

Establishment Heterogeneity, Exporter Dynamics, and the Effects of Trade Liberalization *

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Abstract

We study the effects of tariffs in a dynamic variation of the Melitz (2003) model, a monopolistically competitive model with heterogeneity in productivity across establishments and fixed costs of exporting. With fixed costs of starting to export that are on average 3.7 times as large as the costs incurred to continue as an exporter, the model can match both the size distribution of exporters and annual transition in and out of exporting among US manufacturing establishments. We find the tariff equivalent of these fixed costs is nearly 30 percentage points. We use the calibrated model to estimate the effect of reducing tariffs on welfare, trade, and export participation. We find sizeable gains to moving to free trade equivalent to 1.03 percent of steady state consumption. Considering the transition dynamics following the cut in tariffs, we find that the model predicts economic activity overshoots its steady state, with the peak in output coming 10 years after the trade reform. Because of this overshooting, steady state changes in consumption understate the welfare gain to trade reform. We also find simpler trade models that abstract from these export dynamics provide a poor approximation of the aggregate responses from our more general model.

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1. Introduction

Recent evidence of substantial differences between exporters and non-exporters has led Melitz (2003) to develop a general equilibrium theory of international trade that emphasizes productive heterogeneity across many monopolistically competitive establishments facing fixed costs of exporting. This theory is consistent with the evidence that the biggest, most productive establishments do the bulk of exporting and evidence of large fixed costs of exporting.¹ In this theory, tariffs and trade barriers reduce the value of exporting and thus discourage some relatively productive establishments from incurring the fixed cost to export. This lowers trade flows and shifts production away from relatively productive establishments toward relatively unproductive non-exporters. Reducing tariffs encourages entry into exporting by relatively productive establishments and reallocates production toward these relatively productive exporters. Melitz (2003), Eaton and Kortum (2002), and Alvarez and Lucas (2007) emphasize that this reallocation across heterogeneous producers is an important source of the welfare gains to lowering trade barriers.² In this paper, we evaluate quantitatively the impact of reducing tariffs on welfare, trade, and the organization of production in a particular variation of the Melitz model that captures key cross-sectional and dynamic elements of establishments and exporters in the US economy. Our analysis quantifies how the nature of trade costs and plant heterogeneity determine the aggregate response to a trade liberalization.

Before examining the aggregate implications of lowering tariffs, our first goal is to find out whether the cross-plant distribution of export participation³ and transitions into and out of exporting generated by a model with fixed costs of exporting are consistent with the data. To do this, we introduce elements of Dixit's (1989) partial equilibrium model of plant dynamics and exporting into the general equilibrium Melitz framework.⁴ This involves three main modifications to the Melitz

¹Many papers infer the presence of fixed export costs with a large up-front sunk aspect from the persistent exporting behavior of firms (see Roberts and Tybout, 1997, Campa, 2004, Bernard and Jensen, 2004, Bernard and Wagner, 2001, and Das Roberts and Tybout, 2007).

²The Eaton and Kortum (2002) model is a multicountry version of the Dornbusch-Fisher-Samuelson model with a continuum of goods and idiosyncratic differences across producers. The model is competitive and has no fixed trade costs.

³Eaton, Kortum, and Kramarz (2010) also study the ability of a Melitz model to explain the cross-sectional distribution of export participation. That paper focuses on the number of markets that producers export to rather than the dynamics of exporting.

⁴Alessandria and Choi (2007) and Irarrazabal and Oromolla (2007) also develop general equilibrium models with sunk export costs and persistent idiosyncratic productivity differences. In Irarrazabal and Oromolla, persistent productivity differences arise from plant-level TFP shocks, while in Alessandria and Choi these differences arise from differences in capital accumulation of exporters and non-exporters.

model to allow for richer establishment and exporter dynamics.⁵ First, we subject plants to persistent, idiosyncratic shocks to productivity. Second, we assume individual establishments face a large, up-front cost of starting to export and a smaller, period-by-period cost of continuing to export. We follow the literature in describing the startup cost as being sunk since the investment has no residual value when the plant stops exporting. Third, following Das, Roberts and Tybout (2007) we assume there are temporary, idiosyncratic shocks to the fixed costs of exporting. In the presence of idiosyncratic shocks to technology and fixed export costs, nonexporting establishments start exporting only when the expected value of exporting covers the startup costs. Exporters continue to export as long as the value of doing so exceeds the continuation cost. This generates what Baldwin and Krugman (1989) call *exporter hysteresis* in that establishments continue to export even after their production costs have risen far above the levels that led them to start exporting. Exporter hysteresis implies that some relatively unproductive establishments export and some relatively productive establishments sell only at home, and it is important in getting the model to match both the high persistence of exporting and the substantial dispersion in the size of exporters among US manufacturing establishments.⁶

Our calibration provides an estimate of the precise nature of trade costs faced by US manufacturers divided between variable, startup, and continuation costs. Consistent with the common view in the theoretical work of Dixit (1989) and Baldwin and Krugman (1989) and the empirical findings by Das, Roberts, and Tybout (2007) in a structural analysis of export behavior of 136 Colombian plants,⁷ we find the costs of starting to export are quite large. For US plants we find the average cost of starting to export is roughly 3.7 times the average cost of continuing to export, or equivalent to \$745,000 (\$1992). To put these costs into perspective, the average cost to start exporting incurred is equal to nearly 1 year (4 years) of the export profits of the average (median) exporter. Since exporters are much larger than non-exporters, this cost is a formidable barrier to exporting. In the aggregate, we estimate that the resources devoted to startup costs and continuation costs account for about 25 percent and 28 percent, respectively, of export profits.⁸ In a model without any fixed costs, variable trade costs

⁵Atkeson and Burstein (2006) develop a model of firm dynamics to study the relation between innovation and trade.

⁶Eaton, Kortum, and Kramarz (forthcoming) use a static variation of the Melitz model to study exporting across multiple destinations by French manufacturers.

⁷Bernard and Jensen (2004) also find evidence that US manufacturing establishments face sunk costs of starting to export, but do not quantify the magnitude of these costs.

⁸The near equal importance of continuation costs in the aggregate is a result of the low entry rates into exporting. Most exporters are continuing exporters that are paying the continuation cost.

must be nearly 68 percent larger to generate the same trade (i.e. move from 45.1 percent to 75.7 percent). The high tariff equivalent of these fixed trade costs can partially explain why direct measures of trade costs are so much lower than model-based measures inferred from trade flows (Anderson and van Wincoop, 2004).⁹

Since the model generates exporter characteristics and transitions consistent with US manufacturing plant-level data, our second goal is to use the calibrated model to evaluate how tariffs affect the structure of the economy, namely the number of active producers, export participation, trade, and most importantly welfare. We find that a global reduction of tariffs from 8 percent to free trade increases the total number of available tradable varieties by 11.1 percent but lowers the number of available non-tradable varieties by 0.5 percent. The increase in tradable varieties is a result of a 2.2 percent fall in the number of domestic tradable establishments and a near doubling of export participation, from 22.3 percent of establishments to 39.0 percent. Thus the model predicts a consolidation of production in fewer establishments. The increase in export participation arises from a lowering of both the productivity threshold of non-exporters to start exporting and the productivity threshold of exporters to continue exporting. Consequently, the duration of each exporting spell rises from an average of 5.9 years¹⁰ to 9.1 years. In total, the model predicts an 92.3 percent increase in trade. These changes in export participation and establishments result in a sizeable 0.84 percent rise in steady state consumption.

Our dynamic model also permits us to study the aggregate transition dynamics following an unanticipated move to free trade. Considering this transition period, we find that steady state consumption understates the welfare gain by about 20 percent, since along the transition the economy overshoots the new steady state, with consumption peaking 10 years after the reform at 0.4 percent above its long-run level. The boom in economic activity occurs because tariffs lead to the creation of too many tradable establishments and not enough exporters relative to the free trade steady state. When tariffs are lowered, existing establishments can now be used effectively to produce new varieties for the foreign market by incurring the startup export cost. In addition, current exporters, which have already incurred the big startup cost to export, find it worthwhile to continue exporting longer and thus

⁹For another source of the mismeasured size of trade costs that focuses on shipment level transactions costs, see Alessandria, Kaboski, and Midrigan (2010).

¹⁰This is calculated as the inverse of the annual rate of exit from exporting.

the return on that past investment in export capacity increases. Both margins allow the investment embodied in existing establishments and exporters to be used more effectively along the transition. This overshooting behavior disappears when there is no sunk aspect to export costs. The transition is slowed further when plant productivity is no longer stochastic but instead determined at birth.

Having estimated the aggregate response to a trade liberalization in our benchmark model, we then ask: Do models that abstract from the key empirical features of plant or exporter dynamics emphasized here, and elsewhere, approximate the findings of our more general model? A natural reference is a model without any fixed costs of trade so that all establishments are exporters. In this variation of the Krugman (1980) model, we find that steady state consumption grows by 1.01 percent or nearly 20 percent more than our benchmark. Because this is a variation of the neoclassical growth model, including the transition though yields a welfare gain of only 0.73 percent, about 30 percent less than in our benchmark. Moreover, because this simpler model lacks an extensive margin to trade, the trade response is now roughly half that of our benchmark model while the effect on the number of active producers is also quite different. Indeed, in the Krugman model, a cut in tariffs expands the number of producers of tradable goods. If we adjust the elasticity of substitution across varieties so that the Krugman model generates the same change in trade as in our benchmark model, we find that the welfare gain is now about 40 percent of our benchmark model. Thus, we find that the nature of trade costs and plant heterogeneity are important determinants of both the welfare gain and trade response to a change in tariffs.

One might argue that these differences across models are quite small since the US tariffs are already fairly low. To explore this we evaluate the benefits of the current level of trade relative to autarky. In our benchmark model with sunk startup costs, we find that steady state consumption is now 0.76 percent above the level under autarky while in the Krugman model steady state consumption is 2.77 percent above the autarky level. Thus, again we find that the nature of trade costs substantially affect the gains to international trade.

Our finding that the nature of trade costs and plant heterogeneity matters for the welfare gains to tariff reductions is in contrast to some recent work that shows analytically under certain parametric assumptions the gains from reducing trade costs, but not necessarily tariffs, is the same across models with and without fixed costs of exporting (see Arkolakis, Demidova, Klenow, and Rodriguez-Clare, 2008, and Arkolakis, Costinot, and Rodriguez-Clare, 2009). While there is no reason to expect these

theoretical results should hold in the more general dynamic model with multiple factors of production, plant dynamics, and sunk export costs that we work with, we explore the source of these differences in some variations of our benchmark economy. Again, we find that the main differences arise because of the presence of sunk costs and plant dynamics. When there is no sunk aspect of export costs and all plant-level idiosyncratic uncertainty is resolved at plant creation we find that the welfare gain to a cut in tariffs is nearly the same across models with or without fixed costs even though the trade response is quite different.

A final methodological contribution of this paper is to apply quantitative methods to the study of the aggregate response to changes in trade barriers in a dynamic, general equilibrium model with heterogeneous producers and endogenous exporting. We show how standard dynamic programming tools can be used to solve for the stationary steady state of this model. Applying quantitative methods allows us to consider a more general shock process for individual plant dynamics and different structure of trade costs than commonly employed in the theoretical literature. Moreover, these methods allow us to solve for the first time the transition dynamics to a trade liberalization in a model with sunk export costs and plant dynamics.¹¹ That we find that transition dynamics, the nature of trade costs, and plant heterogeneity are crucial to estimate the aggregate response to trade policies, suggest that quantitative methods offer an important complement to the analytical approach more commonly employed in international trade.

This paper is related to three lines of research. First, our focus on the welfare gains to trade is similar to the work by Eaton and Kortum (2002), Bernard, Eaton, Jensen, and Kortum (2003), and Alvarez and Lucas (2007).¹² These papers evaluate the aggregate consequences of a trade liberalization in a parsimonious static, multicountry Ricardian models with productivity heterogeneity, tariffs, and transportation costs. Unlike these papers, we consider a dynamic model with entry and exit to exporting subject to sunk costs and allow for capital accumulation under a monopolistically competitive market environment. The second line of research studies how the nature of trade costs influence the propagation of business cycles across countries. In particular, Baldwin and Krugman (1989) and Dixit (1989)

¹¹Chaney (2005) discusses the dynamics of trade and establishment dynamics following a trade liberalization in a variation of the Melitz model without plant dynamics or a sunk aspect of exporting, but does not solve for the transition path.

