement error and a time trend, we use equations (3), (6), and (7) to specify the logarithm of *observed* total revenue, export intensity, and import intensity as:

$$\begin{aligned} \ln r_{it} &= \alpha_0 + \alpha_t t + \ln[1+\exp(z_{x,i})]d^x_{it} + \alpha_m \ln[1+\exp(z_{m,i})]d^m_{it} + \ln\varphi_i + \omega_{1,it}, && (25)\\ \ln Nr^f_{it}/r_{it} &= \ln[\exp(z_{x,i})/(1+\exp(z_{x,i}))] + \omega_{2,it}, \quad \text{if } d^x_{it} = 1, && (26)\\ \ln X^m_{it}/X_{it} &= \alpha_m \ln[\exp(z_{m,i})/(1+\exp(z_{m,i})] + \omega_{3,it}, \quad \text{if } d^m_{it} = 1. && (27) \end{aligned}$$

Here Nr^f_{it}/r_{it} is the observed ratio of export revenue to total revenue; X^m_{it}/X_{it} is the observed ratio of imported intermediate costs to total intermediate costs; and $\omega_{1,it}$, $\omega_{2,it}$, and $\omega_{3,it}$ are measurement errors in total revenue, export intensity, and import intensity, respectively. We assume that, conditional on $(\eta_i, d^x_{it}, d^m_{it})$, $\omega_{it} \equiv (\omega_{1,it}, \omega_{2,it}, \omega_{3,it})'$ is randomly drawn from $N(0, \Sigma_\omega)$ and we denote its probability density function by $g_\omega(\cdot)$. We reparametrize Σ_ω using the unique lower triangular Cholesky decomposition as $\Sigma_\omega = \Lambda_\omega \Lambda_\omega'$ and denote the (j,k)-th component of Λ_ω by $\lambda_{j,k}$. In the appendix, we derive the conditional density function for *observed* components of ω_{it} conditional on d_{it} and denote it by $g_\omega(\omega_{it}|d_{it})$.

Given these specifications for revenue, (detrended) firm's net profit may be expressed in terms of reduced-form parameters as:[17]

$$\pi(\eta_i, d_{i,t-1}, d_{it}) = \frac{r(\eta_i, d_{it})}{\sigma} - F(d_{i,t-1}, d_{it}), \tag{28}$$

where

$$r(\eta_i, d_{it}) \quad = \quad \exp(\alpha_0 + \ln[1+\exp(z_{x,i})]d_{it}^x + \alpha_m \ln[1+\exp(z_{m,i})]d_{it}^m + \ln\varphi_i) \tag{29}$$

and

$$F(d_{i,t-1}, d_{it}) = \begin{cases} f & \text{for } (d_{it}^x, d_{it}^m) = (0,0), \\ f + f_x + c_x(1 - d_{i,t-1}^x) & \text{for } (d_{it}^x, d_{it}^m) = (1,0), \\ f + f_m + c_m(1 - d_{i,t-1}^m) & \text{for } (d_{it}^x, d_{it}^m) = (0,1), \\ f + \zeta[f_x + f_m + c_x(1 - d_{i,t-1}^x) + c_m(1 - d_{i,t-1}^m)] & \text{for } (d_{it}^x, d_{it}^m) = (1,1). \end{cases}$$

Here f is the per-period cost of operating in the market while f_x and f_m are per-period fixed cost of exporting and importing, respectively. The parameter c_x represents the sunk cost of exporting for a non-exporting plant to start exporting while the parameter c_m represents the sunk cost of importing. The parameter ζ captures the degree of fixed cost complementarity between exporting and importing.

Denote the parameter vector to be estimated by

$$\theta = (\alpha_0, \alpha_t, f, f_x, f_m, c_x, c_m, \alpha_m, \xi, \varrho^\chi, \varrho^D, \varrho^d, \sigma_\varphi, \mu_x, \mu_m, \sigma_x, \sigma_m, \lambda_{11}, \lambda_{21}, \lambda_{22}, \lambda_{31}, \lambda_{32}, \lambda_{33})'.$$

We estimate this vector by the method of maximum likelihood.[18]

Let $T_{i,0}$ be the first year in which firm i appears in the data. Conditioning on η_i, the

[17] We consider a "detrended" version of firm's problem by using the trend-adjusted discount factor $\beta\exp(\alpha_t)$ in place of the discount factor β in solving the Bellman's equation.

[18] The discount factor β is not estimated but is set to 0.95. It is difficult to identify the discount factor in dynamic discrete choice models (cf., Rust, 1987).

likelihood contribution from the observation of plant i for $t > T_{i,0}$ is computed as:

$$L_{it}(\theta|\eta_i, d_{i,t-1}) = \begin{cases} P_\theta(\chi_{it} = 0|\eta_i, d_{i,t-1}) & \text{for } \chi_{it} = 0, \\ \underbrace{P_\theta(\chi_{it} = 1|\eta_i, d_{i,t-1})}_{\text{Staying}} \underbrace{P_\theta(d_{it}|\eta_i, d_{i,t-1}, \chi_{it} = 1)}_{\text{Export/Import}} \underbrace{g_\omega(\tilde{\omega}_{it}(\eta_i)|d_{it})}_{\text{Revenue/Intensity}} & \text{for } \chi_{it} = 1, \end{cases}$$

where $g_\omega(\tilde{\omega}_{it}(\eta_i)|d_{it})$ is the likelihood contribution from the observations of revenues, export intensity, and import intensity (see the appendix). Note that in estimating the revenue function given by (25), the endogeneity of export/import decisions as well as the sample selection due to endogenous exiting decisions are dealt with by simultaneously considering the likelihood contribution from export/import/exiting decisions.

For the initial period of $t = T_{i,0}$, we observe a plant that decided to stay in the market so that the likelihood is conditioned on $\chi_{it} = 1$,

$$L_{it}(\theta|\eta_i, d_{i,t-1}) = P_\theta(d_{it}|\eta_i, d_{i,t-1}, \chi_{it} = 1) g_\omega(\tilde{\omega}_{it}(\eta_i)|d_{it}).$$

The likelihood contribution from plant i conditioned on $(\eta_i, d_{i,T_{i,0}})$ is

$$L_i(\theta|\eta_i, d_{i,T_{i,0}}) = \prod_{t=T_{i,0}+1}^{T_{i,1}} L_{it}(\theta|\eta_i, d_{i,t-1}),$$

where $T_{i,0}$ is the initial year in which firm i is observed while $T_{i,1}$ is the last year in which firm i appears in the data.

Evaluation of the likelihood function requires computing the likelihood contribution from initial observation $d_{i,T_{i,0}}$ while taking into account of its correlation with unobserved plant heterogeneity (cf., Heckman (1981)). The joint distribution of $(\eta_i, d_{i,T_{i,0}})$, crucially depends on whether a plant is observed in the initial sample period or not. If plant i is observed in the initial sample period, we assume that $(\eta_i, d_{i,T_{i,0}})$ is drawn from the stationary distribution $\mu^*(\eta, d)$. On the other hand, if plant i enters into the sample after the initial sample period, we use the distribution of initial draws upon successful entry given by

$$g_e(\eta) = \frac{P(\chi = 1|\eta, d_{t-1} = (0,0))}{\int P(\chi = 1|\eta', d_{t-1} = (0,0)) g_\eta(\eta') d\eta'} g_\eta(\eta)$$

together with the choice probability function (20) to evaluate the likelihood. Then, the likelihood contribution from plant i is obtained by integrating out unobserved plant-specific vector η as

$$L_i(\theta) = \begin{cases} \int L_i(\theta|\eta', d_{i,T_{i,0}})\mu^*(\eta', d_{i,T_{i,0}})d\eta' & \text{for } T_{i,0} = 1990, \\ \int L_i(\theta|\eta', d_{i,T_{i,0}})P_\theta(d_{i,T_{i,0}}|\eta', d_{i,T_{i,0}-1} = (0,0))g_e(\eta')d\eta' & \text{for } T_{i,0} > 1990. \end{cases}$$

The parameter vector θ can be estimated by maximizing the logarithm of the likelihood function

$$\mathcal{L}(\theta) = \sum_{i=1}^{N} \ln L_i(\theta). \quad (30)$$

Evaluation of the log-likelihood involves solving the dynamic programming problem that approximates the Bellman equations (16)-(18) by discretization of state space. For each candidate parameter vector θ, we solve the discretized version of (16)-(18) and then obtain the choice probabilities, (19) and (20), as well as the stationary distribution from the associated policy function. Once the choice probabilities and the stationary distribution are obtained for a particular candidate parameter vector θ, we may then evaluate the log-likelihood function (30). Repeating this process, we can maximize (30) over the parameter space of θ to determine the estimate.

4.3 Reduced-form vs. Structural Parameters

It is important to note that equations (25)-(27) are *reduced-form* specifications. In particular, we have the following relationships between reduced-form parameters and structural parameters:[19]

$$\alpha_0 = \ln\left[(\Gamma(\sigma-1)/\sigma)^{\sigma-1} RP^{\sigma-1}\right], \quad (31)$$

$$\alpha_m = \frac{(\sigma-1)(1-\alpha)}{\gamma-1}. \quad (32)$$

Since α_0 and α_m are not structural parameters, they could be affected by policy changes. In particular, any policy change that affects the aggregate price P will lead to a change in α_0. Identifying such a relationship is especially important in conducting counterfactual experiments below which quantify the impact of a change in trade policy on welfare and aggregate productivity. Counterfactual policy experiments in this paper explicitly take into account equilibrium price responses using our knowledge of the relationship between the reduced-form parameter α_0 and the aggregate price P.

[19] Also, with abuse of notation, we replace $(\sigma-1)\ln\varphi$ by $\ln\varphi$ since $(\sigma-1)$ cannot be separately identified from the variance of $\ln\varphi$.

4.4 Identification

For simplicity, suppose that the time-dimension is long enough to identify the values of plant-specific productivity φ as well as plant-specific transportation costs, τ_x and τ_m, for each plant from plant-level observations using (25)-(27). In practice, the time-dimension is short but, under the distributional assumption on $\eta = (\varphi, \tau_x, \tau_m)$, we may identify each plant's likelihood of having a particular value of η.

Once plant-specific transportation costs are identified, it is straightforward to identify the parameters in the revenue function (25). For instance, we may consider the moment restriction $E[\omega_{1,it} - \omega_{1,i(t-1)} | d_i^x, d_i^m] = 0$ obtained from taking first differences in (25) using the within-plant variations in export and import status as well as the cross-plant variations in transportation costs. Note that we observe a substantial number of plants who switch their export and import status as discussed in the data section.

Variations in the data may be associated with the identification of different cost parameters as follows. Sunk costs of exporting is identified by differences in exporting frequencies across plants that have similar plant-characteristics (captured by plant-specific productivity and transportation costs) but differ in their past exporting status. Per-period fixed cost of exporting is identified from the frequency that exporters become non-exporters. Similarly, sunk cost and per-period fixed cost of importing may be identified from the corresponding frequencies of importing. The fixed cost complementarity parameter is identified by comparing the frequencies of exporting among non-importers with the frequencies of exporting among importers across plants with similar future revenue prospects. Finally, the fixed cost of operating is identified from the frequencies of exiting across plants with similar plant-characteristics.[20]

We may identify the parameters for the distribution of plant-specific productivities and export/import intensities at the time of entry using the variation in productivities and export/import intensities among new entrants. As we discuss in Section 4.6, there are a substantial number of new entrants every year.

In discrete choice models, the scale of the profit function cannot be identified because multiplying the profit function of each alternative by a positive constant does not change the optimal choice. For identification, we normalize the profit function given by (29).[21] This implies that

[20]Furthermore, the scale parameters for exiting cost shocks are identified (separately from the fixed cost of operating) by differences in exiting frequencies across plants with different plant-characteristics. Similarly, the scale parameters for exporting and importing cost shocks are identified by differences in exporting and importing frequencies across plants with different plant-characteristics.

[21]Specifically, our normalization is such that, multiplying the profit function by σ, we estimate $\sigma\varrho^{\chi}$, $\sigma\varrho^{D}$, $\sigma\varrho^{d}$,

we cannot identify the elasticity of substitution, σ, in the discrete choice model. Furthermore, as shown in (32), we cannot identify α and γ because they are incorporated in the reduced-form parameter α_m. This is problematic because the knowledge of σ and γ is often required to interpret the estimates as well as the results from counterfactual experiments. Hence, we use the inverse of the average markup rate across plants within 4-digit ISIC industries as our estimate of the elasticity of substitution σ. To obtain an estimate of γ, we first compute the average material shares in variable costs as our estimate of α and then derive an estimate of γ using equation (32).

4.5 The Data

Our data set is based on the Chilean manufacturing census for 1990-1996 which covers all plants with at least 10 employees.[22] The original data set is available from 1979 to 1996 but the value of export sales is reported only after 1990 and, thus, we exclude the period before 1990. We estimate the structural parameters separately for three manufacturing industries at the 4-digit level (ISIC code): Wearing Apparel (3220), Plastic Products (3560), and Structural Metal (3813-3815). We chose these three industries because they are relatively large in sample size and include many plants that export and/or import. Furthermore, a substantial number of plants change their export/import status in these industries over this time period. For instance, among 535 plants in Wearing Apparel industry, 141 plants (26.4%) switch their export/import status over the period at least once, and among those, 81 plants (15.1%) change their export/import status more than once.[23] As discussed above, this within-plant variation in export/import status provides an important source of identification of export/import cost parameters.