¹²Baldwin and Forslid (2006) discuss the welfare gains to trade reform in the Melitz model. They point out that trade reform may result in a reduction in the number of varieties available. Baldwin and Robert-Nicoud (2005) discuss the growth implications in the Melitz model.

develop partial equilibrium models of sunk costs of exporting and use them to study trade flows in response to exogenous exchange rate shocks. Roberts and Tybout (1997) and Das, Roberts, and Tybout (2007) develop these models further and use them to estimate structurally the sunk costs of exporting as well as the trade response to a depreciation of the exchange rate. As partial equilibrium studies these papers cannot evaluate welfare or the aggregate effect of tariffs on the organization of production. More recent work by Ruhl (2003), Alessandria and Choi (2007), and Ghironi and Melitz (2005), study how fixed costs affect international business cycle fluctuations in two-country general equilibrium models. Ruhl is probably closest in spirit to our work here in that he also calibrates a model of plant heterogeneity with sunk export cost to the US economy and then considers the aggregate response of trade to a cut in tariffs. He then compares the trade response to a tariff cut to the trade response over the business cycle, finding the response is smaller over the business cycle. Aside from a different focus than Ruhl, our model allows for richer plant dynamics and movements into and out of export. Moreover, we explicitly consider the transition dynamics following a tariff reduction while Ruhl considers the change in the stationary steady state. Third, and more broadly, our paper is related to the macroeconomic literature that studies the impact of producer-level non-convexities in adjustment for aggregate outcomes. For instance, Hopenhayn and Rogerson (1993) quantify the welfare costs of national labor market policies such as firing taxes that affect plant-level adjustment to idiosyncratic shocks. Caballero and Engel (1999) and Khan and Thomas (2008) explore how non-convex adjustment costs in investment affect the propagation of shocks over the business cycle while Golosov and Lucas (2004) and Midrigan (forthcoming) demonstrate that the propagation of monetary shocks depends on the nature of non-convex costs of price adjustment and idiosyncratic shocks. Finally, Atkeson and Kehoe (2005, 2007) show that plant dynamics are central to measuring the stock of organizational capital as well as understanding the transition following technological revolutions such as the Industrial Revolution.

The paper is organized as follows. The next section develops a two-country dynamic general equilibrium model with endogenous export penetration and sunk costs of exporting. Section 3 discusses the calibration of the model and the distribution of establishments and export participation. Section 4 discusses the relationship between tariffs, exporter characteristics, trade, and welfare in the steady state of the model. In Section 5 we examine the transition dynamics following an unanticipated worldwide elimination of tariffs. In Section 6, we investigate the sensitivity of our quantitative results to different

trade costs and plant heterogeneity. Section 7 concludes. The appendix describes our solution methods.

2. The Model

In this section, we develop a model that contains the key features of the Melitz model: producer heterogeneity and fixed costs of exporting.¹³ This model is largely silent on plant and exporter dynamics and so we extend it along the lines of Dixit (1989) and Das, Roberts, and Tybout (2007) to allow for plant-level uncertainty and startup and continuations costs of exporting. This allows us to capture the main aspects about exporter characteristics and transitions.¹⁴

Each period there is a mass of existing establishments distributed over countries, sectors, productivity, fixed export costs, and export status. Productivity and fixed export costs are stochastic and generate movements of establishments into and out of exporting. Unproductive establishments also shutdown and new establishments are created by incurring a cost.

Given our focus on plant dynamics we assume there are two symmetric countries,¹⁵ *home* and *foreign*. Each country is populated by a continuum of identical, infinitely lived consumers with mass of one. Each period, consumers are endowed with a fixed L units of labor and supply them inelastically in the labor market.

In each country there are two intermediate good sectors, tradable and non-tradable. In each sector, there is a large number of monopolistically competitive establishments, each producing a differentiated good. The mass of varieties in the tradable and non-tradable goods sectors are $N_{T,t}$ and $N_{N,t}$, respectively. A non-tradable good producer uses capital and labor inputs to produce its variety, whereas a tradable good producer uses capital, labor, and material inputs to produce its variety.¹⁶ In each sector, establishments differ in terms of total factor productivity, the size of exporting fixed cost, and the markets they serve.

We largely follow Das, Roberts, and Tybout (2007) in modelling establishments heterogeneity in the tradable sector. Specifically, all establishments sell their product in their own country, but only

¹³Unlike the Melitz model we do not have fixed costs of continuing to produce. Instead, we capture the higher exit rates of small establishments in the shock process we consider.

¹⁴Ruhl and Willis (2007) study how both the persistence and intensity of exporting vary with the duration of exporting in a panel of Columbian manufacturers. Eaton, Eslava, Kugler, and Tybout (2008) study similar issues using transaction level data from nearly the universe of Columbian firms over a different period.

¹⁵Eaton, Kortum, and Kramarz (2010) consider a static multi-country version of the Melitz model.

¹⁶We introduce materials into the tradable sector to be consistent with the observation that trade as a share of gross output is considerably smaller than trade as a share of value-added.

some establishments export their goods abroad. When an establishment exports it must incur some international trading cost. The establishment pays tariffs to the government of the destination country with an ad valorem tariff rate of τ in addition to an ad valorem transportation cost with the rate of ξ .¹⁷ Additionally, the establishment incurs a fixed cost to export. The size of the cost depends on the producer's export status in the current period and an idiosyncratic fixed cost shock. We assume there is a (relatively) high up-front cost $f_0 e^v > 0$ that must be borne to gain entry into the export market next period. Here, v is an idiosyncratic shock that an establishment draws each period and shifts the startup cost. In subsequent periods, to continue exporting in the following period, establishments incur a lower but nonzero period-by-period continuation cost $f_1 e^v < f_0 e^v$. If an establishment does not pay this continuation cost, then it no longer exports in the next period. In future periods, the establishment can begin exporting only by incurring the entry cost $f_0 e^v$ again, where ν is a new draw. These costs are valued in units of labor in the domestic country. The cost of exporting implies that the set of goods available to consumers and establishments differs across countries and is changing over time. We assume that the fixed costs must be incurred in the period prior to exporting. This implies that the set of foreign varieties is fixed at the start of each period. All the establishments are owned by domestic consumers.

Any potential establishment can enter either the tradable or non-tradable sector by hiring f_E domestic workers. Once an establishment enters a particular sector though, it is unable to switch sectors. New entrants can actively produce goods and sell their products from the following period on.

The measure of home country tradable establishments with technology z , fixed cost shock, v , and export status, $m = 1$ for exporters and $m = 0$ for non-exporters, equals $\varphi_{T,t}(z, v, m)$. The measure of home country non-tradable establishments with technology z equals $\varphi_{N,t}(z)$. The distribution of establishments over technology, fixed cost shock, exporting status and sector are part of the aggregate state variable. The evolution of this distribution is central to our quantitative results.

In each country, competitive final goods producers purchase intermediate inputs from those establishments actively selling in that country.¹⁸ These final goods are used for both domestic consumption and investment.

¹⁷The transportation costs are 'iceberg'. For one unit of good to be arrived at destination, $1+\xi$ units should be shipped.

¹⁸Final good production technology does not require capital or labor inputs. The final good production technology regulates a country's preferences over local and imported varieties.

In this economy, there exists a one-period nominal bond denominated in the home currency. Let B_t denote the home consumer's holding of the bonds purchased in period t . Let B_t^* denotes the foreign consumer's holding of this bond. The bond pays 1 unit of home currency in period $t + 1$. Let Q_t denote the nominal price of the bond B_t .

A. Consumers

Home consumers choose consumption, investment, and bonds to maximize utility:

$$V_{C,0} = \max \sum_{t=0}^{\infty} \beta^t U(C_t),$$

subject to the sequence of budget constraints,

$$P_t C_t + P_t K_t + Q_t B_t \leq P_t W_t L_t + P_t R_t K_{t-1} + (1 - \delta) P_t K_{t-1} + B_{t-1} + P_t \Pi_t + P_t T_t,$$

where β is the subjective time discount factor with $0 < \beta < 1$; P_t is the price of the final good; C_t is the consumption of final goods; K_{t-1} is the capital available in period t ; Q_t and B_t are the price of bonds and the bond holdings; W_t and R_t denote the real wage rate and the rental rate of capital; δ is the depreciation rate of capital; Π_t is the sum of real dividends from the home country's producers; and T_t is the real lump-sum transfer from the home government.

The problem of foreign consumers is analogous to this problem. Prices and allocations in the foreign country are represented with an asterisk. Money has no role in this economy and is only a unit of account. The foreign budget constraint is expressed as

$$P_t^* C_t^* + P_t^* K_t^* + \frac{Q_t}{e_t} B_t^* \leq P_t^* W_t^* L_t^* + P_t^* R_t^* K_{t-1}^* + (1 - \delta) P_t^* K_{t-1}^* + \frac{B_{t-1}^*}{e_t} + P_t^* \Pi_t^* + P_t^* T_t^*,$$

where $*$ denotes the foreign variables and e_t is the nominal exchange rate with home currency as numeraire.¹⁹

¹⁹ An increase in e_t means a depreciation of domestic currency.

The first order conditions for home consumers' utility maximization problems are

$$Q_t = \beta \frac{U_{C,t+1}}{U_{C,t}} \frac{P_t}{P_{t+1}},$$

where $U_{C,t}$ denotes the derivative of the utility function with respect to its argument. The price of the bond is standard. From the Euler equations of two countries, we have the growth rate of the real exchange rate, $q_t = e_t P_t^* / P_t$,

$$\frac{q_{t+1}}{q_t} = \frac{U_{C,t+1}^* / U_{C,t}^*}{U_{C,t+1} / U_{C,t}}.$$

B. Final Good Producers

In the home country, final goods are produced by combining home and foreign intermediate goods. A final good producer can purchase from any of the home intermediate good producers but can purchase only from those foreign tradable good producers that are actively selling in the home market.

The production technology in this sector is a Cobb-Douglas function of tradable and non-tradable aggregate inputs, $D_{T,t}$ and $D_{N,t}$, with tradable share γ

$$(1) \quad D_t = D_{T,t}^\gamma D_{N,t}^{1-\gamma},$$

where D_t is the output of final goods and $D_{T,t}$ and $D_{N,t}$ are the aggregates of tradable and non-tradable goods, respectively. The aggregation technology is a constant elasticity of substitution (henceforth CES) function

$$(2) \quad D_{T,t} = \left[\sum_{m=0}^1 \int_v \int_z y_{H,t}^d(z, v, m)^{\frac{\theta-1}{\theta}} \varphi_{T,t}(z, v, m) dz dv + \int_v \int_z y_{F,t}^d(z, v, 1)^{\frac{\theta-1}{\theta}} \varphi_{T,t}^*(z, v, 1) dz dv \right]^{\frac{\theta}{\theta-1}},$$

$$(3) \quad D_{N,t} = \left(\int_z y_{N,t}^d(z)^{\frac{\theta-1}{\theta}} \varphi_{N,t}(z) dz \right)^{\frac{\theta}{\theta-1}},$$

where $y_{H,t}^d(z, v, m)$, $y_{F,t}^d(z, v, 1)$, and $y_{N,t}^d(z)$ are inputs of intermediate goods purchased from each type of home tradable good producers, foreign tradable exporters, and home non-tradable good producers,

respectively. The elasticity of substitution between intermediate goods within a sector is θ .