We focus on the following seven observable variables: χ_{it}, r_{it}, Nr^f_{it}, X_{it}, X^m_{it}, d^x_{it}, and d^m_{it}, where i represents plant's identification and t indicates the year. The entry/exiting decisions, χ_{it}, can be identified in the data by looking at the number of workers across years. We use total sales for r_{it}, where the 4-digit industry level output price deflater is used to convert nominal quantities into real terms. Export intensity Nr^f_{it}/r_{it} is measured by the ratio of export sales to total sales.

σf, σf_x, and σf_m rather than ϱ^χ, ϱ^D, ϱ^d, f, f_x, and f_x.

[22] A detailed description of the data as well as Chilean industry trade orientation up to 1986 is found in Liu (1993), Tybout (1996), and Pavcnik (2002). A unit of observation in our sample is a plant not a firm. This is due to limitations of our data set. Unfortunately, we are unable to capture the extent to which multi-plant firms make joint decisions on exporting and importing across different plants they own. Neither are we able to examine whether or not a plant belongs to multinational firm although exporting and importing by multinational firms are important topics (e.g., Helpman et al., 2004; Yi, 2003). Pavcnik (2002) reports that over 90 percent of manufacturing firms had only one plant for 1979-1986.

[23] Among 369 plants in the Plastic Products industry, 24% change their export/import status more than once over the sample period. Of the 326 plants in Structural Metals, 13% switch their status more than once.

Table 5: Descriptive Statistics in 1990

	Total Sales[a]	Intermediate Inputs[a]	Labour	Export Sales[a,b]	Imported Inputs[a,b]	Export Intensity[b]	Import Intensity[b]	Markup Rate[c]
Wearing Apparel	1.33	0.83	73.1	0.96	0.52	0.21	0.28	0.23
	(3.62)	(2.47)	(155.8)	(1.71)	(0.90)	(0.32)	(0.26)	(0.18)
Plastic Products	2.76	1.71	73.6	0.19	1.29	0.05	0.35	0.26
	(5.50)	(3.86)	(81.3)	(0.36)	(2.18)	(0.10)	(0.23)	(0.22)
Structural Metals	3.60	2.18	90.3	0.79	2.42	0.12	0.38	0.24
	(7.72)	(4.67)	(118.1)	(1.11)	(4.25)	(0.17)	(0.28)	(0.19)

Notes: Reported numbers are sample means (standard deviations in parentheses). (*a*) in units of millions of US dollars in 1990. (*b*) computed using the sample of exporting (importing) plants for export (import) intensity. (*c*) is computed as (revenue - variable cost)/revenue using the data for 1990-1996.

Our measurement of intermediate inputs, X_{it}, include materials, fuels, and electricity while we use the reported value of imported materials for X_{it}^m. Accordingly, import intensity X_{it}^m/X_{it} is measured by the ratio of imported materials to total intermediate costs. The export/import status, (d_{it}^x, d_{it}^m), is identified from the data by checking if the value of export sales and/or the value of imported materials are zero or positive.

Descriptive statistics from the sample data in 1990 are provided in Table 5. Examining the standard deviations for total sales and various inputs, we note that the production scale varies substantially across plants. Export and import intensities also differ across trading plants. The average markup rate—computed as revenue minus variable cost divided by revenue—range from 0.23 to 0.26.[24] There are also substantial plant turnovers every year for these industries (not reported in the table). For example, in Wearing Apparel, on average, 37 plants enter into the market every year while 30 plants exit from the market. Having a number of entrants and exiting plants in the sample is important for identifying the parameters determining the exiting choice probabilities as well as the distribution of initial productivity draws.

4.6 Estimation Results

Table 6 presents the maximum likelihood estimates of the empirical models for each industry. The table also reports their asymptotic standard errors, which are computed using the outer product of gradients estimator. The parameters are evaluated in units of millions of US dollars in 1990.

The estimated elasticity of substitution across differentiated final products, σ, ranges from 3.80 for plastic products to 4.41 for wearing apparel while our estimate for the elasticity of

[24]We measure "variable cost" by the sum of costs of materials, fuels, and electricity.

Table 6: Maximum Likelihood Estimates

Parameters	Wearing Apparel		Plastic Products		Structural Metal	
α_0	-0.870	(0.016)	-0.731	(0.023)	-0.359	(0.024)
σf	0.114	(0.033)	0.400	(0.049)	0.181	(0.014)
σf_x	0.364	(0.086)	0.266	(0.041)	0.550	(0.104)
σf_m	0.240	(0.058)	0.202	(0.042)	0.385	(0.079)
σc_x	3.275	(0.660)	3.013	(0.507)	3.811	(0.839)
σc_m	2.724	(0.513)	1.755	(0.313)	2.800	(0.599)
$\sigma \rho^D$	0.735	(0.136)	0.629	(0.110)	0.774	(0.156)
$\sigma \varrho^d$	0.814	(0.175)	0.761	(0.107)	0.955	(0.185)
$\sigma \rho^\chi$	0.849	(0.325)	1.918	(0.456)	0.233	(0.057)
α_t	0.066	(0.002)	0.173	(0.003)	0.125	(0.003)
ξ	0.082	(0.007)	0.047	(0.007)	0.054	(0.006)
α_m	0.623	(0.048)	0.579	(0.039)	0.658	(0.043)
λ_{11}	0.297	(0.002)	0.311	(0.004)	0.326	(0.002)
λ_{22}	1.333	(0.057)	1.396	(0.036)	1.144	(0.052)
λ_{21}	-0.127	(0.128)	0.010	(0.091)	-0.273	(0.142)
λ_{33}	0.689	(0.016)	0.580	(0.006)	0.700	(0.018)
λ_{32}	0.057	(0.066)	0.048	(0.046)	-0.044	(0.069)
λ_{31}	-0.107	(0.049)	0.048	(0.025)	0.087	(0.040)
σ_φ	1.307	(0.052)	1.326	(0.063)	1.503	(0.072)
μ_x	-3.802	(0.326)	-4.253	(0.252)	-4.243	(0.244)
μ_m	-2.926	(0.290)	-2.471	(0.250)	-3.075	(0.303)
σ_x	1.361	(0.193)	1.309	(0.142)	1.313	(0.176)
σ_m	1.476	(0.135)	1.830	(0.157)	1.656	(0.179)
ζ	0.800	(0.034)	0.805	(0.039)	0.791	(0.058)
σf_e	20.495		23.725		44.621	
$\sigma = 1/\text{markup}^a$	4.409		3.802		4.253	
$\gamma = (\sigma-1)(1-\alpha)/\alpha_m + 1^b$	5.064		4.561		4.600	
log-likelihood	4587.21		4423.66		3478.31	
No. of Plants	534		369		392	

Notes: Standard errors are in parentheses. The parameters are evaluated units of millions of US dollars in 1990. a). "markup" is computed as the mean of (revenue-variable cost)/revenue. b). The value of $(1-\alpha)$ is computed as the mean of the material share in total variable cost.

substitution across differentiated intermediate products, γ, ranges from 4.56 to 5.06.[25] In the following, we use these estimates to interpret our estimation results although it is possible to reinterpret our results under different values of σ and γ.

4.6.1 Sunk and Fixed Costs

Our approach allows us to quantify the magnitude of sunk and fixed costs of exporting and importing. The average sunk cost of exporting ranges from 743 thousand 1990 US dollars for

[25] Our estimates for the elasticity of substitution across differentiated intermediate products are in line with those found by Feenstra, Markusen, and Zeile (1992) and Halpern, Koren, and Szeidl (2006). For instance, the latter study finds that the elasticity of substitution between domestic and foreign intermediate goods is 5.4.

wearing apparel to 896 thousand US dollars for structural metals.[26] The sunk costs of importing range from 462 thousand 1990 US dollars for plastic products to 658 thousand US dollars for structural metals. Thus, both exporting and importing requires high start-up costs, which may arise because to begin importing requires establishing a network with foreign suppliers, learning government regulations or implementing new materials. It is important to note that the exporting and importing costs *actually incurred* are lower than these estimates since plants start exporting and/or importing when they get lower cost shocks. Furthermore, as we discuss below, plants that both export and import pay considerably less of the sunk costs because of the cost complementarity.

The fixed costs of exporting range from 70 to 129 thousand US dollars while the fixed costs of importing range from 53 to 91 thousand US dollars, indicating that both exporters and importers also pay substantial per-period fixed costs to continue to export and import. The parameter determining the degree of complementarity in exporting and importing sunk and fixed costs, ζ, ranges from 0.79 to 0.81, indicating that a firm can save approximately 20 percent of the per-period fixed costs and sunk costs associated with trade by simultaneously engaging in both export and import activities. Thus, the estimated total fixed costs of trading for a plant that both exports and imports ranges from 99 thousand 1990 US dollars for Plastic Products to 174 thousand 1990 US dollars for Structural Metals.

4.6.2 Importing and Exporting

The estimates of α_m, μ_x, μ_m, σ_x, and σ_m indicate that the effects of exporting and importing on total revenue differ across plants but, on average, their impact is large. For instance, for the "average" plant with $z_x = -3.80$ and $z_m = -2.93$ in Wearing Apparel, exporting has a substantial impact of a 2.2% (=$\ln(1 + \exp(z_x))$%) increase on total revenues while importing materials from abroad increases total revenue by a 3.3% (=$\alpha_m \ln(1+\exp(z_m))$%). Furthermore, the estimates of σ_x and σ_m suggest substantial heterogeneity in gains from exporting and importing. Note that since plants with larger gains from exporting and importing are more likely to self-select into those activities, the average revenue gains from exporting and importing among *actual* exporters and importers is even larger than the gain for the "average" plant.

[26] To the best of our knowledge, the only previous study that estimates the magnitude of sunk costs of exporting is Das, Roberts, and Tybout (2007) while there is no previous study that estimates importing sunk costs. Despite using different empirical specifications and looking at different countries and industries, our estimates of exporting sunk costs are similar in magnitude, although larger, to the estimates of Das, Roberts, and Tybout, especially given our relatively large standard errors. Their estimates range from 344 thousand 1986 US dollars to 430 thousand 1986 US dollars for leather products, basic chemicals, and knitted fabrics industries in Columbia.

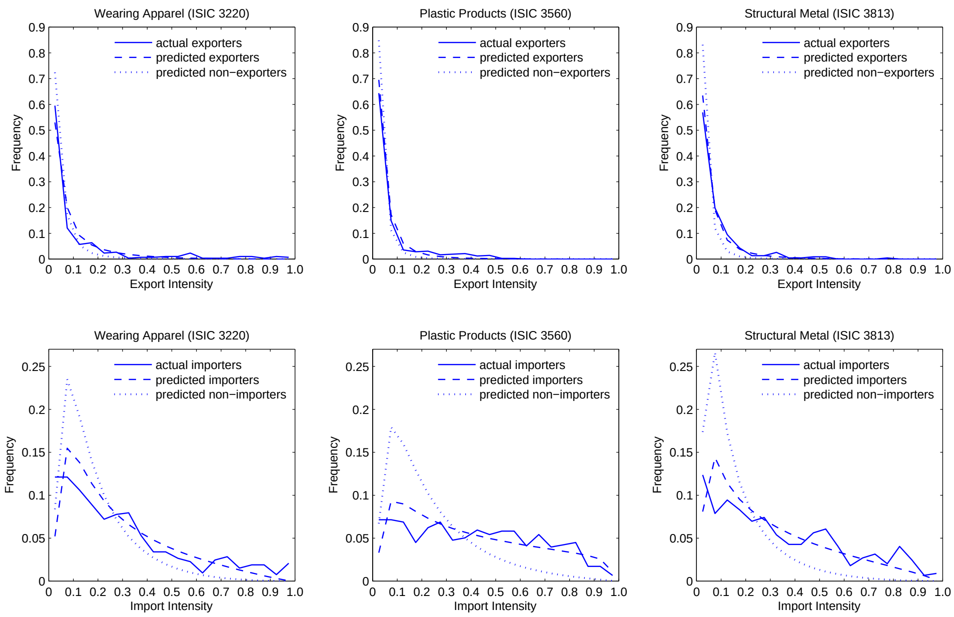

Figure 4: Export and Import Intensities (Actual vs. Predicted)

Figure 4 compares the actual and predicted distribution of export and import intensities. In the top panels, the solid line indicates the actual export intensities while the dashed line indicates the predicted export intensities. The empirical models quantitatively replicate the observed pattern of export intensities, including the fact that a majority of exporters export less than 5 percent of their output for all three industries. The figure also plots the distribution of latent export intensities among non-exporters if they had exported. The distribution of non-exporters (dotted line) is skewed left relative to that of exporters (dashed line). This is because, in the model, plants with lower transportation costs are more likely to export than plants with higher transportation costs. Similarly, in the bottom panels, the estimated model replicates the distribution of import intensities well and the predicted import intensities among non-importers tend to be lower than those among importers.[27]

Table 7 shows that exports and imports are highly concentrated in the data and that the estimated model performs reasonably well in capturing the observed high degree of trade concentration. For instance, in Wearing Apparel, the top 5 percent of exporting (importing) plants account for 55.4 (35.1) percent of total exports (imports) in the actual data, while the prediction

[27] The predicted distribution of import intensities is hump-shaped while the actual distribution is not. This is because we assume that transportation costs are normally distributed.