The final goods market is competitive. Given the final good price at home P_t , the prices charged by each type of tradable and non-tradable good, the final good producer solves the following problem

$$(4) \quad \max \Pi_{F,t} = D_t - \sum_{m=0}^1 \int_v \int_z \left[\frac{P_{H,t}(z, v, m)}{P_t} \right] y_{H,t}^d(z, v, m) \varphi_{T,t}(z, v, m) dz dv \\ - \int_v \int_z \left[\frac{(1 + \tau) P_{F,t}(z, v, 1)}{P_t} \right] y_{F,t}^d(z, v, 1) \varphi_{T,t}^*(z, v, 1) dz dv \\ - \int_z \left[\frac{P_{N,t}(z)}{P_t} \right] y_{N,t}^d(z) \varphi_{N,t}(z) dz,$$

subject to the production technology (1), (2), (3).²⁰ Here, $P_{H,t}(z, v, m)$, $P_{F,t}(z, v, 1)$, and $P_{N,t}(z)$ are the prices of intermediate goods produced by home tradable good producer with (z, v, m) , foreign tradable good producers with $(z, v, 1)$, and the home non-tradable good producers with z , respectively. Solving the problem in (4) gives the input demand functions,

$$(5) \quad y_{H,t}^d(z, v, m) = \gamma \left[\frac{P_{H,t}(z, v, m)}{P_{T,t}} \right]^{-\theta} \left(\frac{P_{T,t}}{P_t} \right)^{\theta-1} D_t,$$

$$(6) \quad y_{F,t}^d(z, v, 1) = \gamma \left[\frac{(1 + \tau) P_{F,t}(z, v, 1)}{P_{T,t}} \right]^{-\theta} \left(\frac{P_{T,t}}{P_t} \right)^{\theta-1} D_t,$$

$$(7) \quad y_{N,t}^d(z) = (1 - \gamma) \left[\frac{P_{N,t}(z)}{P_{N,t}} \right]^{-\theta} \left(\frac{P_{N,t}}{P_t} \right)^{\theta-1} D_t,$$

where the price indices are defined as

$$(8) \quad P_{T,t} = \left\{ \sum_{m=0}^1 \int_v \int_z P_{H,t}(z, v, m)^{1-\theta} \varphi_{T,t}(z, v, m) dz dv + \int_v \int_z [(1 + \tau) P_{F,t}(z, v, 1)]^{1-\theta} \varphi_{T,t}^*(z, v, 1) dz dv \right\}^{\frac{1}{1-\theta}}$$

$$(9) \quad P_{N,t} = \left[\int_z P_{N,t}(z)^{1-\theta} \varphi_{N,t}(z) dz \right]^{\frac{1}{1-\theta}},$$

$$(10) \quad P_t = \left(\frac{P_{T,t}}{\gamma} \right)^\gamma \left(\frac{P_{N,t}}{1 - \gamma} \right)^{1-\gamma}.$$

²⁰Note that the production function is defined only over the available products. It is equivalent to define the production function over all possible varieties but constrain purchases of some varieties to be zero.

The final goods are used for both consumption and investment.

C. Intermediate Good Producers

All the intermediate good producers produce their differentiated good using capital, labor and material inputs. We assume that an incumbent's productivity, z , follows a first order Markov process with a transition probability $\phi(z'|z)$, the probability that the productivity of the establishment will be z' in the next period conditional on its current productivity z , provided that the establishment survived, with $z, z' \in (\underline{z}, \bar{z})$. An entrant draws productivity next period from the distribution $\phi_E(z')$. A tradable good producer draws its exporting fixed cost shock from $\phi_v(v)$. We also assume that establishments receive an exogenous death shock that depends on an establishment's productivity, z , at the end of the period, $0 \leq n_d(z) \leq 1$. The survival rate of producers with productivity z is given as $n_s(z) = 1 - n_d(z)$.

Non-Tradable Good Producers

Consider the problem of a non-tradable good producer from the home country in period t with technology z . The producer chooses the current price $P_{N,t}(z)$, inputs of labor $l_{N,t}(z)$ and capital $k_{N,t}(z)$ given a Cobb-Douglas production technology,

$$(11) \quad y_{N,t}(z) = e^z k_{N,t}(z)^\alpha l_{N,t}(z)^{1-\alpha}$$

to solve

$$(12) \quad V_{N,t}(z) = \max \Pi_{N,t}(z) + n_s(z) Q_t \left(\frac{P_{t+1}}{P_t} \right) \int_{z'} V_{N,t+1}(z') \phi(z'|z) dz',$$

$$(13) \quad \Pi_{N,t}(z) = \left[\frac{P_{N,t}(z)}{P_t} \right] y_{N,t}(z) - W_t l_{N,t}(z) - R_t k_{N,t}(z)$$

subject to the production technology (11), and the constraints that supplies to the non-tradable goods market $y_{N,t}(z)$ are equal to demands by final good producers $y_{N,t}^d(z)$ in (7).

Tradable Good Producers

A producer in the tradable good sector is described by its technology, fixed cost shock, and export status, (z, v, m) . Each period, it chooses current prices for home and/or foreign markets, $P_{H,t}(z, v, m)$

and $P_{H,t}^*(z, v, m)$, and inputs of labor $l_{T,t}(z, v, m)$, capital $k_{T,t}(z, v, m)$, material inputs $x_t(z, v, m)$, and next period's export status, m' . Total materials, $x_t(z, v, m)$, is composed of tradable intermediate goods with a constant elasticity of substitution function

$$(14) \quad x_t(z, v, m) = \left[\sum_{\mu=0}^1 \int_{\varpi} \int_{\zeta} x_{H,t}^d(\zeta, \varpi, \mu, z, v, m)^{\frac{\theta-1}{\theta}} \varphi_{T,t}(\zeta, \varpi, \mu) d\zeta d\varpi + \int_{\varpi} \int_{\zeta} x_{F,t}^d(\zeta, \varpi, 1, z, v, m)^{\frac{\theta-1}{\theta}} \varphi_{T,t}^*(\zeta, \varpi, 1) d\zeta d\varpi \right]^{\frac{\theta}{\theta-1}},$$

where $x_{H,t}^d(\zeta, \varpi, \mu, z, v, m)$ and $x_{F,t}^d(\zeta, \varpi, 1, z, v, m)$ are inputs of intermediate goods purchased from a home tradable good producers with technology ζ , fixed cost shock ϖ , and export status μ , and foreign tradable exporters with technology ζ and fixed cost shock ϖ , respectively, by the tradable good producer with technology z , fixed cost shock v , and export status m . The CES aggregation function yields the input demand functions,

$$(15) \quad x_{H,t}^d(\zeta, \varpi, \mu, z, v, m) = \left[\frac{P_{H,t}(\zeta, \varpi, \mu)}{P_t} \right]^{-\theta} \left(\frac{P_{T,t}}{P_t} \right)^{\theta} x_t(z, v, m),$$

$$(16) \quad x_{F,t}^d(\zeta, \varpi, 1, z, v, m) = \left[\frac{(1+\tau) P_{F,t}(\zeta, \varpi, 1)}{P_t} \right]^{-\theta} \left(\frac{P_{T,t}}{P_t} \right)^{\theta} x_t(z, v, m),$$

given the prices and the choice of the aggregate material input, $x_t(z, v, m)$.

The producer has a Cobb-Douglas production technology,

$$(17) \quad y_{T,t}(z, v, m) = e^z \left[k_{T,t}(z, v, m)^{\alpha} l_{T,t}(z, v, m)^{1-\alpha} \right]^{1-\alpha_x} x(z, v, m)^{\alpha_x}.$$

and solves the following Bellman equation

$$\begin{aligned}
(18) \quad V_{T,t}(z, v, m) &= \max \Pi_{T,t}(z, v, m) - m' W_t e^v [f_1 m + (1 - m) f_0] \\
&\quad + n_s(z) Q_t \left(\frac{P_{t+1}}{P_t} \right) \int_{v'} \int_{z'} V_{T,t}(z', v', m') \phi(z'|z) \phi_v(v') dz' dv' \\
(19) \quad \Pi_{T,t}(z, v, m) &= \left[\frac{P_{H,t}(z, v, m)}{P_t} \right] y_{H,t}(z, v, m) + m \left[\frac{e_t P_{H,t}^*(z, v, m)}{P_t} \right] y_{H,t}^*(z, v, m) \\
&\quad - W_t l_{T,t}(z, v, m) - R_t k_{T,t}(z, v, m) \\
&\quad - \sum_{\mu=0}^1 \int_{\varpi} \int_{\zeta} \left[\frac{P_{H,t}(\zeta, \varpi, \mu)}{P_t} \right] x_{H,t}^d(\zeta, \varpi, \mu, z, v, m) \varphi_{T,t}(\zeta, \varpi, \mu) d\zeta d\varpi \\
&\quad - \int_{\varpi} \int_{\zeta} \left[\frac{(1 + \tau) P_{F,t}(\zeta, \varpi, 1)}{P_t} \right] x_{F,t}^d(\zeta, \varpi, 1, z, v, m) \varphi_{T,t}^*(\zeta, \varpi, 1) d\zeta d\varpi,
\end{aligned}$$

subject to the production technology (11) and the constraints that supplies to home and foreign tradable goods markets, $y_{H,t}(z, v, m)$ and $y_{H,t}^*(z, v, m)$ with $y_{T,t}(z, v, m) = y_{H,t}(z, v, m) + (1 + \xi) y_{H,t}^*(z, v, m)$, are equal to demands by final good producers from (5), the foreign analogue of (6),

$$(20) \quad y_{H,t}^{d*}(z, v, m) = m\gamma \left[\frac{(1 + \tau) P_{H,t}^*(z, v, m)}{P_t^*} \right]^{-\theta} \left(\frac{P_{T,t}^*}{P_t^*} \right)^{\theta-1} D_t^*,$$

and demand by intermediate good producers so that

$$(21) \quad y_{H,t}(z, v, m) = y_{H,t}^d(z, v, m) + \sum_{\mu=0}^1 \int_{\varpi} \int_{\zeta} x_{H,t}^d(z, v, m, \zeta, \varpi, \mu) \varphi_{T,t}(\zeta, \varpi, \mu) d\zeta d\varpi,$$

$$(22) \quad y_{H,t}^*(z, v, m) = y_{H,t}^{d*}(z, v, m) + m \sum_{\mu=0}^1 \int_{\varpi} \int_{\zeta} x_{H,t}^{d*}(z, v, m, \zeta, \varpi, \mu) \varphi_{T,t}^*(\zeta, \varpi, \mu) d\zeta d\varpi.$$

Let the value of the producer with (z, v, m) if it decides to export in period $t + 1$ be

$$\begin{aligned}
(23) \quad V_{T,t}^1(z, v, m) &= \max \Pi_{T,t}(z, v, m) - W_t e^v [f_1 m + (1 - m) f_0] \\
&\quad + n_s(z) Q_t \left(\frac{P_{t+1}}{P_t} \right) \int_{v'} \int_{z'} V_{T,t+1}(z', v', 1) \phi(z'|z) \phi_v(v') dz' dv',
\end{aligned}$$

and let the value if it does not export in period t be

$$(24) \quad V_{T,t}^0(z, v, m) = \max \Pi_{T,t}(z, v, m) + n_s(z) Q_t \left(\frac{P_{t+1}}{P_t} \right) \int_{v'} \int_{z'} V_{T,t+1}(z', v', 0) \phi(z'|z) \phi_v(v') dz' dv'.$$

Then, the actual value of the producer can be defined as

$$V_{T,t}(z, v, m) = \max \{V_{T,t}^1(z, v, m), V_{T,t}^0(z, v, m)\}$$

Clearly the value of a producer depends on its export status and fixed cost shock, and is monotonically increasing and continuous in z given m and v , and the states of the world. Moreover V_T^1 intersects V_T^0 from below as long as there are some establishments that do not export.²¹ Hence, it is possible to solve for the establishment productivity at which an establishment is indifferent between exporting and not exporting; that is, the increase in establishment value from exporting equals the cost of exporting. This level of establishment productivity differs by the establishment's current export status and fixed cost shock. The critical level of technology for exporters and non-exporters $z_{m,t}(v)$ satisfies

$$(25) \quad V_{T,t}^1(z_{m,t}(v), v, m) = V_{T,t}^0(z_{m,t}(v), v, m)$$

if there exists $z_{m,t}^*(v)$ and $z_{m,t}^{**}(v)$ such that $V_{T,t}^1(z_{m,t}^*(v), v, m) < V_{T,t}^0(z_{m,t}^*(v), v, m)$ and $V_{T,t}^1(z_{m,t}^{**}(v), v, m) > V_{T,t}^0(z_{m,t}^{**}(v), v, m)$. If $V_{T,t}^1(z, v, m) < V_{T,t}^0(z, v, m)$ for all $z \in (\underline{z}, \bar{z})$, all the producers with v will not pay the fixed cost. In that case, we set $z_{m,t}(v) = \bar{z}$.²² If $V_{T,t}^1(z, v, m) > V_{T,t}^0(z, v, m)$ for all $z \in (\underline{z}, \bar{z})$, all the producers with v pay the fixed cost. In that case, we set $z_{m,t}(v) = \underline{z}$.

D. Entry

Each period, a new establishment can be created by hiring f_E workers. New establishments are free to enter either the tradable or non-tradable sector. Once an establishment enters a particular sector, it can no longer change sectors. Establishments incur these entry costs in the period prior

²¹If the difference between f_0 and f_1 is relatively large, the economy may have $V^1 > V^0$ for all $z \in (\underline{z}, \bar{z})$ for some states of the world.

²²Note that if $\bar{z} = \infty$, for any v there exists $\tilde{z} \in (\underline{z}, \bar{z})$ such that $V_{T,t}^1(\tilde{z}, v, m) = V_{T,t}^0(\tilde{z}, v, m)$ if there exists $z^* \in (\underline{z}, \bar{z})$ such that $V_{T,t}^1(z^*, v, m) < V_{T,t}^0(z^*, v, m)$.

to production. Once the entry cost is incurred, establishments receive an idiosyncratic productivity shock from the distribution $\phi_E(z')$. All the entrants are free from death shocks. New entrants into the tradable sector can not export in their first productive period. Thus the entry conditions in two sectors are given as

$$(26) \quad V_{T,t}^E = -W_t f_E + Q_t \left(\frac{P_{t+1}}{P_t} \right) \int_{v'} \int_{z'} V_{T,t+1}(z', v', 0) \phi_E(z') \phi_v(v') dz' dv' \leq 0,$$

$$(27) \quad V_{N,t}^E = -W_t f_E + Q_t \left(\frac{P_{t+1}}{P_t} \right) \int_{z'} V_{N,t+1}(z') \phi_E(z') dz' \leq 0.$$

We denote the mass of entrants in the tradable and non-tradable good sectors in period t as $N_{TE,t}$ and $N_{NE,t}$, while the mass of incumbents in the tradable and non-tradable good sectors are denoted as $N_{T,t}$ and $N_{N,t}$. The mass of exporters and non-exporters equal

$$(28) \quad N_{1,t} = \int_v \int_z \varphi_{T,t}(z, v, 1) dz dv,$$

$$(29) \quad N_{0,t} = \int_v \int_z \varphi_{T,t}(z, v, 0) dz dv,$$

and the mass of establishments in the tradable good sector equal

$$(30) \quad N_{T,t} = N_{1,t} + N_{0,t}.$$

The fixed costs of exporting imply that only a fraction $n_{x,t} = N_{1,t}/N_{T,t}$ of home tradable goods are available in the foreign country in period t .

The mass of establishments in the non-tradable sector is written as

$$(31) \quad N_{N,t} = \int_z \varphi_{N,t}(z) dz.$$

Given the critical level of technology for exporters and non-exporters, $z_{1,t}(v)$ and $z_{0,t}(v)$, the starter ratio, the fraction of establishments that start exporting among non-exporters, equals

$$(32) \quad n_{0,t+1} = \frac{\int_v \int_{z_{0,t}(v)}^{\bar{z}} n_s(z) \varphi_{T,t}(z, v, 0) dz dv}{\int_v \int_z n_s(z) \varphi_{T,t}(z, v, 0) dz dv}.$$

Similarly, the stopper ratio, the fraction of exporters who stop exporting among surviving establishments, equals

$$(33) \quad n_{1,t+1} = \frac{\int_v \int_{\underline{z}}^{z_{1,t}(v)} n_s(z) \varphi_{T,t}(z, v, 1) dz dv}{\int_v \int_z n_s(z) \varphi_{T,t}(z, v, 1) dz dv}.$$

The evolutions of mass of establishments are given by

$$\begin{aligned} \varphi_{T,t+1}(z', v', 1) &= \phi_v(v') \int_v \left[\int_{z_{0,t}(v)}^{\bar{z}} n_s(z) \varphi_{T,t}(z, v, 0) \phi(z'|z) dz \right. \\ &\quad \left. + \int_{z_{1,t}(v)}^{\bar{z}} n_s(z) \varphi_{T,t}(z, v, 1) \phi(z'|z) dz \right] \phi_v(v) dv, \\ \varphi_{T,t+1}(z', v, 0) &= \phi_v(v') \int_v \left[\int_{\underline{z}}^{z_{0,t}(v)} n_s(z) \varphi_{T,t}(z, v, 0) \phi(z'|z) dz \right. \\ &\quad \left. + \int_{\underline{z}}^{z_{1,t}(v)} n_s(z) \varphi_{T,t}(z, 1) \phi(z'|z) dz \right] \phi_v(v) dv + N_{TE,t} \phi_E(z') \phi_v(v'), \\ \varphi_{N,t+1}(z') &= \int_z n_s(z) \varphi_{N,t}(z) \phi(z'|z) dz + N_{NE,t} \phi_E(z'). \end{aligned}$$

E. Government

The government collects tariffs from foreign exporters and redistributes the tariff revenue lump sum to domestic consumers each period. The government's budget constraint is given as

$$(34) \quad T_t = \tau \int_v \int_z \left[\frac{P_{F,t}(z, v, 1)}{P_t} \right] y_{F,t}(z, v, 1) \varphi_{T,t}^*(z, v, 1) dz dv.$$

F. Aggregate Variables

Investment, I_t , is given by the law of motion for capital

$$(35) \quad I_t = K_t - (1 - \delta) K_{t-1}.$$

Nominal exports and imports are given as

$$(36) \quad EX_t^N = \int_v \int_z e_t P_{H,t}^*(z, v, 1) y_{H,t}^*(z, v, 1) \varphi_{T,t}(z, v, 1) dz dv,$$

$$(37) \quad IM_t^N = \int_v \int_z P_{F,t}(z, v, 1) y_{F,t}(z, v, 1) \varphi_{T,t}^*(z, v, 1) dz dv,$$

respectively. Nominal GDP of the home country is defined as the sum of value added from non-tradable, tradable and final goods producers,

$$Y_t^N = P_t D_t + EX_t^N - IM_t^N.$$

The trade to GDP ratio is given as

$$(38) \quad TR_t = \frac{EX_t^N + IM_t^N}{2Y_t^N}.$$

The total labor used for production, $L_{P,t}$, is given by

$$(39) \quad L_{P,t} = \sum_{m=0}^1 \int_v \int_z l_{T,t}(z, v, m) \varphi_{T,t}(z, v, m) dz dv + \int_z l_{N,t}(z) \varphi_{N,t}(z) dz.$$

The domestic labor²³ hired by exporters, $L_{X,t}$, is given by

$$(40) \quad L_{X,t} = f_0 \int_v \int_{z_{0,t}(v)}^{\bar{z}} e^v \varphi_{T,t}(z, v, 0) dz dv + f_1 \int_v \int_{z_{1,t}(v)}^{\bar{z}} e^v \varphi_{T,t}(z, v, 1) dz dv.$$

From (40), we see that the trade cost, measured in units of domestic labor, depends on the exporter status from the previous period.

Aggregate profits are measured as the difference between profits and fixed costs and equal

$$\begin{aligned} \Pi_t = & \Pi_{F,t} + \sum_{m=0}^1 \int_v \int_z \Pi_{T,t}(z, v, m) \varphi_{T,t}(z, v, m) dz dv + \int_z \Pi_{N,t}(z) \varphi_{N,t}(z) dz \\ & - W_t L_{X,t} - f_E W_t (N_{TE,t} + N_{NE,t}). \end{aligned}$$

²³Entry costs are measured in units of labor to ensure a balanced growth path.

For each type of good, there is a distribution of establishments in each country. For the sake of exposition we have written these distributions separately by country and type of establishment. It is also possible to rewrite the world distribution of establishments over types as $\varphi : \mathbb{R} \times \mathbb{R} \times \{0, 1\} \times \{H, F\} \times \{T, NT\}$, where now we have indexed establishments by their origin and their sector. The exogenous evolution of establishment technology and fixed cost shock as well as the endogenous export participation and entry decisions determines the evolution of this distribution. The law of motion for this distribution is summarized by the operator T , which maps the world distribution of establishments and entrants into the next period's distribution of establishments,

$$\varphi'_t = T \left(\{ \varphi_t, N_{TE,t}, N_{NE,t}, N_{TE,t}^*, N_{NE,t}^* \} \right).$$

G. Equilibrium Definition

In an equilibrium, variables satisfy several resource constraints. The final goods market clearing conditions are given by $D_t = C_t + I_t$, and $D_t^* = C_t^* + I_t^*$. Each individual goods market clears; the labor market clearing conditions are $L = L_{P,t} + L_{X,t} + f_E(N_{TE,t} + N_{NE,t})$, and the foreign analogue; the capital market clearing conditions are $K_{t-1} = \sum_{m=0}^1 \int_v \int_z k_{T,t}(z, v, m) \varphi_{T,t}(z, v, m) dz dv + \int_z k_{N,t}(z) \varphi_{N,t}(z) dz$, and the foreign analogue. The government budget constraint is given by (34) and the foreign analogue. The profits of establishments are distributed to the shareholders, Π_t , and the foreign analogue. The international bond market clearing condition is given by $B_t + B_t^* = 0$. Finally, our decision to write the budget constraints in each country in units of the local currency permits us to normalize the price of consumption in each country as $P_t = P_t^* = 1$.

An equilibrium of the economy is a collection of allocations for home consumers C_t, B_t, K_t ; allocations for foreign consumers C_t^*, B_t^*, K_t^* ; allocations for home final good producers; allocations for foreign final good producers; allocations and prices for home non-tradable good producers; allocations and prices for foreign non-tradable good producers; allocations, prices, and export policies for home tradable good producers; allocations, prices and export decisions for foreign tradable good producers; labor used for exporting costs at home and foreign; labor used for entry costs; transfers T_t, T_t^* by home and foreign governments; real wages W_t, W_t^* , real rental rates of capital R_t, R_t^* , real and nominal exchange rates q_t and e_t ; and bond prices Q_t that satisfy the following conditions: (i) the consumer allocations solve the consumer's problem; (ii) the final good producers' allocations solve their profit

maximization problems; (iii) the non-tradable good producers' allocations and prices solve their profit maximization problems; (iv) the tradable good producers' allocations, prices, and export decisions solve their profit maximization problems; (v) the entry conditions for tradable and non-tradable sectors hold; (vi) the market clearing conditions hold; and (vii) the transfers satisfy the government budget constraint.

3. Calibration

We now describe the functional forms and parameter values of our benchmark economy. The parameter values used in the simulation exercises are reported in Table 1.

The instantaneous utility function equals

$$U(C) = \frac{C^{1-\sigma}}{1-\sigma},$$

where $1/\sigma$ is the intertemporal elasticity of substitution.

The establishment size distribution is largely determined by the underlying structure of shocks. We assume an incumbent's productivity has an autoregressive component ($\rho < 1$) of

$$z' = \rho z + \varepsilon, \quad \varepsilon \stackrel{iid}{\sim} N(0, \sigma_\varepsilon^2).$$

The assumption that establishment technology follows an AR(1) with shocks drawn from an iid normal distribution implies that this conditional distribution follows a normal distribution $\phi(z'|z) = N(\rho z, \sigma_\varepsilon^2)$ and that the unconditional distribution is $N\left(0, \frac{\sigma_\varepsilon^2}{1-\rho^2}\right)$. This unconditional distribution leads to a log normal distribution of manufacturing plants. Rossi-Hansberg and Wright (2007) document clearly that the US manufacturing establishment distribution is log normal. This is a departure from most formulation of the Melitz model which assume productivity follows a Pareto distribution. Luttmer (2007) and Irrazzabal and Oppromolla (2007) show that a Pareto distribution arises if shocks to the growth rate of the plant are iid which clearly occurs if $\rho = 1$.

We assume that entrants draw productivity based on the unconditional distribution

$$z' = \mu_E + \varepsilon_E, \quad \varepsilon_E \stackrel{iid}{\sim} N\left(0, \frac{\sigma_\varepsilon^2}{1-\rho^2}\right).$$

However, to match the observation that entrants start out small relative to incumbents we assume that $\mu_E < 0$. We also assume that establishments receive an exogenous death shock that depends on an establishment's last period productivity, z , so that the probability of death is given as

$$n_d(z) = 1 - n_s(z) = \max \left\{ 0, \min \left\{ \lambda e^{-\lambda e^z} + n_{d0}, 1 \right\} \right\}.$$

Each period, tradable good producers draw their fixed cost shock from

$$v \stackrel{iid}{\sim} N(0, \sigma_v^2).$$

The choice of the discount factor, β , the rate of depreciation, δ , and risk-aversion, σ , is standard in the literature, $\beta = 0.96$, $\delta = 0.10$, and $\sigma = 2$. The labor supply is normalized to $L = 1$.