Table 7: Export and Import Concentration (Actual vs. Predicted)

Export	Wearing Apparel		Plastic Products		Structural Metal	
	% of Total Exports		% of Total Exports		% of Total Exports	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
Top 5%	55.43	42.45	46.79	40.34	29.16	38.46
Top 10%	71.03	57.37	64.46	54.42	45.27	51.37

Import	Wearing Apparel		Plastic Products		Structural Metal	
	% of Total Imports		% of Total Imports		% of Total Imports	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
Top 5%	35.13	33.95	38.58	35.10	36.63	39.30
Top 10%	54.70	43.25	57.63	44.32	51.49	48.94

of the empirical model is 42.5 (34.0) percent.[28]

4.6.3 Productivity

In the model, plants with higher productivity are more likely to survive than lower productivity plants. Figure 5 shows the importance of such a selection mechanism. In the top panels, the actual productivity distribution among incumbents (solid line) is skewed right relative to the actual productivity distribution among new entrants.[29] The bottom panels show that the empirical models qualitatively capture the observed difference in the productivity distributions between incumbents and new entrants.[30] In Table 8, the predicted average productivity advantage of incumbents relative to that of plants attempting to enter ranges from 15 percent in Wearing Apparel to 56 percent for Structural Metal, indicating that the selection through endogenous exiting may play an important role in determining aggregate productivity.

Exporters and importers tend to have higher productivities than domestic plants that do not engage in any trading activities because higher productivity plants are more likely to export and import. This is shown in Figure 6. In the top panels, the actual productivity distributions among plants that export, plants that import and plants that do both are skewed right relative to the actual distribution among plants that do neither. As the bottom panels show, the estimated models replicate the basic patterns of the differences in productivity distributions

[28]In our preliminary investigation, we estimated a model without heterogeneity in transportation costs and found that the degree of trade concentration predicted by the model without heterogeneous transportation costs is far less than observed. Hence, heterogeneity in transportation costs is crucial to quantitatively explain the heavy concentration of exports and imports among a small number of plants in our data.

[29]To construct the actual productivity distribution, we first compute a revenue residual, $\ln \phi_i + \omega_{1,it}$, for each plant-time observation as our measure of "actual productivity," and then plot a histogram of these residuals.

[30]The numbers used to construct Figures 4-6 as well as those reported in Tables 8-10 are directly computed using the approximated distribution function rather than simulating the data from the estimated models. The approximation methods are presented in a supplementary appendix which is available upon request.

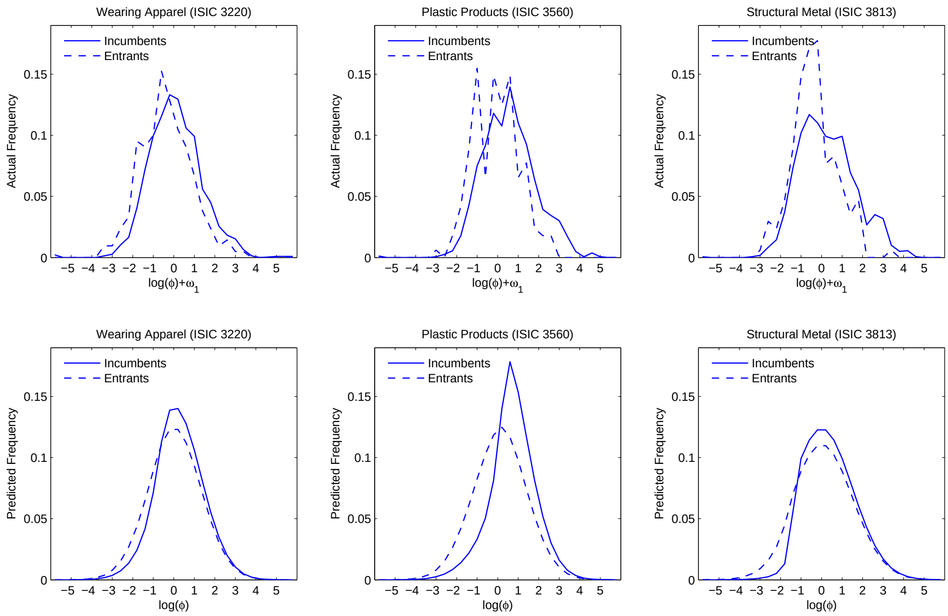

Figure 5: Productivity Distribution of Incumbents and New Entrants (Actual vs. Predicted)

Table 8: Mean of Predicted Productivity

	Wearing Apparel	Plastic Products	Structural Metals
Mean of φ at Entry Trial	1.000	1.000	1.000
Mean of φ among Incumbents	1.149	1.556	1.163
Mean of φ among Importers	2.047	2.136	2.591
Mean of φ among Exporters	2.644	2.778	4.061
Mean of φ among Ex/Importers	3.459	3.188	5.075

Notes: The reported numbers are relative to the productivity level at entry in the estimated model. In particular, the original numbers are divided by the mean of φ at entry (i.e., $\int \varphi g_{\varphi}(\varphi) d\varphi$). "Exporters" are plants that export while "Importers" are plants that import. "Ex/Importers" represent plants that both export and import.

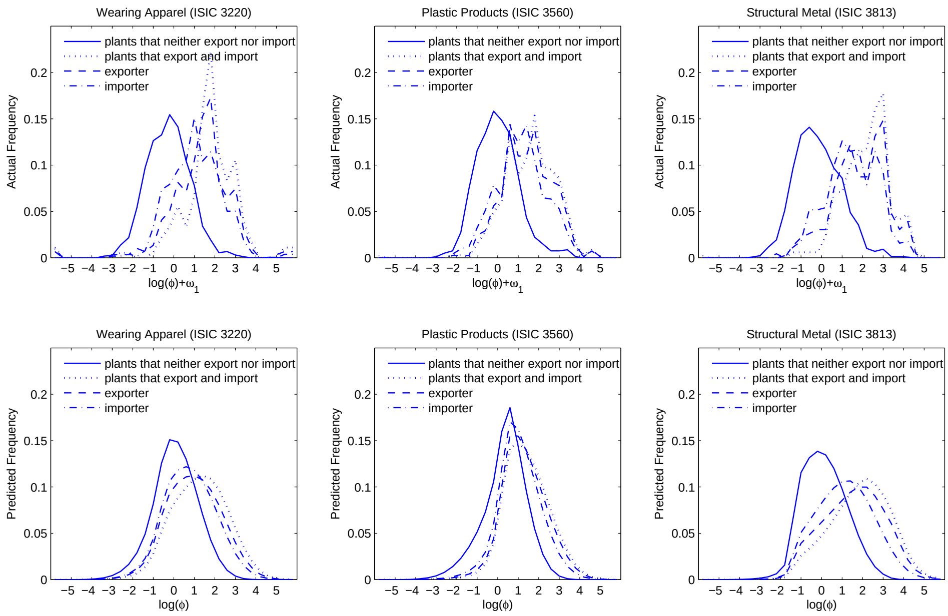

Figure 6: Productivity Distribution of Domestic Plants, Exporters, and Importers (Actual vs. Predicted)

across plants with different trading status. As reported in the last three rows of Table 8, the average productivity advantage of exporters and importers relative to the average incumbent is large, ranging from 37 percent for importers in Plastic Products to 436 percent for exporters in Structural Metals. The table also demonstrates that plants that both export and import are even more productive on average.

4.6.4 Dynamics

Table 9 compares actual and predicted transition probabilities of export/import status conditional on not exiting from the market for the Structural Metal industry. The table also reports the distribution for entrants as well as the steady state distribution of plants according to export/import status. The results from the other two industries are similar and are presented in the appendix. In the data, export/import status is quite persistent. For instance, the frequency that plants that neither export nor import will not engage in any trading activities next period is 92.7 percent. The estimated models are able to replicate the observed persistence in export/import status as well as new entrant's distribution and the steady state distribution of

Table 9: Transition of Export/Import Status for Structural Metal (Actual vs. Predicted)

	(1) No-Export /No-Import	(2) Export /No-Import	(3) No-Export /Import	(4) Export /Import
Actual				
No-Export/No-Import at t	0.927	0.018	0.050	0.006
Export/No-Import at t	0.265	0.367	0.000	0.367
No-Export/Import at t	0.170	0.009	0.740	0.081
Export/Import at t	0.043	0.101	0.101	0.754
New Entrants	0.877	0.012	0.099	0.012
Steady State Distribution	0.735	0.032	0.144	0.089
Predicted				
No-Export/No-Import at t	0.928	0.014	0.050	0.008
Export/No-Import at t	0.242	0.564	0.028	0.166
No-Export/Import at t	0.223	0.007	0.697	0.073
Export/Import at t	0.035	0.119	0.166	0.680
New Entrants	0.879	0.019	0.077	0.025
Steady State Distribution	0.742	0.041	0.150	0.067

export/import status reasonably well.[31]

4.7 Counterfactual Experiments

We now present the results of a series of counterfactual experiments which examine the effect of trade barriers on trading activity, productivity, and welfare. To determine the full impact of a counterfactual experiment, it is crucial to compute how the equilibrium aggregate price changes as a result of the experiment. This can be done by finding a new equilibrium aggregate price at which the free entry condition (22) holds in the experiment. The appendix provides a detailed description of how we compute the equilibrium aggregate price under a counterfactual experiment. There it is shown that we may identify the logarithm of the equilibrium price change up to the parameter $(\sigma - 1)$.

To quantitatively investigate the impact of trade barriers and export/import complementarities, we conduct the following six counterfactual experiments: (1) Autarky ($f_x, f_m \to \infty$); (2) No Trade in Final Goods ($f_x \to \infty$); (3) No Trade in Intermediates ($f_m \to \infty$); (4) No Complementarity in Fixed Trading Costs ($\zeta = 1$); (5) The transportation cost of exporting, τ_x, increases by 10%; and (6) The transportation cost of importing, τ_m, increases by 10%.

Note that we can investigate the impact of the counterfactual experiments on welfare by

[31] The empirical models generate the *observed* persistence in export/import status for the following reasons. First, the presence of sunk costs of exporting and importing generates "true state dependence" in export/import decisions. Second, unobserved heterogeneity may lead to "spurious state dependence" even without sunk costs because, for instance, highly productive plants are likely to keep exporting while less productive plants do not export. When we estimated a model without sunk costs, the model could not replicate the observed high degree of persistence in export/import status. Thus, it is important to incorporate sunk costs to capture the observed persistence in export/import status.

Table 10: Counterfactual Experiments for Structural Metal

	Free Trade	Counterfactual Experiments (1) Autarky	(2) No Trade in Final Goods	(3) No Trade in Intermediates	(4) No Complement.	(5) 10% inc. in τ_x	(6) 10% inc. in τ_m
$\Delta \ln P$	0.000	0.030	0.008	0.026	0.002	0.002	0.006
Δ ln(Average φ)	0.000	-0.027	-0.012	-0.011	0.003	-0.002	-0.002
Δ ln(Average TFP)	0.000	-0.180	-0.012	-0.163	0.003	-0.002	-0.050
A Fraction of Exporters	0.108	0.000	0.000	0.045	0.063	0.099	0.104
A Fraction of Importers	0.216	0.000	0.169	0.000	0.180	0.214	0.195
Aggregate Exports	1.000	0.000	0.000	0.765	0.872	0.743	0.960
Aggregate Imports	1.000	0.000	0.934	0.000	0.960	0.989	0.753

examining the aggregate price response. This is so because the aggregate price is inversely related to welfare.[32]

Table 10 presents the results of the counterfactual experiments using the estimated model for one industry, Structural Metals. The appendix provides results for the other two industries. According to these experiments, moving from autarky to trade decreases the equilibrium aggregate price by 3.0 percent. This implies that exposure to full trade increases real income by 3.0 percent, leading to a substantial increase in welfare. This positive welfare effect occurs because under trade, more productive firms start exporting and importing, which in turn increases aggregate labor demand and the real wage.

The impact of trade on aggregate productivity–measured by a productivity average using the plants' market shares as weights—can be understood by comparing "ln(Average φ) at Steady State" between trade and autarky. Moving from trade to autarky leads to a 2.7% decrease in this measure of aggregate productivity at the steady state. Once we take into account the additional productivity effect from importing, however, the impact of trade on total factor productivity (TFP) is much larger at 18.0 percent, indicating that most of TFP effect of trade is induced by importing intermediates.

The counterfactual experiments under no trade in final goods or no trade in intermediates (but not both) highlight the interaction between exporting and importing in the presence of heterogeneous firms. According to the estimated model, when the economy moves from full trade to no trade in final goods, the fraction of *importers* declines from a 21.6% to 16.9% and aggregate imports fall by 6.6%. Similarly, when the economy moves from full trade to no trade in intermediates, the fraction of *exporters* declines from a 10.8% to 4.5% and aggregate exports

[32] Recall that aggregate income is constant at the level of L. From the budget constraint $PQ = L$ we have that aggregate utility is given by $U = Q = P^{-1}L$.

fall by 23.5%. Thus, policies that prohibit the import of foreign materials could have a large negative impact on the export of final consumption goods – that is, import protection can lead to export destruction.

To examine the role of complementarities between export and import fixed and sunk costs relative to the role played by the complementarities in the revenue function, we conducted an experiment to determine what would happen to the fraction of importers and the fraction of exporters if there was no complementarity between export and import in the fixed and sunk cost function. As the table demonstrates, eliminating the cost complementarity lowers the fraction of exporters and importers as well as aggregate exports and imports, as expected, but the impact is less than under trade restrictions. These results suggest that *both* forms of complementarities are present.

We conduct additional (less extreme) experiments to examine what would happen to welfare and productivity if the transportation cost parameters, τ_x and τ_m, were 10 percent higher than the actual estimates. The results are presented in columns (5) and (6) of Table 10. Note that a 10 percent increase in transportation costs of either form have a relatively small impact on the fraction of exporters and importers but a substantial impact on aggregate exports and imports. This implies that the impact of an increase in transportation costs on aggregate exports and imports operates mainly through the intensive margin rather than through the extensive margin. This finding is consistent with the findings of Das, Roberts, and Tybout (2007).