The parameter θ determines both the producer's markup as well as the elasticity of substitution across varieties. We set $\theta = 5$, which gives the producer's markup of 25 percent. This value of θ is consistent with the US trade-weighted import elasticity of 5.36 estimated by Broda and Weinstein (2006) for the period 1990-2001.²⁴ Anderson and Van Wincoop (2004) summarize measures of tariff and non-tariff barriers. For industrialized countries, tariff barriers are approximately 5 percent while non-tariff barriers are about 8 percent.²⁵ We set the tariff rate to 8 percent, near the midpoint of the sum of tariff and non-tariff barriers. The transportation cost parameter, ξ , is set to match the exporters' export sales to the total sales ratio of 13.3 percent from the 1992 Census of Manufactures. Given the tariff rate and elasticity of substitution, this implies $\xi = 0.451$. In total, our calibration implies that tariffs and transportation costs increase the per unit cost by 57 percent. Anderson and van Wincoop (2004) find slightly larger costs of about 65 percent (excluding distribution/retail costs), but their measure includes the trade distortions from fixed costs.

The tradable share parameter of the final good producer, γ , is set to 0.21 to match the ratio of manufacturers' nominal value-added relative to private industry GDP excluding agriculture and mining for the US from 1987 to 1992. The labor share parameter in production, α , is set to match the

²⁴ Anderson and van Wincoop survey elasticity estimates from bilateral trade data and conclude $\theta \in [5, 10]$.

²⁵ Tariff measures can vary. For instance, Yi (2003) reports a tariff on manufactured goods of 4.5 percent in the US in 1992. Similarly, US tariff revenue in 1992 was equal to 3.3 percent of imports. The World Bank reports an unweighted average tariff of 6.4 percent. For comparison Alvarez and Lucas (2006) calibrate their model to 11 percent tariffs.

labor income to GDP ratio of 66 percent. In the model, the ratio of value-added to gross output in manufacturing equals $1 - \alpha_x (\theta - 1) / \theta$. In the US this ratio averages 2.8 from 1987 to 1992 and implies that $\alpha_x = 0.804$.

The total mass of establishments, $N_{T,t} + N_{N,t}$, is normalized to 2 with the entry cost parameter f_E . In all the analysis, we assume that the mean establishment size of the tradable sector is as in the US.

In order to quantify the gains to trade reform in a dynamic environment, we need a model that can generate reasonable establishment characteristics, including the entry and exit decisions of both new and exporting establishments. For this reason, we target moments of the establishment size distribution as well as dynamic moment of exporters and non-exporters. Similar to Bernard et al. (2003), we target the 1992 US economy. We have 8 parameters, ρ , σ_ε , σ_v , μ_E , λ , f_0 , f_1 , and n_{d0} which we choose to match the following 7 observations:

1. A exporter rate of 22.3 percent (1992 Census of Manufactures).
2. A stopper rate of 17 percent as in Bernard and Jensen (1999) based on the Annual Survey of Manufactures (ASM) of the Bureau of the Census 1984-1992.
3. Five-year exit rate of entrants of 37 percent based on plants that first began producing (Dunne et al. 1989).
4. Entrants' labor share of 1.5 percent reported in Davis et al. (1996) based on the ASM.
5. Shutdown establishments' labor share of 2.3 percent (Davis et al. 1996).
6. Establishment employment size distribution (fractions of establishments) as in the 1992 Census of Manufactures.
7. Establishment export participation rate distribution (fractions of exporting establishments) as in the 1992 Census of Manufactures.

The first two targets relate exporters to the population of establishments. As is well known, not all establishments export. Those that do are much bigger than the average establishment. There is also substantial churning in the export market, with only 17 percent of exporters exiting per year.

The next three targets help to pin down the establishment creation, destruction, and growth process. New establishments and dying establishments tend to be small, respectively accounting for only 1.5 percent and 2.3 percent of employment. Moreover, new establishments have high failure rates,

with a 37 percent chance of exiting in the first five years. Atkeson and Kehoe (2005) show that these features of the plant lifecycle are important determinants of the stock of intangible, or organizational,²⁶ capital in an economy.

Since the establishment, employment size, and export participation distributions cannot be perfectly matched given our limited number of parameters, we choose the parameters that match the first 5 moments, and then minimize the sum of squared residuals from the data and the model’s implied distributions of establishments, employment size, and export participation rates.²⁷ The parameter values are reported in Table 1 and the fit of the benchmark model, dubbed *Sunk-Cost*, and some variations, is summarized in Table 2.

We also consider three other variations of the model to isolate the role of the structure of fixed costs and idiosyncratic shocks. These variations are special cases of our benchmark model and so for calibration purposes we must give up on one or more moments as calibration targets. We choose to separately calibrate each of these variations rather than performing sensitivity on our benchmark to give each of these models the best chance of approximating the findings from our benchmark model.

In the first variation, which we call *Fixed-Cost*, we constrain $f_0 = f_1$ so that the startup cost and the continuation cost of exporting are identical. In this parameterization, the entry and exit thresholds are identical and so there is no exporter hysteresis, consequently we give up on our target of matching transitions in and out of exporting. In our second variation, called *Permanent*, we set $f_0 = f_1$ and also assume that establishments draw their technology at birth. With no plant-level uncertainty in productivity, we can only match either the employment share of entrants, deaths, or the 5-year survival rate. We match the employment share of dying establishments. To match export participation, we still allow for shocks to the fixed costs. In our third variation, we also calibrate an alternate model with no fixed costs of exporting, which we call the *No-Cost* model. This is a variation of the Krugman (1980) model with a plant lifecycle embedded in a neoclassical growth model. To make this last model comparable with the other three, we calibrate the iceberg trade cost so that total trade flows are the same as in our benchmark model with a sunk cost.

²⁶This organizational capital determines the size of payments, or organization rents, to plant owners. These rents compensate owners for the upfront costs of creating plants as well as the costs of waiting for plants to grow.

²⁷Specifically, we use the following 10 bins for employment sizes: 1-4, 5-9, 10-19, 20-49, 50-99, 100-249, 250-499, 500-999, 1000-2499, and 2500 and more employees; and 6 bins for export participation rates: 1-99, 100-249, 250-499, 500-999, 1000-2499, and 2500 and more employees. See the technical appendix for the detailed procedures.

A. Algorithm for Finding an Equilibrium and Calibration

We now describe an algorithm for finding an equilibrium. The details of the algorithm are more fully documented in the technical appendix. There are two reasons for describing the algorithm. First, this algorithm is the one used to compute and calibrate numerically the stationary equilibrium of the model. Second, the algorithm provides some insight into the working of the model.

The algorithm to solve for the steady state and calibrate the model consists of two steps. In the first step, we set the parameter values for the production technology and fixed cost shock processes together with the fixed costs in exporting up to a normalization factor. In the second step, we use the aggregate equilibrium conditions to obtain the steady state values of variables together with the entry and exporting fixed costs.

Solving for the steady state of this economy poses some computational challenges. The key challenge is approximating the distribution of plants, φ_t , as this is potentially an infinitely dimensional object. To simplify this, we discretize the state space so that there $N \times M$ nodes of productivity and fixed costs.

In the first step, there are three substeps. Prior to these substeps, we normalize the mass of new plants in each sector, $N_{NE} = N_{TE} = 1$. In the first substep, given a guess of the parameters $(\mu_E, n_{d0}, \rho, \sigma_v, \sigma_\varepsilon)$ we search for the exit rate parameter, λ , and the fixed trade costs, f_0 and f_1 , up to a normalization, that match export participation, export persistence, and the exit rate of newborn plants. In this substep, we use value function iteration to solve for the marginal starter and stopper for each fixed trade cost. The marginal exporter is not restricted to our discrete nodes but can be in the interval between nodes. When this is the case, the fraction of establishments choosing to export is interpolated. This effectively makes the decision rules continuous and improves the stability of the solution algorithm tremendously.²⁸ Given these decision rules and the entry rate, we iterate on the distribution of plants until the densities converge. We then have an exporter ratio, stopper rate, and exit rate of entrants which we can compare to our targets. In the second substep, along with the first substep we search for the values of μ_E , n_{d0} , ρ , and σ_v to match the entrant and shutdown labor share and to minimize the sum of squared residuals from the data (1992 Census of Manufactures) and the

²⁸Indeed, this is the key step in making the solution algorithm converge. Without it, given the discrete choice nature of exporting, when iterating on the distribution of exporters small changes in aggregate can lead to large changes in the stock of exporters.

models implied distributions of establishments and export participation. Finally, in the third substep, along with the first two previous substeps we search over σ_ε to minimize the sum of squared residuals from the data (1992 Census of Manufactures) and the models implied distributions of establishments and export participation.

With the procedure within a procedure described above, we can avoid computational complications stemming from matching many moments with many parameters.

In the second step, we essentially choose two more parameter values, f_E and α . These parameters are chosen to ensure that the labor share is equal to its calibrated level and that the total mass of establishments is normalized to $N_T + N_N = 2$. Since there are no scale economies here, the normalization of the number of plants is without loss of generality. In this step we use the equilibrium conditions of the model to solve for the K , N_T , N_N , C and W .

Given a change in the tariff, we modify our calibration algorithm to solve for the new steady state. Essentially, we now guess the new aggregate variables of the economy plus the exporting thresholds and the productivity distribution. We then compare these guesses to the aggregate equilibrium conditions as well as the decision rules that come out of the updated value functions. If these are consistent, we are done. Otherwise, we update our guess until things converge.

B. Exporter Characteristics and Dynamics

Our first aim is to evaluate whether the model can explain both the rate of export participation across plants and the churning in exporting by US manufacturing plants. Our calibration has targetted the establishment and employment size distribution in manufacturing as well as the distribution of exporters plus a limited set of moments about exporter characteristics and transitions. There are obviously many more moments than parameters and so our fit will not be exact. We find that both the benchmark model with a startup cost of exporting and the fixed-cost model without this startup cost generate export participation rates by establishment size similar to those in the data, but that the fixed-cost model generates too much churning in the export market (indeed for calibration purposes we did not target export persistence). Some sense of the benefit of modelling the differences between export startup and continuation costs is apparent in that our calibration implies startup costs are 3.7 times continuation costs and the standard deviation of shocks to fixed costs is substantially smaller (1.1 vs 1.6).

Figure 1 plots the distribution of plants, exporters, non-exporters, and newborn plants by productivity level for our benchmark model. We also plot the shutdown, starter, and stopper probabilities by productivity level. The shutdown probability is exogenous while the starter and stopper hazards are endogenously determined given idiosyncratic shocks, export status, and trade costs. To match the low employment share and high shutdown rate of entrants, newborn productivity starts out on average about 35 percent lower than the average incumbent. Because of the idiosyncratic shocks to fixed export costs, the likelihood of starting (stopping) is increasing (decreasing) in the current productivity of a plant. Because of the relatively high costs of starting to export, the average productivity threshold for starting to export exceeds the productivity threshold to stop exporting by 63 percent (in logs). Table 3 shows that these different thresholds imply a large range of exporter hysteresis as the mean (median) non-exporter that starts to export will have 171 (60) employees, while the mean (median) exporter that stops exporting has 13.4 (5.0) employees in steady state. In contrast, in the fixed cost model without exporter hysteresis starters on average have 93 employees and stoppers 43 employees.

The top two panels of Figure 2 plot the establishment and employment distribution by employment size in the data and the model. The first panel shows the share of establishments is decreasing in size in the data and all the models we consider. The second panel shows that the share of manufacturing employment accounted for by establishments in each employment category is hump-shaped, with establishments with 100 to 249 employees accounting for almost 20 percent of total employment. All four models can approximate this basic shape since this is largely governed by the underlying productivity process (μ_E, ρ, σ_z) . Statistically, from the bottom panel of Table 2 we see that the sunk-cost and fixed cost models generate the lowest root mean squared errors of 0.38 percent relative to the establishment distribution and 0.76 and 0.77 percent, respectively relative to the employment share distribution.

The last panel of Figure 2 plots export participation in the data and the three models with a decision to export. Similar to above, for the three models with an export decision, we minimize the distance between the model and the data. In all three models export participation increases with establishment size, although slightly more so than in the data. Again, the Sunk-Cost model has the lowest root mean squared error of 2.49 percent against 2.51 percent for the Fixed Cost model and 5.16 percent for the model with permanent productivity differences. Note that only the *Sunk-Cost* model can generate highly persistent exporters. Compared to the 17 percent stopper rate in the benchmark model, the *Fixed Cost* model generates an exit rate of 66.9 percent.

C. Plant-level Growth and Export Transitions

Our focus has been on matching the characteristics of exporters and non-exporters as well as the transitions across export status. We next consider the relationship between plant-level employment and sales growth and changes in export status at different horizons. Empirically, Bernard and Jensen (1999) document these relations in panels of U.S. manufacturing plants. We find that in our benchmark calibration with a sunk cost of exporting we get plant dynamics about right both qualitatively and quantitatively. Specifically, at different horizons starters tend to grow faster than stoppers and continuing exporters. The model without the sunk startup cost gets the qualitative nature of plant growth and changes in export status about right as well, but is off quantitatively, particularly when we constrain export persistence to match the data.

Define the growth rate of a variable X as

$$\% \Delta X_{iT} = \frac{1}{T} (\ln X_{iT} - X_{i0})$$

Bernard and Jensen (99) run the following regressions

$$\% \Delta X_{iT} = \alpha + \beta_1 \text{Start}_{iT} + \beta_2 \text{Both}_{iT} + \beta_3 \text{Stop}_{iT} + \gamma \text{Size}_{i0} + \varepsilon_{iT}$$

where $\text{Start}_{iT} = 1$ if $(m_0, m_T) = (0, 1)$, $\text{Both}_{iT} = 1$ if $(m_0, m_T) = (1, 1)$; and $\text{Stop}_{iT} = 1$ if $(m_0, m_T) = (1, 0)$. The coefficients β_1 , β_2 , and β_3 give the differential in growth rates of variable X for starters, continuous exporters, and stoppers relative to non-exporters in both years.²⁹ We focus on the growth rate of employment and sales. These are indistinguishable in our model, so we average these responses.

These regressions are run on different waves (1984 to 1988, and 1989 to 1992) of the Annual Survey of Manufacturers (which are done between Census years) as well as the plants in both waves. This panel of US manufacturing plants is very heavily weighted towards the largest manufacturing plants, particularly in the longer horizons regressions.³⁰ To take this into account, we construct a

²⁹Note that $\text{Both}_{iT} = 1$ if the plant exports in the first and last year. If the time frame is longer than 1 year, it may not have exported every year.

³⁰In footnote 5 of BJ (1999) they explain that large plants (>250 employees) are sampled with certainty while small plants are sampled randomly. Moreover, non-certainly plants sampled in one wave are not sampled in subsequent waves. Thus, the sample within a wave is quite different from the sample across waves.

sample of tradable plants from our ergodic distribution based on a size cutoff in both years.

Table 4 reports how plant-level growth relates to changes in export status in the data and our benchmark sunk costs model. We also include the results for two variations of the fixed cost model. The first variation is the fixed cost model that substantially understates the persistence of exporting with a stopper rate of 67 percent. In the second variation, denoted fixed-high persistence, we recalibrate the shock process to generate a stopper rate of 17 percent.

In the data, at all horizons, relative to continuing nonexporters, starters tend to grow slightly faster than continuing exporters while stoppers tend to shrink. The gaps become smaller over longer horizons. For instance, the growth rate premium for starters is 7.4 percent at one year, 4.7 percent at three years, 3.6 percent for four years, and 2.8 percent at 8 years. The sunk and fixed cost models both capture the tendency for starters to grow faster than continuing exporters and for stoppers to shrink relative to continuous non-exporters. However, statistically, the sunk cost model is a better fit for these dynamic moments though, with a mean absolute deviation (MAD) of 1.5 percentage points compared to the fixed cost model with a MAD of 2.3 percentage points. In general, the models are better at getting the one year and eight-year growth rates than the three or four year growth rates. While these two models seem roughly comparable, recall that this calibration of the fixed cost model generates nearly 4 times the churning of export status per year as in the benchmark sunk cost model.

When we recalibrate the fixed cost model to match the high persistence of exporting observed, the model misses out badly on both exporter characteristics and plant level dynamics around changes in export status. To capture the high persistence of exporting requires very persistent productivity shocks ($\rho = 0.96$) and relatively small productivity and fixed cost shocks ($\sigma_\varepsilon = 0.14, \sigma_v = 0.13$). With these idiosyncratic shocks most of medium to large plants export. The export participation rate for the plants with 100-249 employees is 97 percent in the model whereas only 40 percent of these plants did export in the data. For larger plants, the participation rate becomes more than 99 percent in the model. The overall root-mean-squared error for the export participation rate distribution is 36.3 percent compared to 2.4 percent in the benchmark model. Focusing on the plants with 10 or more employees,³¹ the mean absolute deviation of growth rates from the data are now 14.5 compared to 3.6

³¹Because of the high persistence of the underlying productivity shock and small variance of productivity and fixed cost shocks in this calibration, when we look at one year transitions there are no stoppers with 100+ employees in consecutive years and so we can't run the same regressions on our model as in the data.

for the benchmark sunk cost model. The fixed cost model misses out badly on plant dynamics because now current productivity is much more highly correlated with the productivity that lead the plant to change export status in the first place. Thus, sunk costs are needed to match the relationship between plant-level dynamics and changes in export status.

D. The Size of Trade Costs

Given the model delivers the right plant characteristics and dynamics of exporters and non-exporters, we next use the model to estimate of the size and nature of trade costs. Das, Roberts, and Tybout (2007, DRT hereafter) also provide an estimate of these costs in a structural estimation of a similar model on 136 plants in the three industries in Columbia. Similar to DRT, we find that the cost of starting to export are relatively high. In our calibration the startup costs is nearly 19 times the cost of continuing to export, while in the median industry it is about 40 times in DRT. However, because of the shocks to these costs, we find that the average (median) startup cost incurred is about 3.7 (4.7) times the average (median) continuation cost incurred by a continuing exporter. In \$1992, the average startup cost is about 745k while the average continuation cost is about 203k. To put these costs into perspective, the average startup costs are equal to 0.99 (3.88) times the profits of the mean (median) starters. In DRT, startup costs are about 1.5 (8 to 9) times average (median) profits.³²

In the aggregate, the resources devoted to startup and continuation costs are equal to 5.1 and 5.5 percent of international trade respectively (respectively, 25 and 28 percent of gross export profits). From comparing the variable trade cost in our benchmark model (0.451) to that in the No-Cost model (0.757), we see that the startup and continuation costs decrease variable trade costs by roughly 68 percent. The high tariff equivalent of these fixed trade costs can partially explain why direct measures of trade costs are so much lower than model-based measures inferred from trade flows (Anderson and van Wincoop 2004).

4. Tariffs and Steady State

To gain some insight into how tariffs distort economic activity in the presence of non-convex costs of exporting and plant heterogeneity, we begin by studying how the steady state depends on

³²Using the data in DRT, we measure this ratio as $f_S / \left(\sum_i \sum_t \frac{\text{exports}_{it}}{\theta_{it}} / \sum_i \sum_t I_{it} (\text{exports}_{it} > 0) \right)$, where θ_{it} is a firm specific demand elasticity.

tariffs. We first explore the impact of tariffs on the characteristics of exporters vs. non-exporters. We then consider the relation between tariffs and aggregates such as consumption, investment, trade, and export participation. For exposition, all series are measured relative to the level under free trade.

A. Exporter Characteristics and Dynamics

Figure 3 depicts the relationship between exporter characteristics and tariffs ranging from 0 to 30 percent. Panel (a) shows that the exporter productivity premia in the stationary distribution of establishments is increasing in the tariff.³³ With free trade, exporters are on average 26 percent more productive than non exporters while with 30 percent tariffs the premium rises to 44 percent. Panel (b) shows the average productivity threshold of starters and stoppers is increasing in tariffs. Panel (c) shows how these changes in the characteristics of starters and stoppers translate into equilibrium starter and stopper rates for each tariff level. As tariffs increase, we find that non-exporters start exporting less frequently and establishments that do export exit fairly frequently. The duration of exporting is inversely proportional to the stopper rate. With 8 percent tariffs, the model predicts that each export spell lasts about 5.9 years. Under free trade, the duration of each export spell rises to about 9.1 years.³⁴

Finally, panel (d) plots the share of establishments in the tradable sector that are exporters. Moving from 8 percent tariffs to free trade increases export participation from 22.3 percent of the establishments to 39.0. Similarly, as we increase tariffs above 8 percent, exporters exit foreign markets in droves. To get an idea of the importance of the exit margin for participation, we have also plotted the export participation rate that would have prevailed if we had held the exit threshold constant at the level with 8 percent tariffs. This partial equilibrium counterfactual implies that modelling the exit margin just about doubles the sensitivity of exporting to tariffs.³⁵

B. Aggregates

We start our analysis of the aggregate effect of tariffs by considering trade-related variables. To highlight the role of fixed export costs, we also report the results of the *No-Cost* model, which is nearly

³³The productivity premium is calculated as the difference between the average productivity of exporters and that of non-exporters in logarithm.

³⁴Since the plant-level productivity is persistent, the export spell is increasing in the plant-level productivity.

³⁵Of course this understates the role of the exit margin, since it is the exit margin that determines the duration of exporting. A longer expected duration of exporting raises the expected value of exporting and increases entry.

identical to our benchmark model except that there are no costs of exporting, $f_0 = f_1 = 0$, so that all plants export.

We first consider how tariffs influence the stock of establishments in each model. From panel (a) of Figure 4, in *No-Cost* the mass of tradable establishments (N_T) decreases with tariffs, while the mass of non-tradable establishments (N_N) increases with tariffs. Here, tariffs are effectively a tax on investment in tradable establishments and thus the economy substitutes toward non-tradable establishments. In our benchmark *Sunk-Cost* model, both the mass of tradable and non-tradable establishments increases with tariffs. However, from panel (b) we see that the mass of available differentiated varieties, measured as imports plus domestic tradables, declines with tariffs as the increase in local tradable establishments is offset by a decline in foreign varieties as export participation declines with tariffs. This effect is much stronger in the *Sunk-Cost* model than the *No-Cost* model.

There are two reasons why higher tariffs lead to the accumulation of a larger stock of establishments in the *Sunk-Cost* model. First, tariffs raise the relative price of physical capital to establishments or export capacity, as physical capital is produced using labor, capital, and materials, while establishments and exporters are produced just using labor whose price, the real wage rate, is decreasing in tariffs (panel e). Second, higher tariffs reduce the gain from investing in creating exporters. When the tariff is raised, the return to producing additional varieties of goods by incurring the cost of exporting is reduced. We see that tariffs encourage savings through investment in establishments rather than capital (panel f), while discouraging saving through export capacity. Moving from free trade to 30 percent tariffs increases the mass of tradable varieties by about 6.9 percent. However, the net effect is to decrease the mass of available varieties by about 20.7 percent. Thus, tariffs encourage establishment creation³⁶ over capital accumulation and discourage investing in export capacity.

Panel (c) shows that the relationship between the nominal trade to GDP ratio and tariffs is about twice as strong in the *Sunk-Cost* model compared to the *No-Cost* model. For instance, going from 30 percent tariffs to free trade raises trade from 0.6 percent to 8.6 percent in the *Sunk-Cost* model, while in the *No-Cost* model the increase is about half as big, from 1.9 to 6.8.