As the appendix demonstrates we find similar results for the other two industries in our study so here we briefly summarize the results of the counterfactual experiments. We find that trade barriers have a substantial negative effect on aggregate welfare and aggregate productivity. Furthermore, there are significant revenue and cost complementarities between the exportation of final goods and the importation of intermediate goods. Thus, policies which restrict imports of intermediates harm exporters of final goods and restricting exports of those goods decreases the ability of firms to use productivity-enhancing imported intermediates.

5 Conclusions and Extensions

We have developed and estimated a stochastic industry model of importing and exporting with heterogeneous firms. The analysis highlights interactions between imports of intermediate goods and exports of final goods. In doing so, we have identified a potential mechanism whereby import policy can affect exports and export policy can affect imports.

Our model has a simple parsimonious structure and, yet, is able to replicate the basic features of the plant-level data. To maintain its parsimony, and also because of data limitations and computational complexity, the model ignores several important features. We do not address the important issue of how multi-plant and multinational firms make joint decisions on exporting and importing across different plants. We also ignore plant capital investment decisions. Finally, we do not allow adjustment in the measure of varieties of intermediates produced within a country in response to changes in the trading environment. These features could be incorporated into our theoretical and empirical framework and such extensions are important topics for our future research.

A Appendix

A.1 Estimation of the Density Function

Conditioning on φ_i, we may compute the estimate of $\omega_{it} = (\omega_{1,it}, \omega_{2,it}, \omega_{3,it})'$ from (25)-(27) as

$$\begin{aligned}
\tilde{\omega}_{1,it}(\eta_i) &= \ln r_{it} - \alpha_0 - \alpha_t - \ln[1+\exp(z_{x,i})]d_{it}^x - \alpha_m \ln[1+\exp(z_{m,i})]d_{it}^m - \ln \varphi_i, \\
\tilde{\omega}_{2,it}(\eta_i) &= \ln N r_{it}^f / r_{it} - \ln[\exp(z_{x,i})/(1+\exp(z_{x,i}))], \\
\tilde{\omega}_{3,it}(\eta_i) &= \ln X_{it}^m / X_{it} - \alpha_m \ln[\exp(z_{m,i})/(1+\exp(z_{m,i})].
\end{aligned}$$

Since whether we may observe $\tilde{\omega}_{2,it}$ and $\tilde{\omega}_{3,it}$ or not depends on the export/import choices, we use the following conditional density function to compute the likelihood contribution from revenues and export/import intensities:

$$g_\omega(\tilde{\omega}_{it}|d_{it}) = \begin{cases} g_{\omega_1}(\tilde{\omega}_{1,it}) & \text{for } d_{it} = (0,0), \\ g_{\omega_1}(\tilde{\omega}_{1,it}) g_{\omega_2|\omega_1}(\tilde{\omega}_{2,it}|\tilde{\omega}_{1,it}) & \text{for } d_{it} = (1,0), \\ g_{\omega_1}(\tilde{\omega}_{1,it}) g_{\omega_3|\omega_1}(\tilde{\omega}_{3,it}|\tilde{\omega}_{1,it}) & \text{for } d_{it} = (0,1), \\ g_\omega(\tilde{\omega}_{it}) & \text{for } d_{it} = (1,1), \end{cases}$$

where $g_{\omega_1}(\cdot)$ is a marginal distribution of $\omega_{1,it}$ while $g_{\omega_j|\omega_1}(\cdot|\omega_{1,it})$ is a conditional distribution of $\omega_{j,it}$ given $\omega_{1,it}$ for $j = 2,3$. Specifically, given the lower triangular Cholesky decomposition of Σ_ω, we may write $(\omega_{1,it}, \omega_{2,it}, \omega_{3,it})' \equiv (\lambda_{11}e_{1,it}, \lambda_{21}e_{1,it} + \lambda_{22}e_{2,it}, \lambda_{31}e_{1,it} + \lambda_{32}e_{2,it} + \lambda_{33}e_{3,it})'$, where $\lambda_{m,n}$ is the (m,n)-th element of Λ_ω, and $e_{j,it}$ is independently distributed $N(0,1)$ for all j,i,t. Then, $g_{\omega_j|\omega_1}(\tilde{\omega}_{j,it}|\tilde{\omega}_{1,it}) = \frac{1}{\sqrt{2\pi}\lambda_{jj}} \exp\left(-\frac{1}{2}\left(\frac{\tilde{\omega}_{j,it} - (\lambda_{j1}/\lambda_{11})\tilde{\omega}_{1,it}}{\lambda_{jj}}\right)^2\right)$ for $j = 2,3$.

A.2 Counterfactual Experiments

Denote the equilibrium aggregate price under the parameter θ by $P(\theta)$. Suppose that we are interested in a counterfactual experiment characterized by a counterfactual parameter vector $\tilde{\theta}$ that is different from the estimated parameter vector $\hat{\theta}$. Recall that we have the following relationship between α_0 and the equilibrium price P:

$$\hat{\alpha}_0 = \ln\left[(\Gamma(\sigma-1)/\sigma)^{\sigma-1} R\right] + (\sigma-1)\ln P(\hat{\theta}),$$

where the aggregate price is explicitly written as a function of θ. At the counterfactual aggregate price $P(\tilde{\theta})$, the coefficient α_0 takes a value of

$$\tilde{\alpha}_0 = \ln\left[(\Gamma(\sigma-1)/\sigma)^{\sigma-1}R\right] + (\sigma-1)\ln P(\tilde{\theta}) = \hat{\alpha}_0 + k(\tilde{\theta},\hat{\theta}),$$

where

$$k(\tilde{\theta},\hat{\theta}) \equiv (\sigma-1)\ln\left(P(\tilde{\theta})/P(\hat{\theta})\right)$$

represents the equilibrium price change (up to the parameter $(\sigma-1)$).

Thus, replacing $\hat{\alpha}_0$ with $\tilde{\alpha}_0$, we may evaluate the revenue function (29) at the *counterfactual* aggregate price $P(\tilde{\theta})$ (i.e. at the counterfactual value of α_0):

$$r(\eta_i, d_{it}; k(\tilde{\theta},\hat{\theta})) = \exp\left(k(\tilde{\theta},\hat{\theta}) + \hat{\alpha}_0 + \ln[1+\exp(z_{x,i})]d_{it}^x + \hat{\alpha}_m \ln[1+\exp(z_{m,i})]d_{it}^m + \ln\varphi_i\right). \quad (33)$$

The equilibrium price change, $k(\tilde{\theta},\hat{\theta})$, is then determined so that the following equilibrium free entry condition holds:

$$\hat{f}_e = \int V\left(\eta', d_{it}=(0,0); \tilde{\theta}, k(\tilde{\theta},\hat{\theta})\right) g_\eta(\eta';\tilde{\theta})d\eta'.$$

Here $V\left(\eta', d_{it}; \tilde{\theta}, k(\tilde{\theta},\hat{\theta})\right)$ is the solution to the Bellman equations (16)-(18) when the revenue function (33) is used to compute profits and $g_\eta(\eta';\tilde{\theta})$ is the probability density function from which the initial plant characteristic vector is drawn.[33]

A.3 Additional Empirical Results for Wearing Apparel and Plastic Products

Tables 11-12 show the results of counterfactual experiments for wearing apparel and plastic products. The basic patterns of the results are similar across industries although the magnitudes of the impact of counterfactual policies are different.

Tables 13 and 14 compare the actual and the predicted transition pattern of export and import status for wearing apparel and plastic product, respectively.

[33]For every pair $(\tilde{\theta},\hat{\theta})$, there exists a unique value of $k(\tilde{\theta},\hat{\theta})$ that satisfies the free entry condition because the value function $V\left(\eta', d_{it}; \tilde{\theta}, k(\tilde{\theta},\hat{\theta})\right)$ is strictly increasing in $k(\tilde{\theta},\hat{\theta})$.

Table 11: Counterfactual Experiments for Wearing Apparel

	Free Trade	Counterfactual Experiments (1) Autarky	(2) No Trade in Final Goods	(3) No Trade in Intermediates	(4) No Complement.	(5) 10% inc. in τ_x	(6) 10% inc. in τ_m
$\Delta \ln P$	0.000	0.033	0.014	0.025	0.004	0.002	0.005
Δ ln(Average φ)	0.000	-0.030	-0.014	-0.011	0.004	-0.003	-0.004
Δ ln(Average TFP)	0.000	-0.136	-0.016	-0.117	0.003	-0.003	-0.041
A Fraction of Exporters	0.125	0.000	0.000	0.065	0.078	0.115	0.121
A Fraction of Importers	0.219	0.000	0.167	0.000	0.177	0.217	0.201
Aggregate Exports	1.000	0.000	0.000	0.816	0.878	0.683	0.964
Aggregate Imports	1.000	0.000	0.887	0.000	0.925	0.981	0.715

Table 12: Counterfactual Experiments for Plastic Products

	Free Trade	Counterfactual Experiments (1) Autarky	(2) No Trade in Final Goods	(3) No Trade in Intermediates	(4) No Complement.	(5) 10% inc. in τ_x	(6) 10% inc. in τ_m
$\Delta \ln P$	0.000	0.069	0.014	0.064	0.005	0.002	0.012
Δ ln(Average φ)	0.000	-0.014	-0.004	-0.001	0.006	-0.001	-0.002
Δ ln(Average TFP)	0.000	-0.339	-0.005	-0.326	0.006	-0.001	-0.097
A Fraction of Exporters	0.239	0.000	0.000	0.086	0.140	0.228	0.235
A Fraction of Importers	0.426	0.000	0.358	0.000	0.377	0.425	0.401
Aggregate Exports	1.000	0.000	0.000	0.663	0.858	0.780	0.950
Aggregate Imports	1.000	0.000	0.955	0.000	0.978	0.992	0.786

Table 13: Transition of Export/Import Status for Wearing Apparel (Actual vs. Predicted)

	(1) No-Export /No-Import	(2) Export /No-Import	(3) No-Export /Import	(4) Export /Import
Actual				
No-Export/No-Import at t	0.911	0.025	0.060	0.004
Export/No-Import at t	0.255	0.553	0.032	0.160
No-Export/Import at t	0.244	0.015	0.676	0.065
Export/Import at t	0.028	0.063	0.113	0.796
New Entrants	0.794	0.049	0.081	0.076
Steady State Distribution	0.742	0.048	0.137	0.073
Predicted				
No-Export/No-Import at t	0.908	0.023	0.058	0.011
Export/No-Import at t	0.239	0.605	0.022	0.134
No-Export/Import at t	0.221	0.008	0.699	0.072
Export/Import at t	0.045	0.139	0.176	0.640
New Entrants	0.882	0.028	0.070	0.020
Steady State Distribution	0.720	0.061	0.155	0.064

Table 14: Transition of Export/Import Status for Plastic Products (Actual vs. Predicted)

	(1) No-Export /No-Import	(2) Export /No-Import	(3) No-Export /Import	(4) Export /Import
Actual				
No-Export/No-Import at t	0.845	0.029	0.108	0.018
Export/No-Import at t	0.162	0.412	0.118	0.309
No-Export/Import at t	0.193	0.021	0.661	0.125
Export/Import at t	0.030	0.068	0.091	0.810
New Entrants	0.626	0.050	0.268	0.056
Steady State Distribution	0.532	0.049	0.234	0.184
Predicted				
No-Export/No-Import at t	0.823	0.028	0.125	0.023
Export/No-Import at t	0.143	0.575	0.042	0.240
No-Export/Import at t	0.191	0.012	0.703	0.094
Export/Import at t	0.029	0.154	0.159	0.659
New Entrants	0.779	0.028	0.154	0.038
Steady State Distribution	0.487	0.087	0.274	0.152

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Supplemental Appendix for "Import Protection as Export Destruction"

NOT FOR PUBLICATION

A Theoretical Derivations and Results

A.1 Fixed Cost Bounds

The restrictions on the fixed costs of importing and exporting which guarantee a positive measure of firms in each export/import category are as follows:

$$f_m + \underline{\epsilon} < \frac{\zeta f_x(b_m - 1)}{b_m(b_x - \zeta) + (\zeta - 1)} \tag{34}$$

$$f_m + \bar{\epsilon} > \frac{f_x[b_x(b_m - \zeta) + (\zeta - 1)]}{\zeta(b_x - 1)} \tag{35}$$

$$f_x > \left(\frac{f}{N}\right)(b_x - 1) \tag{36}$$

$$f_m + \underline{\epsilon} > \left(\frac{f}{N}\right)(b_m - 1) \tag{37}$$

$$\zeta(f_x + f_m + \underline{\epsilon}) > \left(\frac{f}{N}\right)(b_x b_m - 1) \tag{38}$$

First note that because a firm's revenue will be highest if the firm both exports and imports and because revenue is increasing in φ and φ is unbounded, there will always be a set of firms (those with high φ) which will both export and import. Condition (34) ensures that the minimum fixed cost of importing is low enough so that some firms will choose to import but not export. The second restriction implies that the maximum fixed cost of importing is large enough so that some firms will choose to export but not import. The third condition guarantees that the fixed costs of exporting are high enough so that some firms will neither export nor import. The last two conditions imply that the profits earned by a firm with the cutoff productivity are maximized by neither importing nor exporting.