Despite the stronger trade response in the *Sunk-Cost* model, we see from panel (d) that lowering tariffs increases steady state consumption by more in the *No-Cost* model. For low tariffs, the gap

³⁶The pro-variety of tariffs is also found in the work by Baldwin and Forslid (2006).

between the two models is not too large. For larger tariffs, the *No-Cost* model substantially overstates the change in steady state consumption from eliminating tariffs. Of course, these differences may actually understate the differences in the gains from trade in the models since tariffs distort trade by more in the *Sunk-Cost* model than the *No-Cost* model. To account for this, we consider an experiment where we raise tariffs in both models until we are close to autarky. In particular, we raise tariffs in each economy to a level that yields trade flows of 0.01 percent of GDP. The results are reported in the bottom two lines of Table 4. Because of the high sensitivity of trade to tariffs in the *Sunk-Cost* model, this requires tariffs of 70.4 percent. In contrast in the *No-Cost* model tariffs of 261 percent are necessary to generate the same trade flows. Relative to our benchmark calibration with 8 percent tariffs, the welfare gains to trade, measured by steady state consumption, is almost four times as large in the *No-Cost* model as in our benchmark model (0.76 percent vs. 2.77 percent).

That tariffs distort steady state consumption by more in the model without export decisions may appear surprising. After all, the literature has emphasized that the gains to lowering trade barriers should be larger in models with export decisions, since the lower barriers attract more relatively productive exporters. We actually view this result as being sensible. In the model with an export decision, tariffs are a tax on exporting and so the economy invests less in exporting but more in producing tradable varieties. In the *No-Cost* model, tariffs are a tax on the entire tradable sector and so it leads to fewer tradable establishments. In a sense, the model with an exporting decision has one additional margin with which to adjust and hence the impact on steady state consumption is smaller.

Now, a question arises: Are the welfare gains with transition dynamics similar to the steady state comparisons?

5. Transition Dynamics

In this section, we consider a move from a world in which both countries charge 8 percent tariffs to free trade. The results from this policy experiment provide some guide to the expected changes in the US and the rest of the world from moving to free trade. This change in policy is assumed to be completely unanticipated.³⁷ The long-run changes in the model economy are reported in Table 5 and

³⁷This distinction is quite important in the sunk-cost model since an anticipated trade reform will generate a change in trade prior to the reform as the increase in the expected value of continuing to export will lead some relatively unproductive exporters to not exit.

the first 50 periods³⁸ of the transition³⁹ are plotted in Figures 5 and 6. We begin by discussing the aggregate implications and then consider the implications for the volume of trade and exporting. The algorithm for the solution is described in the technical appendix.

A. Welfare

From Table 5 we see that taking into account the transition to the new steady state the gains to lowering tariffs are about 30 percent larger in the *Sunk-Cost* model than in the *No-Cost* model (1.03 vs. 0.73). This discrepancy from our steady state results arises because in our benchmark model, steady consumption understates the true welfare gain of trade reform by 20 percent (0.84 vs. 1.03) while in the *No-Cost* model steady state consumption overstates the true welfare gain by approximately 30 percent.

Figure 5 depicts the transition to the new steady state in the *No-Cost* and *Sunk-Cost* models. In the *No-Cost* model, along the transition to the new steady state there is the familiar gradual expansion in economic activity common to the neoclassical growth model. With lower tariffs, the price of tradables and physical capital both fall so that more tradable establishments are created and more capital is accumulated. The investment in capital and establishments is financed by foregone consumption along the transition and so steady state consumption overstates the true welfare gain.

In the benchmark model, a trade liberalization leads to a sustained economic expansion that slightly overshoots the new steady state along the transition. From panel (a) of Figure 5 we see that consumption grows quite strongly following the cut in tariffs, peaking 0.4 percent above the new steady state 10 years after the policy change. This overshooting is somewhat surprising given the strong consumption smoothing motive in the model, and largely reflects the economy's ability to better use existing assets, namely establishments, along the transition. This improved efficiency is captured in the

³⁸The evolution of the establishment distribution and the use of capital in production give rise to a slow transition to the new steady state. The most interesting dynamics though are in the first 50 years.

³⁹With the fixed costs, a large change in policy can give rise to oscillations as a large mass of establishments can be created in a particular period. To reduce the oscillatory behavior with high frequency in the establishment creation during the transitions, we introduce small adjustment cost, which depends on the mass of new establishments relative to that of incumbents, rather than a constant cost. The modified costs of creating a new variety in the tradable and non-tradable sectors are given as

$$f_{TE,t} = f_E \left[\frac{(\kappa - 1) N_{TE,t}}{\kappa a N_{T,t} - N_{TE,t}} \right]^{0.2} \quad \text{and} \quad f_{NE,t} = f_E \left[\frac{(\kappa - 1) N_{NE,t}}{\kappa a N_{N,t} - N_{NE,t}} \right]^{0.2},$$

respectively. Here, a is the steady state level of establishment destruction rate, $N_{TE}/N_T = N_{NE}/N_N$, and κ is set to 10. With this variation, the maximum variation of costs is about 0.7 percent during the entire transitions suggesting the modification has only negligible effects on the results.

dynamics of the Solow residual⁴⁰ in panel (c). By this measure, following a trade liberalization there are both permanent and persistent changes in the Solow residual. As with a persistent productivity shock in a standard real business cycle model, agents take advantage of this shock by investing in capital accumulation (panel b) and smoothing out consumption, and this contributes to the overshooting in consumption.

Unlike the Solow residual in a real business cycle model, the Solow residual in our benchmark model is endogenous and reflects changes in the number of establishments and exporters, as well as changes in the productivity distribution of establishments. In the previous section we showed that tariffs lead to an over-accumulation of establishments and under-accumulation of exporters compared to free trade. Along the transition there are many establishments that can easily be converted into exporters. Thus along the transition the economy will invest less in establishments (panel e) and invest more in creating exporters. The net effect is a rapid increase in the number of tradable varieties available, which also overshoots its long-run level (panel f). Because this expansion in variety occurs through an increase in exporters and decrease in the creation of establishments, the distribution of productivity over plants is also changing over time. Since entrants are generally less productive than incumbents, the decline in entry reduces the mass of relatively unproductive establishments, thereby raising the average productivity, measured as a simple average, of the existing establishments (panel d). This measure peaks 0.3 percent above its initial and long-run levels⁴¹ in year 4. In contrast, in the *No-Cost* model since the number of tradeable producers increases, along the transition the average productivity of the plants in the tradable sector initially falls.

B. Trade and Exporters

The four panels of Figure 6 plot the evolution of trade-related variables along the transition to the new steady state. Starting with the trade to GDP ratio (panel a), we see that in both the *Sunk-Cost* and *No-Cost* models trade expands substantially with tariff reductions. In the *No-Cost* model, the trade share jumps by 44.6 percent to its new long-run level right away since the trade-GDP ratio is determined by the tariff rate and transportation costs. In the *Sunk-Cost* model, the trade

⁴⁰The Solow residual is constructed as $z = \ln D - 0.34 \ln K - 0.66 \ln L$. Obviously, a finer decomposition that takes into account the stock of varieties would yield a different Solow residual.

⁴¹Given that exit and productivity evolve exogenously, the distribution of establishments over productivity is identical across all steady states of the model.

expansion is much more drawn out. In the first period trade increases by 44.6 percent since existing varieties become less expensive. In the second period, trade expands another 17.0 percent as export participation increases. Five years after the policy change, the trade-GDP ratio is 85.3 percent above its initial level. From then on, trade grows more gradually to its long-run value, which exceeds the initial level by 92.3 percent.

The gradual increase in trade reflects a slightly more gradual increase in export participation (panel b). On impact, export participation rises by 23 percent. In the next period it expands another 16 percent. From then on export participation grows gradually another 32.1 percent to its long-run level, which is greater than the initial level by 74.6 percent. The increase in exporting occurs through a persistent increase in the starter ratio and persistent decrease in the stopper ratio, both of which overshoot their long-run levels (panel c). From panel (d) we see that very little of the overshooting of the stopper and starter rates results in overshooting in the entry and exit thresholds, but instead reflects the fact that when the policy is enacted there are many relatively productive non-exporters at the margin and very few unproductive exporters. Given the large gap between the entry and exit threshold, this implies that along the transition, the mass of exporters clustered around the upper threshold is quite large relative to the steady state. So, just as the establishment distribution was shifted toward relatively more productive establishments, the exporter distribution is shifted toward relatively productive establishments. The change in exporter distribution contributes to the overshooting in economic activity.

6. Sensitivity

To make the model consistent with the data, we embedded a number of real-world features into our benchmark model that the theoretical literature on international trade commonly abstracts from.⁴² We now ask whether models that abstract from these key features of plant and exporter characteristics and dynamics affect the relation between tariffs, trade, and welfare. In doing so, we highlight the key margins that matter in the model. In terms of the nature of trade costs, we find that nearly all of the overshooting arises because of the sunk nature of export costs.

Specifically, we consider 5 variations of our benchmark model. In addition to the *Permanent*

⁴²Some papers using versions of the Melitz model to study different issues related to international trade include Ruhl (2003), Baldwin and Robert-Nicoud (2005), Chaney (2005), Gibson (2006), Baldwin and Forslid (2006), Arkolakis et al (2009).

and *Fixed-Cost* model we already described, we include a model with no capital, called *No-Capital*, and another model in which tradable producers do not use intermediate goods, called *No-Materials*. We also consider a version of our benchmark model calibrated to have more persistent exporters, which we denote *Sunk-High*. The parameter values used for these variations are reported in Table 1. The calibration targets and the fit of the models are reported in Table 2. With these variations, we consider the effect of eliminating a tariff rate of 8 percent. The long-run effects are reported in Table 5 and transitions of some key variables are plotted in Figure 7.

From the *Fixed-Cost* variation, we see that the structure of fixed costs matters for both the trade and export participation response to tariffs but less so for welfare. When the startup cost is the same as the continuation cost of exporting, the trade and export participation increase is, respectively, 12 and 38 percent less than in the benchmark model. The alternate model generates a smaller response of trade and exporting because the threshold for entry and exit is identical and there are fewer establishments affected by changes in this threshold than in the benchmark model. In *Fixed-Cost*, export capacity is no longer a durable asset and hence increasing export participation uses up more resources along the transition, while in *Sunk-Cost* the economy can use existing exporters more effectively. From Figure 7 panel (f) we see that these exporter dynamics eliminate the overshooting of consumption following trade liberalization implying the welfare gains is smaller than the steady state change in consumption.

Considering next the *Sunk-High* model, we see an even larger difference from the *Fixed-Cost* model. Now, along the transition there is even more overshooting. There is also a smaller increase in steady state consumption. In this economy, the average startup cost is now 16 times the continuation cost and 53 percent of export profits are devoted to costs of exporting. In this economy, trade rises substantially more from the cut in tariffs.

Turning next to our *Permanent* model, we see that further eliminating the establishment idiosyncratic uncertainty in productivity reduces both the welfare gain and trade response to trade reform. With productivity determined at birth, the distribution of productivity over establishments is unaffected by the rate of new establishment creation. Thus, there is no overshooting and consumption grows much more gradually to its new steady state, and steady state consumption overstates the welfare gain. Additionally, now export participation and trade rise only 33 percent and 62 percent, respectively, as much as in the *Sunk-Cost* model.

From our *No-Capital* variation we see that capital accumulation is important primarily for

the welfare results. Abstracting from capital accumulation lowers the welfare gain to moving to free trade by about one-quarter but has no noticeable impact on either export participation or trade flows. Without capital, the timing of the expansion following the trade liberalization is a bit different too, with the economy expanding more early on, with output peaking 6 years earlier and 23 percent below the peak in the benchmark model. The more drawn-out expansion in the benchmark model results from capital being useful to smooth out consumption, while the larger long-run gains with capital point to the benefits of capital being complementary to exporting.

Without intermediates, the welfare gains to trade reform are about 22 percent of our benchmark model. Yi (2003) also found that intermediates magnified the welfare costs of tariffs. Tariffs are more distortionary with materials because it is as if the same good is sold multiple times, with each producer adding a markup each time the good is sold and a tariff each time it crosses the border. However, the trade response is nearly identical to the *Sunk-Cost* model without intermediates.⁴³

Another reason tariffs might distort steady state consumption by more in the *No-Cost* model is that trade responds very little in this model to a cut in tariffs.⁴⁴ In recent work, Arkolakis et al. (2009) have shown that under certain conditions the welfare gains to trade are identical across a large class of models if the trade elasticity is the same in these models. The models studied here are outside the class of models studied by Arkolakis et al. (2009). Nonetheless, to explore this idea we recalibrate the elasticity of substitution, θ , in each variation so that an 8 percent cut in tariffs yields the same growth in trade as in the *Sunk-Cost* model.⁴⁵ The top line of Table 6 reports the new elasticity for each model that yields the same growth in trade. In the *No-Cost* model we need to increase the elasticity from 5 to 9.16. The rest of the table reports how the structure of the steady state of each economy changes following a cut in tariffs. Now, we see that in the *No-Cost* model steady state consumption rises only 0.58 percent. The *Fixed-Cost* model consumption rises 0.63 percent and in the *Permanent* it rises 0.54

⁴³Yi (2003) develops a model of trade in which intermediates move back and forth across borders in different stages of production and endogenizes the number of times goods cross the border. In some respects, there is some of this back and forth in our model in that when establishments choose to export they are selling goods overseas which then will be reimported in the goods of intermediates of foreign exporters. Adding materials does not magnify this effect because in our model all of the changes come in the first stage of production with the change in range of varieties available.