A.2 Cutoff Productivities

If the cutoff productivity for operation in autarky, φ_A^*, exists, it must satisfy $\int_{\underline{\epsilon}}^{\bar{\epsilon}} \pi_A(\varphi_A^*, 0, 0, \epsilon)h(\epsilon)d\epsilon = 0$, from which we have $r_A(\varphi_A^*, 0, 0) = \sigma f.$. If the cutoff productivities exist for the trading economies, they will also satisfy this condition. To demonstrate this we must show that

$(0,0) = argmax_{d \in \{0,1\}^2} \pi_S(\varphi_S^*, d, \epsilon)$ for all ϵ when $r_S(\varphi_S^*, 0, 0) = \sigma f$ for $S \in \{X, M, T\}$. It can easily be shown that conditions (36)-(38) guarantee that this is the case for the full trading economy. Similarly, condition (36) implies that this is the case for the economy with no trade in intermediates and condition (37) guarantees this for the economy with no trade in final goods. Thus we have for all $S \in \{A, X, M, T\}$

$$r_S(\varphi_S^*, 0, 0) = \sigma f. \tag{39}$$

Then, from (39), we can derive

$$r_S(\varphi, d) = b_x^{d^x} b_m^{d^m} \left(\frac{\varphi}{\varphi_S^*}\right)^{\sigma-1} \sigma f \tag{40}$$

We now demonstrate that for each economy a cutoff productivity exists and is unique. Define the following function of φ:

$$\gamma_A(\varphi) \equiv \varphi^{1-\sigma} f \int_{\varphi}^{\infty} z^{\sigma-1} g(z) dz - f[1 - G(\varphi)].$$

Note that since $\sigma > 1$, $\gamma_A(\cdot) > 0 \ \forall \ \varphi$. Using the two equilibrium equations in Section 3.2.3 and (40), we know that the equilibrium cutoff level in autarky, φ_A^* satisfies

$$\gamma_A(\varphi_A^*) = \xi f_e. \tag{41}$$

Following Melitz (2003), we will show that $\gamma_A(\varphi)$ is monotonically decreasing from ∞ to 0 on $(0,\infty)$. The elasticity of this function is given by

$$\frac{\partial \ln \gamma_A}{\partial \ln \varphi} = (1 - \sigma) \left[1 + \frac{f[1 - G(\varphi)]}{\gamma_A(\varphi)}\right] < (1 - \sigma) < 0,$$

where the second inequality follows from $\sigma > 1$. Since the elasticity is negative and bounded away from zero, $\gamma_A(\varphi)$ is decreasing to 0 as φ goes to ∞. Also, we see by inspection that $lim_{\varphi \to 0} \gamma_A(\varphi) = \infty$. This implies that the solution to equation (41) exists and is unique.

Turning to the economies with trade, we define the following functions for $i \in \{1, 2, 3\}$ and

$j \in \{0, 1, 2, 3, 4, X, M\}$:

$$\delta_i(\varphi, \tilde{\varphi}_j(\varphi,\epsilon), \epsilon_L, \epsilon_H) \equiv \varphi^{1-\sigma} B_i \int_{\epsilon_L}^{\epsilon_H} \left(\int_{\tilde{\varphi}_j(\varphi,\epsilon)}^{\infty} z^{\sigma-1} g(z) dz \right) h(\epsilon) d\epsilon$$
$$- \int_{\epsilon_L}^{\epsilon_H} \left(C_i(\epsilon) \int_{\tilde{\varphi}_j(\varphi,\epsilon)}^{\infty} g(z) dz \right) h(\epsilon) d\epsilon, \qquad (42)$$

where $B_1 = f(b_x - 1)$, $B_2 = f(bm - 1)$, $B_3 = f(b_x - 1)(b_m - 1)$, $C_1(\epsilon) = N f_x$, $C_2(\epsilon) = N(f_m + \epsilon)$, $C_3(\epsilon) = N(\zeta - 1)(f_x + f_m + \epsilon)$, and

$$\tilde{\varphi}_o(\varphi,\epsilon) \equiv \varphi \left(\frac{N\Phi_x(1,\epsilon)}{f} \right)^{\frac{1}{\sigma-1}}, \quad \tilde{\varphi}_1(\varphi,\epsilon) \equiv \varphi \left(\frac{N\Phi_m(0,\epsilon)}{f} \right)^{\frac{1}{\sigma-1}}, \quad \tilde{\varphi}_2(\varphi,\epsilon) \equiv \varphi \left(\frac{N\Phi_{xm}(\epsilon)}{f} \right)^{\frac{1}{\sigma-1}},$$

$$\tilde{\varphi}_3(\varphi,\epsilon) \equiv \varphi \left(\frac{N\Phi_m(1,\epsilon)}{f} \right)^{\frac{1}{\sigma-1}}, \qquad \tilde{\varphi}_4(\varphi,\epsilon) \equiv \varphi \left(\frac{N\Phi_x(0,\epsilon)}{f} \right)^{\frac{1}{\sigma-1}},$$

$$\tilde{\varphi}_X(\varphi,\epsilon) \equiv \varphi \left(\frac{N f_x}{f(b_x - 1)} \right)^{\frac{1}{\sigma-1}}, \qquad \tilde{\varphi}_M(\varphi,\epsilon) \equiv \varphi \left(\frac{N(f_m + \epsilon)}{f(b_m - 1)} \right)^{\frac{1}{\sigma-1}}.$$

Note that $\tilde{\varphi}_X(\varphi,\epsilon)$ is the productivity of a firm which is indifferent between exporting and not exporting in the economy with no trade in intermediates. This function does not depend on ϵ and henceforth we write $\tilde{\varphi}_X(\varphi)$. Similarly $\tilde{\varphi}_M(\varphi,\epsilon)$ is the productivity of a firm with random fixed import cost equal to $f_m + \epsilon$ which is indifferent between importing and not importing in the economy with no trade in final goods.

For the economy with no trade in intermediates, define the following function of φ:

$$\gamma_X(\varphi) \equiv \gamma_A(\varphi) + \delta_1(\varphi, \tilde{\varphi}_X(\varphi), \underline{\epsilon}, \bar{\epsilon}) > 0.$$

The equilibrium cutoff level for operation in economy X, φ_X^*, satisfies

$$\gamma_X(\varphi_X^*) = \xi f_e. \qquad (43)$$

The elasticity of the second function on the right-hand side with respect to φ is given by

$$\frac{\partial \ln \delta_1}{\partial \ln \varphi} = (1-\sigma) \left[1 + \frac{N f_x (1 - G(\tilde{\varphi}_X(\varphi)))}{\delta_1} \right] < (1-\sigma) < 0.$$

Since this elasticity is negative and bounded away from zero, δ_1 is decreasing to 0 as φ goes to ∞. Also, we see by inspection that $lim_{\varphi \to 0} \delta_1 = \infty$. Thus, $\gamma_X(\cdot)$ is the sum of two functions which are decreasing from ∞ to 0 on $(0, \infty)$ and so φ_X^* exists and is unique.

Define the following function of φ:

$$\gamma_M(\varphi) \equiv \gamma_A(\varphi) + \delta_2(\varphi, \tilde{\varphi}_M(\varphi, \epsilon), \underline{\epsilon}, \bar{\epsilon}) > 0. \tag{44}$$

The equilibrium cutoff level for operation in economy M, φ_M^*, satisfies

$$\gamma_M(\varphi_M^*) = \xi f_e. \tag{45}$$

The elasticity of the second function on the right-hand side with respect to φ is given by

$$\frac{\partial \ln \delta_2}{\partial \ln \varphi} = (1-\sigma)\left[1 + \frac{N \int_{\underline{\epsilon}}^{\bar{\epsilon}} (f_m + \epsilon) \left(\int_{\tilde{\varphi}_M(\varphi,\epsilon)}^{\infty} g(\varphi) d\varphi\right) h(\epsilon) d\epsilon}{\delta_2}\right] < (1-\sigma) < 0.$$

Since this elasticity is negative and bounded away from zero, δ_2 is decreasing to 0 as φ goes to ∞. Also, we see by inspection that $lim_{\varphi \to 0}\, \delta_2 = \infty$. Thus, $\gamma_M(\cdot)$ is the sum of two functions which are decreasing from ∞ to 0 on $(0, \infty)$ and so φ_M^* exists and is unique.

We now turn to existence in the full trading economy. Let ϵ_1 and ϵ_2 be implicitly defined as follows:

$$\Phi_m(0, \epsilon_1) = \Phi_x(1, \epsilon_1) = \Phi_{xm}(\epsilon_1), \qquad \Phi_m(1, \epsilon_2) = \Phi_x(0, \epsilon_2) = \Phi_{xm}(\epsilon_2).$$

Define the following functions of φ:

$$\gamma_1(\varphi) \equiv \sum_{i \in \{1,3\}} \delta_i(\varphi, \tilde{\varphi}_0(\varphi, \epsilon), \underline{\epsilon}, \epsilon_1), \qquad \gamma_2(\varphi) \equiv \delta_2(\varphi, \tilde{\varphi}_1(\varphi, \epsilon), \underline{\epsilon}, \epsilon_1),$$

$$\gamma_3(\varphi) \equiv \sum_{i \in \{1,2,3\}} \delta_i(\varphi, \tilde{\varphi}_2(\varphi, \epsilon), \epsilon_1, \epsilon_2), \qquad \gamma_4(\varphi) \equiv \sum_{i \in \{2,3\}} \delta_i(\varphi, \tilde{\varphi}_3(\varphi, \epsilon), \epsilon_2, \bar{\epsilon}),$$

$$\gamma_5(\varphi) \equiv \delta_1(\varphi, \tilde{\varphi}_4(\varphi, \epsilon), \epsilon_2, \bar{\epsilon}).$$

It is easy to show that each of these functions are positive-valued. We define the following function of φ

$$\gamma_T(\varphi) \equiv \gamma_A(\varphi) + \sum_{i=1}^{5} \gamma_i(\varphi). \tag{46}$$

The equilibrium cutoff productivity level for operation in the full trading economy, φ_T^* satisfies

$$\gamma_T(\varphi_T^*) = \xi f_e. \tag{47}$$

Using derivations similar to those in the partial trading economies, we can show that the limit of each of these functions as $\varphi \to 0$ equals ∞ and their elasticities are less than $1 - \sigma$. This implies that $\gamma_T(\varphi)$ is the sum of functions which decrease monotonically from ∞ to 0 on $(0, \infty)$ and, so, must also have this property. Thus, the φ_T^* which satisfies equation (47) exists and is unique.

Next, we demonstrate that trade in either final goods or intermediates increases the cutoff productivities, i.e. $\varphi_A^* < \varphi_X^* < \varphi_T^*$ and $\varphi_A^* < \varphi_M^* < \varphi_T^*$. We also note that the second equilibrium equation in Section 3.2.3 implies that average profits will have a similar ranking across economies. The equilibrium equations given by (41), (43), (45), and (47) for the respective economies imply

$$\gamma_A(\varphi_A^*) = \gamma_A(\varphi_X^*) + \delta_1(\varphi_X^*, \tilde{\varphi}_X(\varphi_X^*), \underline{\epsilon}, \bar{\epsilon}) = \gamma_A(\varphi_M^*) + \delta_2(\varphi_M^*, \tilde{\varphi}_M(\varphi_M^*, \epsilon), \underline{\epsilon}, \bar{\epsilon}). = \gamma_A(\varphi_T^*) + \sum_{i=1}^{5} \gamma_i(\varphi_T^*).$$

Now since $\delta_1(\cdot)$, $\delta_2(\cdot)$, and $\gamma_i(\cdot)$ for $i \in \{1, 5\}$ are positive-valued and since $\gamma_A(\varphi)$ is a decreasing function, we have $\varphi_A^* < \varphi_X^*$, $\varphi_A^* < \varphi_M^*$, and $\varphi_A^* < \varphi_T^*$.

Note that $\varphi_X^* = \varphi_T^*$ when $b_m = \zeta = 1$ and $\varphi_M^* = \varphi_T^*$ when $b_x = \zeta = 1$. Below we show that φ_T^* is increasing in b_m, increasing in b_x, and decreasing in ζ. Now a movement from the economy with no trade in intermediates to the economy with full trade can be represented by an increase in b_m and, possibly, a decrease in ζ. Thus, if we show that the cutoff productivity in the full trading equilibrium is increasing in b_m and decreasing in ζ, then we have the result that $\varphi_X^* < \varphi_T^*$. Using a similar argument for increases in b_x, we have the result that $\varphi_M^* < \varphi_T^*$.

Let the elasticity of a function $f(z) : \Re^n \to \Re$ with respect to z_j be written as $\hat{f}^{z_j}$. Then equation (47) implies (where it is understood in equation (46) that γ_T depends on φ as well as on economy parameters)

$$\hat{\varphi}_T^{*z_j} = -\left(\frac{\hat{\gamma}_T^{z_j}}{\hat{\gamma}_T^{\varphi}}\right) \tag{48}$$

¿From equation (46), we can derive the following elasticities:

$$\hat{\gamma}_T^{\varphi} = \left[\frac{(1-\sigma)\varphi^{1-\sigma} f}{\gamma_T(\varphi)}\right] \left[\int_{\varphi}^{\infty} z^{\sigma-1} g(z) dz \right.$$
$$+ \int_{\underline{\epsilon}}^{\epsilon_1} \left(b_m(b_x - 1) \int_{\tilde{\varphi}_0(\varphi,\epsilon)}^{\infty} z^{\sigma-1} g(z) dz + (b_m - 1) \int_{\tilde{\varphi}_1(\varphi,\epsilon)}^{\infty} z^{\sigma-1} g(z) dz \right) h(\epsilon) d\epsilon$$
$$+ \int_{\epsilon_1}^{\epsilon_2} \left((b_m b_x - 1) \int_{\tilde{\varphi}_2(\varphi,\epsilon)}^{\infty} z^{\sigma-1} g(z) dz \right) h(\epsilon) d\epsilon$$

$$+\int_{\epsilon_2}^{\bar{\epsilon}}\left(b_x(b_m-1)\int_{\tilde{\varphi}_3(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz+(b_x-1)\int_{\tilde{\varphi}_4(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon\Bigg]$$

$$<0$$

$$\hat{\gamma}_T^{b_m}=\left[\frac{b_m\varphi^{1-\sigma}f}{\gamma_{T(\varphi)}}\right]\Bigg[\int_{\underline{\epsilon}}^{\epsilon_1}\left((b_x-1)\int_{\tilde{\varphi}_0(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz+\int_{\tilde{\varphi}_1(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon$$

$$+\int_{\epsilon_1}^{\epsilon_2}\left(b_x\int_{\tilde{\varphi}_2(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon$$

$$+\int_{\epsilon_2}^{\bar{\epsilon}}\left(b_x\int_{\tilde{\varphi}_3(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon\Bigg]$$

$$>0$$

$$\hat{\gamma}_T^{b_x}=\left[\frac{b_x\varphi^{1-\sigma}f}{\gamma_T(\varphi)}\right]\Bigg[\int_{\underline{\epsilon}}^{\epsilon_1}\left(b_m\int_{\tilde{\varphi}_0(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon$$

$$+\int_{\epsilon_1}^{\epsilon_2}\left(b_m\int_{\tilde{\varphi}_2(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon$$

$$+\int_{\epsilon_2}^{\bar{\epsilon}}\left((b_m-1)\int_{\tilde{\varphi}_3(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz+\int_{\tilde{\varphi}_4(\varphi,\epsilon)}^{\infty}z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon\Bigg]$$

$$>0$$

$$\hat{\gamma}_T^{\zeta}=\left[\frac{-\zeta N}{\gamma_T(\varphi)}\right]\Bigg[\int_{\underline{\epsilon}}^{\epsilon_1}\left(\int_{\tilde{\varphi}_0(\varphi,\epsilon)}^{\infty}(f_x+f_m+\epsilon)g(z)dz\right)h(\epsilon)d\epsilon$$

$$+\int_{\epsilon_1}^{\epsilon_2}\left(\int_{\tilde{\varphi}_2(\varphi,\epsilon)}^{\infty}(f_x+f_m+\epsilon)g(z)dz\right)h(\epsilon)d\epsilon$$

$$+\int_{\epsilon_2}^{\bar{\epsilon}}\left(\int_{\tilde{\varphi}_3(\varphi,\epsilon)}^{\infty}(f_x+f_m+\epsilon)g(z)dz\right)h(\epsilon)d\epsilon\Bigg]$$

$$<0$$

Hence, using equation (48) and the signs of these elasticities, we have

$$\hat{\varphi}_T^{*b_m} > 0, \qquad \hat{\varphi}_T^{*b_x} > 0, \qquad \hat{\varphi}_T^{*\zeta} < 0. \tag{49}$$

Therefore, we have $\varphi_A^* < \varphi_X^* < \varphi_T^*$ and $\varphi_A^* < \varphi_M^* < \varphi_T^*$.

A.3 Revenue and Average Productivity Comparisons

Consider the economy with no trade in intermediates. Similar to Melitz (2003), we have the following revenue comparison between autarky and the open economy for a firm with inherent productivity φ:

$$r_X(\varphi, 0, 0) < r_A(\varphi, 0, 0) < r_X(\varphi, 1, 0). \tag{50}$$

The first inequality follows from equation (40) and the result that $\varphi_A^* < \varphi_X^*$. For the second inequality, we first note that $lim_{b_x \to 1} r_X(\varphi, 1, 0) = r_A(\varphi, 0, 0)$. Now if we can show that $r_X(\varphi, 1, 0)$ is increasing in b_x, then we have proved the second inequality. The elasticity of $r_X(\varphi, 1, 0)$ with respect to b_x is given by

$$\hat{r}_X^{b_x}(\varphi, 1, 0) = 1 + (1 - \sigma)\hat{\varphi}_X^{*b_x}, \tag{51}$$

where, from equation (43), we have

$$\hat{\varphi}_X^{*b_x} = -\frac{\hat{\gamma}_X^{b_x}(\varphi_X^*)}{\hat{\gamma}_X^{\varphi}(\varphi_X^*)}.$$

Now if we derive these elasticities, substitute them into equation (51), and rearrange we can show

$$Sign\left\{\hat{r}_X^{b_x}(\varphi, 1, 0)\right\} = Sign\left\{\int_{\varphi_X^*}^{\infty} z^{\sigma-1} g(z) dz - \int_{\tilde{\varphi}_X(\varphi_X^*)}^{\infty} z^{\sigma-1} g(z) dz\right\}.$$

Now, since $\varphi_X^* < \tilde{\varphi}_X(\varphi_X^*)$, this expression must be positive, so $r_X(\varphi, 1, 0)$ is increasing in b_x.

Next consider the economy with no trade in final goods. Then we have the following revenue comparison between autarky and the open economy for a firm with inherent productivity φ:

$$r_M(\varphi, 0, 0) < r_A(\varphi, 0, 0) < r_M(\varphi, 0, 1). \tag{52}$$

The first inequality follows from equation (40) and the result that $\varphi_A^* < \varphi_M^*$. For the second inequality, we first note that $lim_{b_m \to 1} r_M(\varphi, 0, 1) = r_A(\varphi, 0, 0)$. The elasticity of $r_M(\varphi, 0, 1)$ with respect to b_m is given by

$$\hat{r}_M^{b_m}(\varphi, 0, 1) = 1 + (1 - \sigma)\hat{\varphi}_M^{*b_m}, \tag{53}$$

where, from equation (45), we have

$$\hat{\varphi}_M^{*b_m} = -\frac{\hat{\gamma}_M^{b_m}(\varphi_M^*)}{\hat{\gamma}_M^{\varphi}(\varphi_M^*)}.$$

Now if we derive these elasticities, substitute them into equation (53), and rearrange we can show

$$Sign\left\{\hat{r}_M^{b_m}(\varphi,0,1)\right\} = Sign\left\{\int_{\underline{\epsilon}}^{\bar{\epsilon}}\left(\int_{\varphi_M^*}^{\infty} z^{\sigma-1}g(z)dz - \int_{\tilde{\varphi}_M(\varphi_M^*,\epsilon)}^{\infty} z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon\right\}. \quad (54)$$

Now, since $\varphi_M^* < \tilde{\varphi}_M(\varphi_M^*,\epsilon)\ \forall\ \epsilon \in (\underline{\epsilon},\bar{\epsilon})$, this expression must be positive, so $r_M(\varphi,0,1)$ is increasing in b_m which implies that $r_A(\varphi,0,0) < r_M(\varphi,0,1)$.

Finally, we examine the economy with both types of trade where we can demonstrate the following $\forall\ \varphi$:

$$r_T(\varphi,0,0) < r_A(\varphi,0,0) < r_T(\varphi,1,1). \quad (55)$$

The first inequality follows from equation (40) and the result that $\varphi_A^* < \varphi_T^*$. For the second inequality, we first note that $r_T(\varphi,1,1) \to r_A(\varphi,0,0)$ as $b_x \to 1$ and $b_m \to 1$. Now if we can show that $r_T(\varphi,1,1)$ is increasing in b_x and increasing in b_m, then we have proved the second inequality. Using an approach similar to that for the economies with partial trade, we can show that

$$\begin{aligned} Sign\left\{\hat{r}_T^{b_x}(\varphi,1,1)\right\} = Sign\Bigg\{ &\int_{\underline{\epsilon}}^{\epsilon_1}\left(\int_{\varphi_T^*}^{\infty} z^{\sigma-1}g(z)dz - \int_{\tilde{\varphi}_1(\varphi_T^*,\epsilon)}^{\infty} z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon \\ &+\int_{\epsilon_1}^{\epsilon_2}\left(\int_{\varphi_T^*}^{\infty} z^{\sigma-1}g(z)dz - \int_{\tilde{\varphi}_2(\varphi_T^*,\epsilon)}^{\infty} z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon \\ &+\int_{\epsilon_2}^{\bar{\epsilon}}\left(\int_{\varphi_T^*}^{\infty} z^{\sigma-1}g(z)dz - \int_{\tilde{\varphi}_4(\varphi_T^*,\epsilon)}^{\infty} z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon \\ &+b_m\int_{\underline{\epsilon}}^{\epsilon_1}\left(\int_{\tilde{\varphi}_1(\varphi_T^*,\epsilon)}^{\infty} z^{\sigma-1}g(z)dz - \int_{\tilde{\varphi}_0(\varphi_T^*,\epsilon)}^{\infty} z^{\sigma-1}g(z)dz\right)h(\epsilon)d\epsilon\Bigg\} \end{aligned}$$

Now, since $\varphi_T^* < \tilde{\varphi}_j(\varphi_T^*,\epsilon)\ \forall j$ and $\forall\ \epsilon \in (\underline{\epsilon},\bar{\epsilon})$, the last three terms in this expression must be positive. Furthermore, since $\tilde{\varphi}_1(\varphi_T^*,\epsilon) < \tilde{\varphi}_0(\varphi_T^*,\epsilon)$ for all $\epsilon \in [\underline{\epsilon},\epsilon_1]$, the last term must also be positive. Hence, $r_T(\varphi,1,1)$ is increasing in b_x. Similarly, we can show that $r_T(\varphi,1,1)$ is increasing in b_m (these derivations are omitted for brevity).

We can also compare the revenue of firms which only export final goods or only import intermediates, but not both, with those firms' revenues in autarky. First consider a firm which exports it output good but does not import intermediates and note that $r_T(\varphi, 1, 0) \to r_A(\varphi, 0, 0)$ as $b_x \to 1$ and $b_m \to 1$. Using methods similar to those above, we can show that that $r_T(\varphi, 1, 0)$ is increasing in b_x so $r_T(\varphi, 1, 0) > r_A(\varphi, 0, 0)$ when $b_x > 1$ and $b_m = 1$. Also, because φ_T^* is increasing in b_m, $r_T(\varphi, 1, 0)$ is decreasing in b_m with $lim_{b_m \to 1} r_T(\varphi, 1, 0) = 0$. Thus, $\exists$ a $\bar{b}_m > 1$ such that $r_T(\varphi, 1, 0) \gtreqless r_A(\varphi, 0, 0)$ as $b_m \lesseqgtr \bar{b}_m$. Similarly, we can show that $\exists$ a $\bar{b}_x > 1$ such that $r_T(\varphi, 0, 1) \gtreqless r_A(\varphi, 0, 0)$ as $b_x \lesseqgtr \bar{b}_x$.

Next we demonstrate that trade increases average productivity measured using firms revenue shares as weights. To simplify the presentation, define the following revenue functions for each economy

$$\hat{r}_A(\varphi) \equiv \begin{cases} 0 & \text{for } \varphi < \varphi_A^* \\ r_A(\varphi, 0, 0) & \text{for } \varphi \geq \varphi_A^* \end{cases}$$

$$\hat{r}_X(\varphi) \equiv \begin{cases} 0 & \text{for } \varphi < \varphi_X^* \\ r_X(\varphi, 0, 0) & \text{for } \varphi_X^* \leq \varphi < \tilde{\varphi}_X(\varphi_X^*) \\ r_X(\varphi, 1, 0) & \text{for } \varphi \geq (\varphi_X^*) \end{cases}$$

For $\epsilon \in [\underline{\epsilon}, \bar{\epsilon}]$:

$$\hat{r}_M(\varphi, \epsilon) \equiv \begin{cases} 0 & \text{for } \varphi < \varphi_M^* \\ r_M(\varphi, 0, 0) & \text{for } \varphi_M^* \leq \varphi < \tilde{\varphi}_M(\varphi_M^*, \epsilon) \\ r_M(\varphi, 0, 1) & \text{for } \varphi \geq \tilde{\varphi}_M(\varphi_X^*, \epsilon) \end{cases}$$

For $\epsilon \in [\underline{\epsilon}, \epsilon_1]$:

$$\hat{r}_T(\varphi, \epsilon) \equiv \begin{cases} 0 & \text{for } \varphi < \varphi_T^* \\ r_T(\varphi, 0, 0) & \text{for } \varphi_T^* \leq \varphi < \tilde{\varphi}_1(\varphi_T^*, \epsilon) \\ r_T(\varphi, 0, 1) & \text{for } \tilde{\varphi}_1(\varphi_T^*, \epsilon) \leq \varphi < \tilde{\varphi}_0(\varphi_T^*, \epsilon) \\ r_T(\varphi, 1, 1) & \text{for } \varphi \geq \tilde{\varphi}_0(\varphi_T^*, \epsilon) \end{cases}$$

For $\epsilon \in [\epsilon_1, \epsilon_2]$:

$$\hat{r}_T(\varphi, \epsilon) \equiv \begin{cases} 0 & \text{for } \varphi < \varphi_T^* \\ r_T(\varphi, 0, 0) & \text{for } \varphi_T^* \leq \varphi < \tilde{\varphi}_2(\varphi_T^*, \epsilon) \\ r_T(\varphi, 1, 1) & \text{for } \varphi \geq \tilde{\varphi}_2(\varphi_T^*, \epsilon) \end{cases}$$

For $\epsilon \in [\epsilon_2, \bar{\epsilon}]$:

$$\hat{r}_T(\varphi, \epsilon) \equiv \begin{cases} 0 & \text{for } \varphi < \varphi_T^* \\ r_T(\varphi, 0, 0) & \text{for } \varphi_T^* \leq \varphi < \tilde{\varphi}_4(\varphi_T^*, \epsilon) \\ r_T(\varphi, 1, 0) & \text{for } \tilde{\varphi}_4(\varphi_T^*, \epsilon) \leq \varphi < \tilde{\varphi}_3(\varphi_T^*, \epsilon) \\ r_T(\varphi, 1, 1) & \text{for } \varphi \geq \tilde{\varphi}_3(\varphi_T^*, \epsilon) \end{cases}$$

Recall that the total factor productivity of a firm with inherent productivity φ and import status d_m equals $\varphi\lambda^{d_m}$. Thus average productivity measured using firms revenue shares as weights in each economy is given by

$$\bar{a}_A \equiv \int_0^\infty \left(\frac{\hat{r}_A(\varphi)}{R}\right) \varphi g(\varphi) d\varphi$$

$$\bar{a}_X \equiv \int_0^\infty \left(\frac{\hat{r}_X(\varphi)}{R}\right) \varphi g(\varphi) d\varphi$$

$$\bar{a}_M \equiv \int_{\underline{\epsilon}}^{\bar{\epsilon}} \left(\int_0^{\tilde{\varphi}_M(\varphi_M^*, \epsilon)} \left(\frac{\hat{r}_M(\varphi, \epsilon)}{R}\right) \varphi g(\varphi) d\varphi + \lambda \int_{\tilde{\varphi}_M(\varphi_M^*, \epsilon)}^\infty \left(\frac{\hat{r}_M(\varphi, \epsilon)}{R}\right) \varphi g(\varphi) d\varphi \right) h(\epsilon) d\epsilon \quad (56)$$

$$\begin{aligned} \bar{a}_T \equiv & \int_{\underline{\epsilon}}^{\epsilon_1} \left(\int_0^{\tilde{\varphi}_1(\varphi_T^*, \epsilon)} \left(\frac{\hat{r}_T(\varphi, \epsilon)}{R}\right) \varphi g(\varphi) d\varphi + \lambda \int_{\tilde{\varphi}_1(\varphi_T^*, \epsilon)}^\infty \left(\frac{\hat{r}_T(\varphi, \epsilon)}{R}\right) \varphi g(\varphi) d\varphi \right) h(\epsilon) d\epsilon \\ & + \int_{\epsilon_1}^{\epsilon_2} \left(\int_0^{\tilde{\varphi}_2(\varphi_T^*, \epsilon)} \left(\frac{\hat{r}_T(\varphi, \epsilon)}{R}\right) \varphi g(\varphi) d\varphi + \lambda \int_{\tilde{\varphi}_2(\varphi_T^*, \epsilon)}^\infty \left(\frac{\hat{r}_T(\varphi, \epsilon)}{R}\right) \varphi g(\varphi) d\varphi \right) h(\epsilon) d\epsilon \\ & + \int_{\epsilon_2}^{\bar{\epsilon}} \left(\int_0^{\tilde{\varphi}_3(\varphi_T^*, \epsilon)} \left(\frac{\hat{r}_T(\varphi, \epsilon)}{R}\right) \varphi g(\varphi) d\varphi + \lambda \int_{\tilde{\varphi}_3(\varphi_T^*, \epsilon)}^\infty \left(\frac{\hat{r}_T(\varphi, \epsilon)}{R}\right) \varphi g(\varphi) d\varphi \right) h(\epsilon) d\epsilon \quad (57) \end{aligned}$$

Now, as in Melitz(2003), equation (50) implies that the distribution $\frac{\hat{r}_X(\varphi)}{R} g(\varphi)$ first order stochastically dominates the distribution $\frac{\hat{r}_A(\varphi)}{R} g(\varphi)$. Thus, $\bar{a}_X > \bar{a}_A$; trade in final goods alone increases average productivity measured using revenue shares as weights. This occurs because resources are shifted away from less productive firms toward more productive ones.

Similarly, equation (52) implies that for all $\epsilon \in [\underline{\epsilon}, \bar{\epsilon}]$, $\frac{\hat{r}_M(\varphi,\epsilon)}{R} g(\varphi)$ first order stochastically dominates the distribution $\frac{\hat{r}_A(\varphi)}{R} g(\varphi)$. Furthermore, there is a direct increase in productivity from the increasing returns to variety in production which is captured by $\lambda > 1$ in the definition of average productivity given by $\bar{a}_M$ in equation (56). Thus $\bar{a}_M > \bar{a}_A$ so trade in intermediates alone increases average productivity both through the direct effect and through the reallocation of resources toward the most productive firms.

Finally, equation (55) implies that for all $\epsilon \in [\underline{\epsilon}, \bar{\epsilon}]$, $\frac{\hat{r}_T(\varphi,\epsilon)}{R} g(\varphi)$ first order stochastically dominates the distribution $\frac{\hat{r}_A(\varphi)}{R} g(\varphi)$. Thus, from equation (57), we see that because of the direct increase in productivity from the use of imported intermediates and the indirect increase due to reallocation of resources, trade in both final goods and intermediates increases this measure of average productivity.

A.4 Equilibrium Mass of Firms and Welfare

Let Z_S denote the equilibrium mass of firms in a country in economy $S \in \{A, X, M, T\}$ and let $\nu_S(d)$ denote the fraction of those firms with export/import status d. In autarky, aggregate profits equal

$$\Pi_A = \frac{R}{\sigma} - Z_A f = Z_A \left(\frac{\bar{r}_A}{\sigma} - f \right) = Z_A \bar{\pi}_A,$$

where $\bar{r}_A$ and $\bar{\pi}_A$ are average revenue and profits respectively. Thus, average revenue is related to average profit according to

$$\bar{r}_A = \sigma \left(\bar{\pi}_A + f \right) \tag{58}$$

In the economy with no trade in intermediates, aggregate profits equal

$$\Pi_X = \frac{R}{\sigma} - Z_X f - \nu_X(1,0) Z_X N f_x = Z_X \left(\frac{\bar{r}_X}{\sigma} - f - \nu_X(1,0) N f_x \right) = Z_X \bar{\pi}_X.$$

Thus, average revenue is related to average profit according to

$$\bar{r}_X = \sigma \left(\bar{\pi}_X + f + \nu_X(1,0) N f_x \right). \tag{59}$$

In the economy with no trade in final goods, aggregate profits equal

$$\Pi_M = \frac{R}{\sigma} - Z_M f - Z_M N \left(\int_{\underline{\epsilon}}^{\bar{\epsilon}} \int_{\tilde{\varphi}_M(\varphi_M^*,\epsilon)}^{\infty} (f_m + \epsilon) \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_M^*)} \right) h(\epsilon) d\epsilon \right)$$

$$= Z_M \left(\frac{\bar{r}_M}{\sigma} - f - N \left(\nu_M(0,1) f_m - \int_{\underline{\epsilon}}^{\bar{\epsilon}} \int_{\tilde{\varphi}_M(\varphi_M^*,\epsilon)}^{\infty} \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_M^*)} \right) h(\epsilon) d\epsilon \right) \right) = Z_M \bar{\pi}_M.$$

Thus, average revenue is related to average profit according to

$$\bar{r}_M = \sigma \left(\bar{\pi}_M + f + \nu_M(0,1) N f_m + N \int_{\underline{\epsilon}}^{\bar{\epsilon}} \int_{\tilde{\varphi}_M(\varphi_M^*,\epsilon)}^{\infty} \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_M^*)} \right) h(\epsilon) d\epsilon \right). \tag{60}$$

Finally, in the full trading economy aggregate profits equal

$$\Pi_T = \frac{R}{\sigma} - Z_T f - Z_T N \left(\int_{\epsilon_2}^{\bar{\epsilon}} \int_{\tilde{\varphi}_4(\varphi_T^*,\epsilon)}^{\tilde{\varphi}_3(\varphi_T^*,\epsilon)} f_x \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon \right.$$

$$+ \int_{\underline{\epsilon}}^{\epsilon_1} \int_{\tilde{\varphi}_1(\varphi_T^*,\epsilon)}^{\tilde{\varphi}_0(\varphi_T^*,\epsilon)} (f_m + \epsilon) \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon + \int_{\underline{\epsilon}}^{\epsilon_1} \int_{\tilde{\varphi}_0(\varphi_T^*,\epsilon)}^{\infty} \zeta (f_x + f_m + \epsilon) \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon$$

$$\left. + \int_{\epsilon_1}^{\epsilon_2} \int_{\tilde{\varphi}_2(\varphi_T^*,\epsilon)}^{\tilde{\varphi}_0(\varphi_T^*,\epsilon)} \zeta (f_x + f_m + \epsilon) \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon + \int_{\epsilon_2}^{\bar{\epsilon}} \int_{\tilde{\varphi}_3(\varphi_T^*,\epsilon)}^{\infty} \zeta (f_x + f_m + \epsilon) \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon \right)$$

$$= Z_T \left(\frac{\bar{r}_T}{\sigma} - f - N \left(f_x(\nu_T(1,0) + \nu_T(1,1)\zeta) + f_m(\nu_T(0,1) + \nu_T(1,1)\zeta \right) \right.$$

$$+ \int_{\underline{\epsilon}}^{\epsilon_1} \int_{\tilde{\varphi}_1(\varphi_T^*,\epsilon)}^{\tilde{\varphi}_0(\varphi_T^*,\epsilon)} \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon + \int_{\underline{\epsilon}}^{\epsilon_1} \int_{\tilde{\varphi}_0(\varphi_T^*,\epsilon)}^{\infty} \zeta \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon$$

$$\left. + \int_{\epsilon_1}^{\epsilon_2} \int_{\tilde{\varphi}_2(\varphi_T^*,\epsilon)}^{\infty} \zeta \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon + \int_{\epsilon_2}^{\bar{\epsilon}} \int_{\tilde{\varphi}_3(\varphi_T^*,\epsilon)}^{\infty} \zeta \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon \right) \Bigg) = Z_T \bar{\pi}_T.$$

Thus, average revenue is related to average profit according to

$$\bar{r}_T = \sigma \Bigg[\bar{\pi}_T + f + \nu_T(1,0) N f_x + \nu_T(0,1) N f_m + \nu_T(1,1) N \zeta (f_x + f_m)$$

$$+ N \int_{\underline{\epsilon}}^{\epsilon_1} \int_{\tilde{\varphi}_1(\varphi_T^*,\epsilon)}^{\tilde{\varphi}_0(\varphi_T^*,\epsilon)} \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon + N \zeta \left(\int_{\underline{\epsilon}}^{\epsilon_1} \int_{\tilde{\varphi}_0(\varphi_T^*,\epsilon)}^{\infty} \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon \right.$$

$$\left. + \int_{\epsilon_1}^{\epsilon_2} \int_{\tilde{\varphi}_2(\varphi_T^*,\epsilon)}^{\infty} \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon + \int_{\epsilon_2}^{\bar{\epsilon}} \int_{\tilde{\varphi}_3(\varphi_T^*,\epsilon)}^{\infty} \epsilon \left(\frac{g(\varphi) d\varphi}{1 - G(\varphi_T^*)} \right) h(\epsilon) d\epsilon \right) \Bigg] \tag{61}$$

Now in each economy GNP equals payments to labour so we have $R = Z_S \bar{r}_S = L$, where $\bar{r}_S$ denotes average revenue across operating firms. Thus the equilibrium mass of firms must equal

$$Z_S = \frac{L}{\bar{r}_S}. \tag{62}$$

So, using this equation and equations (58), (59), (60), and (61), we can determine the equilibrium mass of firms in each economy. We now demonstrate that $Z_A > Z_X$, $Z_A > Z_M$, and $Z_A > Z_T$.

Recall that $\bar{\pi}_A < \bar{\pi}_X < \bar{\pi}_T$ and $\bar{\pi}_A < \bar{\pi}_M$. This and inspection of equations (58), (59), (60), and (61) implies that $\bar{r}_A < \bar{r}_X$, $\bar{r}_A < \bar{r}_M$, and $\bar{r}_A < \bar{r}_T$. Thus, equation (62) implies that $Z_A > Z_X$, $Z_A > Z_T$ and $Z_A > Z_T$.

We now turn to welfare comparisons across economies. Recall that welfare in each economy is the inverse of the price index. Now, using the mark-up pricing equation in the home market as well as equation (39) and recalling that the firm with the cutoff productivity φ^*_S does not import nor export and that $R = L$, we have

$$P_S = p^h(\varphi^*_S, 0, 0) \left(\frac{r(\varphi^*_S, 0, 0)}{L} \right)^{\frac{1}{\sigma-1}} = \left(\frac{1}{\rho\Gamma\varphi^*_S} \right) \left(\frac{\sigma f}{L} \right)^{\frac{1}{\sigma-1}}.$$

Thus, aggregate welfare in economy S is equal to

$$W_S = (\rho\Gamma) \left(\frac{\sigma f}{L} \right)^{\frac{1}{1-\sigma}} \varphi^*_S,$$

and since $\varphi^*_A < \varphi^*_X < \varphi^*_T$ and $\varphi^*_A < \varphi^*_M < \varphi^*_T$, we have $W_A < W_X < W_T$ and $W_A < W_M < W_T$.

A.5 Import Restrictions

We show that in the economy with full trade, the fraction of firms exporting final goods and their revenue share is greater than in the economy with no trade in intermediates. Consider the variables on the axes of Figure 2:

$$\Phi \equiv \left(\frac{\varphi}{\varphi^*} \right)^{\sigma-1} \left(\frac{f}{N} \right), \qquad let \qquad \theta \equiv f_m + \epsilon.$$

Since these variables are monotonically increasing functions of φ and ϵ, respectively, they will have the same densities and cdfs as those variables. Using, Figure 2, we see that the fraction of firms who export in the full trading equilibrium can be written as

$$\nu^x_T \equiv \nu_T(1,0) + \nu_T(1,1) = \left(\frac{1}{1 - G(f/N)} \right) \left(\int_{\underline{\theta}}^{\theta_1} (1 - G(\Phi_x(1, \theta - f_m))\, h(\theta) d\theta \right.$$

$$\left. + \int_{\theta_1}^{\theta_2} (1 - G(\Phi_{xm}(\theta - f_m)))\, h(\theta) d\theta + \int_{\theta_2}^{\bar{\theta}} (1 - G(\Phi_x(0, \theta - f_m)))\, h(\theta) d\theta \right),$$

where $\underline{\theta} \equiv f_m + \underline{\epsilon}$, $\theta_j \equiv f_m + \epsilon_j$, and $\bar{\theta} \equiv f_m + \bar{\epsilon}$. First note that when $b_m \to 1$, this fraction equals the fraction of exporting firms in the economy with no trade in intermediates, $\nu_X(1,0)$. We will show that ν^x_T is increasing in b_m which implies that the fraction of exporting firms is higher in the full trade economy.

Now in the above expression θ_1, θ_2, $\Phi_x(1,\cdot)$, and $\Phi_{xm}(\cdot)$ depend upon b_m, so changes in b_m will affect the fraction of exporting firms through its effect on these variables. The derivatives of the right-hand side of this expression with respect to θ_1 and with respect to θ_2 equal zero (because $\Phi_x(1,\cdot) = \Phi_{xm}(\cdot)$ at θ_1 and $\Phi_x(0,\cdot) = \Phi_{xm}(\cdot)$ at θ_2). Dropping the ϵ arguments of the cutoff functions, the elasticity of ν_T^x with respect to b_m, is given by

$$\hat{\nu}_T^{xb_m} = \frac{-\left(\int_{\underline{\theta}}^{\theta_1} g(\Phi_x(1))\Phi_x(1)\hat{\Phi}_x^{b_m}(1)h(\theta)\theta + \int_{\theta_1}^{\theta_2} g(\Phi_{xm})\Phi_{xm}\hat{\Phi}_{xm}^{b_m}h(\theta)\theta\right)}{(1-G(f/N))\nu_T^x} \tag{63}$$

Taking derivatives of $\Phi_x(d,\epsilon)$ and $\Phi_{xm}(\epsilon)$, we can derive the following elasticities with respect to b_m:

$$\hat{\Phi}_x(1) = -1 < 0, \qquad \hat{\Phi}_{xm} = \frac{-b_x b_m}{b_x b_m - 1} < 0.$$

Since these elasticities are both negative, $\hat{\nu}_T^{xb_m}$ must be positive.

Turning to revenue shares, we see from equation (39) that revenue shares in the full trading economy can be written as

$$\frac{r_T(\varphi,d)}{R} = \frac{b_x^{d_x} b_m^{d_m} N\sigma\Phi}{R}$$

Thus, the share of revenue by exporting firms in the full trading economy equals

$$\frac{r_T^x}{R} = \left(\frac{b_x N\sigma}{R(1-G(f/N))}\right)\left(b_m\left(\int_{\underline{\theta}}^{\theta_1}\left(\int_{\Phi_x(1,\theta-f_m)}^{\infty}\Phi g(\Phi)d\Phi\right)h(\theta)d\theta + \int_{\theta_1}^{\theta_2}\left(\int_{\Phi_{xm}(\theta-f_m)}^{\infty}\Phi g(\Phi)d\Phi\right)h(\theta)d\theta\right)\right.$$
$$\left.+\int_{\theta_2}^{\bar{\theta}}\left(\int_{\Phi_x(0,\theta-f_m)}^{\infty}\Phi g(\Phi)d\Phi\right)h(\theta)d\theta\right)\Bigg),$$

Now since these revenue shares equal the revenue shares of exporters in the economy with no trade in intermediates when $b_m \to 1$, it is sufficient to show that these revenue shares are increasing in b_m to show that restricting intermediate trade decreases the market share of exporting firms. Again dropping the ϵ arguments in the cutoff functions, the elasticity of exporters market shares with respect to b_m are given by

$$\frac{\hat{r}_T^{x\,b_m}}{R} = \left(\frac{b_m R}{r_T^x(1-G(f/N))}\right)\left(\left(\int_{\underline{\theta}}^{\theta_1}\left(\int_{\Phi_x(1,\theta-f_m)}^{\infty}\Phi g(\Phi)d\Phi\right)h(\theta)d\theta + \int_{\theta_1}^{\theta_2}\left(\int_{\Phi_{xm}(\theta-f_m)}^{\infty}\Phi g(\Phi)d\Phi\right)h(\theta)d\theta\right)\right.$$
$$\left.-\left(\int_{\underline{\theta}}^{\theta_1} g(\Phi_x(1))\Phi_x(1)^2\hat{\Phi}_x^{b_m}(1)h(\theta)\theta + \int_{\theta_1}^{\theta_2} g(\Phi_{xm})\Phi_{xm}^2\hat{\Phi}_{xm}^{b_m}h(\theta)\theta\right)\right),$$

which is clearly positive since the elasticities of the cutoff functions were shown to be negative above.

B Properties of Type I Extreme-Value Distributions

Here, we discuss the properties of the Type I extreme-value distributed random variables. Assume that $\epsilon(0)$ and $\epsilon(1)$ are independently drawn from the identical extreme-value distribution with mean zero and variance $\frac{\varrho^2\pi^2}{6}$, where ϱ is the shape parameter.[34] Let $V(0)$ and $V(1)$ be real numbers. We have the following two properties of extreme-value distributed random variables:
Property One:

$$E[\max(V(0)+\epsilon(0), V(1)+\epsilon(1)] = \varrho \ln[\exp(V(0)/\varrho) + \exp(V(1)/\varrho)],$$

where the expectation is taken with respect to the distribution of $\epsilon(0)$ and $\epsilon(1)$.
Property Two:

$$P(V(0)+\epsilon(0) > V(1)+\epsilon(1)) = \frac{\exp(V(0)/\varrho)}{\exp(V(0)/\varrho)+\exp(V(1)/\varrho)}.$$

In the multivariate case, when we have $\epsilon(d)$ for $d = 0, 1, 2, ..., J$, Property One is

$$E[\max_{j=0,1,...,J} V(j) + \epsilon(j)] = \varrho \ln[\sum_{j=0}^{J} \exp(V(j)/\varrho)].$$

Property Two is

$$P[V(d)+\epsilon(d) > V(j)+\epsilon(j) \text{ for all } j \neq d] = \frac{\exp(V(d)/\varrho)}{\sum_{j'=0}^{J} \exp(V(j')/\varrho)}.$$

[34] The cumulative distribution function of $\epsilon(d)$ for $d = 0, 1$ is $\exp(-\exp(-(\epsilon(d) - \gamma)))$, where γ is Euler's constant.

C Estimation Methods

A firm's optimization problem is recursively written in terms of the Bellman's equation as

$$\begin{aligned} V(\eta, d_{t-1}) &= \int \max\{\epsilon^{\chi}(0), W(\eta, d_{t-1}) + \epsilon^{\chi}(1)\} dH^{\chi}(\epsilon^{\chi}), \\ W(\eta, d_{t-1}) &= \int \max\{J(\eta, d_{t-1}, D_0) + \epsilon^D(D_0), J(\eta, d_{t-1}, D_1) + \epsilon^D(D_1)\} dH^D(\epsilon^D), \\ J(\eta, d_{t-1}, D) &= \begin{cases} \pi(\eta, d_{t-1}, (0,0)) + \beta(1-\xi)V(\eta, (0,0)), & \text{for } D = D_0, \\ \int \left(\max_{d' \in D_1} \pi(\eta, d_{t-1}, d') + \beta(1-\xi)V(\eta, d') + \epsilon^d(d')\right) dH^d(\epsilon^d) & \text{for } D = D_1, \end{cases} \end{aligned}$$

By using the properties of the type I extreme-value distributed random variables as presented above, we may write these equations as

$$V(\eta, d_{t-1}) = \varrho^{\chi} \ln(\exp(0) + \exp(W(\eta, d_{t-1})/\varrho^{\chi})) \tag{64}$$

$$W(\eta, d_{t-1}) = \varrho^D \ln\left(\sum_{D \in \{D_0, D_1\}} \exp\left(J(\eta, d_{t-1}, D)/\varrho^D\right)\right) \tag{65}$$

$$J(\eta, d_{t-1}, D) = \begin{cases} \pi(\eta, d_{t-1}, (0,0)) + \beta(1-\xi)V(\eta, (0,0)), & \text{for } D = D_0, \\ \varrho^d \ln\left(\sum_{d' \in D_1} \exp\left([\pi(\eta, d_{t-1}, d') + \beta(1-\xi)V(\eta, d')]/\varrho^d\right)\right), & \text{for } D = D_1, \end{cases} \tag{66}$$

While the model we present in the paper assumes a continuous state space of η, in practice we solve an approximated model with a finite number of grid points. The continuous state space of φ is approximated by 30 grid points uniformly distributed between -6 and 6 while the continuous state space of z_x and z_m is approximated by 20 grid points uniformly distributed between 0 and 1 together with two extra grid points at 0.0001 and 0.9999 to capture the probability mass around 0 and 1. Thus, the continuous state space of $\eta = (\varphi, z_x, z_m)$ is approximated by $N_\eta = 14520 (= 30 \times 22 \times 22)$ points. The distribution function of η is accordingly approximated by multinomial distribution.

Let η^k and ω^k ($k = 1, ..., 14520$) be the grid points and weights associated with the multinomial distribution, respectively. Then, for each η^k, we find the fixed point of the Bellman equations by iterating on (64)-(66) starting from an initial guess $W^{(0)}(\eta^k) = 0$ until it converges (i.e., successive approximation). Once the fixed point of (64)-(66) is computed, then we may evaluate the conditional choice probabilities

$$P(\chi_t = 1 | \eta^k, d_{t-1}) = (1-\xi) \frac{\exp(W(\eta^k, d_{t-1})/\varrho^{\chi})}{\exp(0) + \exp(W(\eta^k, d_{t-1})/\varrho^{\chi})},$$

$$P(d_t|\eta^k, d_{t-1}, \chi = 1) = \begin{cases} P(D_0|\eta^k, d_{t-1}, \chi = 1) & \text{for } d_t \in D_0, \\ P(D_1|\eta^k, d_{t-1}, \chi = 1)P(d_t|\eta^k, d_{t-1}, \chi = 1, D = D_1), & \text{for } d_t \in D_1, \end{cases}$$

where

$$\begin{aligned} P(D|\eta^k, d_{t-1}, \chi = 1) &= \frac{\exp(J(\eta^k, d_{t-1}, D)/\varrho^D)}{\sum_{D' \in \{D_0, D_1\}} \exp(J(\eta^k, d_{t-1}, D')/\varrho^D)}, \\ P(d_t|\eta^k, d_{t-1}, \chi = 1, D = D_1) &= \frac{\exp([\pi(\eta^k, d_{t-1}, d_t) + \beta(1-\xi)V(\eta^k, d_t)]/\varrho^d)}{\sum_{d' \in D_1} \exp([\pi(\eta^k, d_{t-1}, d') + \beta(1-\xi)V(\eta^k, d')]/\varrho^d)}. \end{aligned}$$

for $k = 1, 2, ..., N_\eta$.

The stationary distribution $\mu^*(\eta, d)$ is computed from the following conditions that correspond to (23) and (24):

$$M \sum_{k=1}^{N_\eta} \sum_{d'} P(\chi = 0|\eta^k, d')\mu^*(\eta, d') = M_e \sum_{k=1}^{N_\eta} \omega^k P(\chi = 1|\eta^k, d_{t-1} = (0,0)), \tag{67}$$

and

$$M\mu^*(\eta^k, d) = M \sum_{d'} P(d, \chi = 1|\eta^k, d')\mu^*(\eta^k, d') + M_e \omega^k P(d, \chi = 1|\eta^k, d_{t-1} = (0,0)) \quad \text{for all } (\eta^k, d). \tag{68}$$

On the other hand, the density of initial draws upon successful entry $g_e(\eta)$ is evaluated at η^k as

$$g_e(\eta^k) = \frac{\omega^k P(\chi = 1|\eta^k, d_{t-1} = (0,0))}{\sum_{j=1}^{N_\eta} \omega^j P(\chi = 1|\eta^j, d_{t-1} = (0,0))}. \tag{69}$$

Using these two density functions, we may evaluate the likelihood contribution from plant i as:

$$L_i(\theta) = \begin{cases} \sum_{k=1}^{N_\eta} L_i(\theta|\eta^k, d_{i,T_{i,0}})\mu^*(\eta^k, d_{i,T_{i,0}}) & \text{for } T_{i,0} = 1990, \\ \sum_{k=1}^{N_\eta} L_i(\theta|\eta^k, d_{i,T_{i,0}})P_\theta(d_{i,T_{i,0}}|\eta^k, d_{i,T_{i,0}-1} = (0,0))g_e(\eta^k) & \text{for } T_{i,0} > 1990. \end{cases}$$

where $L_i(\theta|\eta', d_{it})$ is defined as in the main text.

The parameter θ is estimated by maximizing $\sum_{i=1}^N \ln L_i(\theta)$ with $L_i(\theta)$ defined above. To estimate, we first use the Nelder-Mead simplex method to get the estimate in the neighborhood of the maximum and then use the BFGS quasi-Newton method to find the maximum.

We also note that the variables defined at the steady state reported in Figures 4-6 as well as Tables 8-10 are computed by using the approximated density at the steady state defined by

(67)-(68) evaluated at the estimated parameters.