⁴⁴We thank an anonymous referee for suggesting this comparison to us.

⁴⁵Let $*$ denote the benchmark value in our original calibration of each variation. We then adjust the productivity distribution to keep the same size distribution of plants. We know that the size of a producer is proportional to $e^{(\theta-1)z}$. To maintain the same size distribution with various θ , we set $\sigma_\varepsilon = \sigma_\varepsilon^* \left(\frac{\theta^*-1}{\theta-1} \right)$, $\mu_E = \mu_E^* \left(\frac{\theta^*-1}{\theta-1} \right)$, and the slope shutdown probability to $\max \left\{ 0, \min \left\{ \lambda \exp \left[-\lambda e^{\left(\frac{\theta^*-1}{\theta^*-1} \right) z} \right] + n_{d0}, 1 \right\} \right\}$. With these changes, the steady state is invariant to the choice of θ .

percent. Overall, in these three models the change in trade generates roughly 60 to 70 percent of the change in steady state consumption in the Sunk-Cost model. Including the transition to the steady state, we can expect to find an even larger gap between these competing models and the *Sunk-Cost* model.

7. Conclusions

We study the ability of a generalized version of the Melitz model, the workhorse model of plant heterogeneity and international trade, to account for differences in US export participation among manufacturing establishments as well as the frequent transitions into and out of exporting. With plant-level uncertainty in technology and trade costs as well as costs of starting to export that are on average 3.7 times as big as the cost of continuing in the export market, the model matches up well with the distribution of export participation among US manufacturing plants. Our finding of an important sunk aspect in export costs of US manufacturers is consistent with the estimates of sunk costs among firms in Colombia by Das, Roberts, and Tybout (2007). In total, resources devoted to startup and continuation costs are estimated to account for about 10.6 percent of international trade US or 53 percent of export profits. The tariff equivalent of these fixed costs is roughly 30 percentage points. The important role for fixed export costs helps to explain in part, a key puzzle that measures of trade costs are low while those inferred from trade flows are quite high (Anderson and van Wincoop, 2004).

We use the model to calculate the aggregate response to moving to free trade. We find that cutting tariffs from 8 percent to zero, increase welfare a sizeable 1.03 percent and trade by nearly 92.3 percent. Overall, with current tariff levels, we find steady state consumption is 0.76 percent higher than under autarky. We find that models that lack a sunk cost of exporting or plant-level uncertainty provide an imprecise estimate of this welfare gain, particularly when calibrated to match the aggregate trade response. Moreover, we find that the transition following a cut in tariffs depends on the nature of trade costs. With a sunk cost of exporting, we find that the transition is much faster and may overshoot, while without a sunk cost the transition takes on the familiar gradual neoclassical transition. Thus, the benefits to trade liberalization are much more immediate when costs are sunk.

The model was used to provide some guidance on the key margins that matter for trade and welfare in models with establishment heterogeneity. If one is mostly interested in trade flows, we find that models without sunk costs substantially understate the long-run increases in trade, since increases

in export participation are much smaller. We also found that the dynamics of trade growth are more gradual in models with sunk costs. In terms of welfare, we found an important quantitative role for both capital and intermediate inputs in the production process of tradables.

Even though we focus on a symmetric policies with two symmetric economies, our quantitative approach is well-suited to consider a range of alternative and asymmetric policies. For instance, the model is well suited to considering the impact of unilateral cuts in tariffs as well. In particular, we can consider the impact on both net exports and the real exchange rate of a unilateral change in trade policies. One would expect that unilaterally lowering tariffs would generate somewhat larger economic expansions along the transitions to the new steady state as the reforming country can borrow to finance greater investment. Our model is also well-suited to examine the aggregate implications of a range of non-tariff policies meant to encourage exporting, such as subsidies or corporate taxes, as well as policies targeted to assist workers following trade related displacements. In general, studying the interaction between trade and labor market policies related to the recruitment or dismissal of workers is possible in our framework.

Finally, we consider the implications of a popular theory of trade that is consistent with a key set of cross-sectional and dynamic facts about exporters and non-exporters emphasized in the literature. Doing so, we find that when there is a dynamic aspect to the export decision the aggregate outcomes are quite different from models with only static exporting decisions. There is much heterogeneity across establishments in the time series and cross section and so this theory is likely to be inconsistent with some of additional features of the data. For instance, Ruhl and Willis (2007) find high exit rates among new exporters. Exploring how these additional micro features matter for aggregate outcomes is likely to be an important area of future research.⁴⁶

⁴⁶Indeed, in our technical appendix (Alessandria and Choi, 2011) we consider how the trade response depends on different dynamic aspects of exporting.

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Table 1: Parameter Values

Common Parameters							
	β	σ	θ	δ	τ		
	0.96	2	5.0	0.10	0.08		
Model Parameters							
	Sunk- Cost	No- Cost	Fixed- Cost	Permanent (stoch. fixed)	No- Capital	No- Materials	Sunk- High
α	0.286	0.281	0.285	0.223	0	0.304	0.286
λ	7.351	7.472	7.350	7.350	7.351	7.351	7.372
n_{d0}	0.022	0.022	0.022	0.023	0.022	0.022	0.022
α_m	0.804	0.804	0.804	0.804	0.804	0	0.804
γ	0.210	0.210	0.210	0.210	0.210	0.582	0.224
ξ	0.451	0.757	0.452	0.481	0.451	0.451	0.451
ρ	0.655	0.655	0.655	1	0.655	0.655	0.640
σ_ε	0.333	0.335	0.333	0.445	0.333	0.333	0.340
μ_E	-0.353	-0.368	-0.353	0	-0.353	-0.353	-0.355
f_E	1.652	1.685	1.663	3.189	1.258	1.195	1.678
σ_v	1.104	0	1.617	3.60	1.104	1.104	0.430
f_0	0.342	0	0.064	0.108	0.261	0.247	0.336
f_1	0.018	0	0.064	0.108	0.014	0.013	0.021

Note: For the permanent productivity case, there are no shocks to the idiosyncratic productivity, but σ_ε determines the unconditional productivity distribution.

Table 2: Target Moments

	Target value	Sunk- Cost	No- Cost	Fixed- Cost	Permanent (stoch. fixed)	No- Capital	No- Materials	Sunk- High
5-year exit rate	0.370	0.370	0.370	0.370	0.110	0.370	0.370	0.370
Startups' labor share	0.015	0.015	0.015	0.015	0.021	0.015	0.015	0.015
Shutdowns' labor share	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Stopper rate	0.170	0.170	-	0.669	0.685	0.170	0.170	0.043
Exporter ratio	0.223	0.223	-	0.223	0.223	0.223	0.223	0.223
Trade Share	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039
Root mean squared error (%)								
Overall Fit	0	1.553	5.258	1.563	3.245	1.553	1.553	1.629
Establishments	0	0.376	1.065	0.376	0.924	0.376	0.376	1.131
Employment share	0	0.762	1.162	0.765	0.623	0.762	0.762	0.721
Export participation	0	2.489	8.475	2.506	5.162	2.489	2.489	2.224

Note: Overall fit is defined as the root mean squared error of establishment and export participation bins.

Table 3: Additional Implications

	Target value	Sunk- Cost	No- Cost	Fixed- Cost	Permanent (stoch. fixed)	Sunk High
Exporter Premium	5.60	3.50	-	3.51	4.04	3.07
Starter (employment)						
Mean		171.29		92.52	69.01	439.60
Median		60.85		28.63	19.86	237.19
Stopper (employment)						
Mean		13.38		42.68	59.22	1.26
Median		4.96		13.59	17.20	0.82
Startup Cost (1992 \$ mill.)						
Mean		0.745	-	0.168	0.070	2.108
Median		0.639	-	0.111	0.024	2.128
Continuation Cost (1992 \$ mill.)						
Mean		0.203		0.252	0.180	0.223
Median		0.136		0.111	0.024	0.190
Costs (% of Gross Export Profits)		52.98		33.26	17.58	64.24
Startup		25.27		19.59	8.19	29.15
Continuation		27.71		13.67	9.39	35.09
Startup Cost (% of)						
Mean profits of starters		99.08		34.42	18.43	1.31
Median profits of starters		388.24		139.43	63.82	4.36

Table 4: US Micro Growth Rates: Data and Models

		Annual (1 year)			1989-1992 (3 years)			1984-1988 (4 years)			Long run (8 years)		
	MAD	Start	Stop	Both	Start	Stop	Both	Start	Stop	Both	Start	Stop	Both
Employment		5.6	-1.0	4.7	3.8	-1.2	3.2	3.0	0.0	2.7	2.3	-0.6	2.1
Shipments		9.1	-3.3	5.0	5.6	-2.3	3.5	4.2	-1.6	2.4	3.2	-1.4	2.1
Average		7.4	-2.1	4.8	4.7	-1.7	3.4	3.6	-0.8	2.6	2.8	-1.0	2.1
100+ employees in t=0,t=T													
Sunk-Cost	1.5	6.6	-1.3	3.4	7.8	-3.2	6.1	5.8	-2.8	4.9	2.8	-0.3	2.9
Fixed-Cost	2.3	5.4	-3.8	2.5	9.2	0.1	8.6	7.2	0.2	6.7	2.9	0.0	3.1
Fixed-High persistence	7.6	-	-	-	18.4	-0.3	17.5	12.9	-2.1	12.7	10.7	1.5	10.3
10+ employees in t=0,t=T													
Sunk-Cost	3.6	6.2	-3.7	-0.7	12.9	-5.1	7.2	10.4	-2.9	7.1	5.1	-0.2	4.8
Fixed-Cost	4.9	3.4	-6.9	-0.2	14.2	-0.8	14.0	11.3	-0.4	11.1	5.7	0.0	5.8
Fixed-High persistence	14.5	6.4	-19.4	-0.9	31.8	-9.5	30.9	27.8	-6.6	27.9	17.6	-2.0	18.4

Table 5: Percent Changes in Steady State and Transition Changes from Eliminating 8
Percent Tariff

	Sunk- Cost	No- Cost	Fixed- Cost	Permanent (Stoch. fixed)	No- Capital	No- Materials	Sunk- High
Consumption	0.84	1.01	0.92	0.87	0.58	-0.01	0.80
Trade to GDP ratio	92.31	44.60	63.79	53.41	92.31	90.49	128.32
Capital stock	1.06	1.23	1.14	1.09	-	0.37	1.02
Production labor	-0.26	-0.09	-0.18	-0.12	-0.20	-0.16	-0.32
Non-tradable variety	-0.45	-0.28	-0.36	-0.30	-0.39	-0.47	-0.51
Domestic tradable variety	-2.19	1.21	-0.17	0.52	-2.13	-3.13	-4.38
Total tradable variety	11.13	1.21	4.29	2.72	11.20	10.05	18.69
Starter ratio	63.84	-	23.48	11.47	63.84	63.84	152.87
Stopper ratio	-35.51	-	-8.54	-4.02	-35.51	-35.51	-86.25
Exporter ratio	74.66	-	24.49	11.98	74.66	74.66	132.33
Output premium	-1.97	-	-0.75	4.62	-1.97	-1.97	-2.77
Productivity premium	-10.30	-	-2.49	-1.64	-10.30	-10.30	-12.01
Static welfare gains	0.84	1.01	0.92	0.87	0.58	-0.01	0.80
Transitional welfare gains	1.03	0.73	0.87	0.74	0.79	0.24	1.20
Tariff to get to Autarky*	0.70	2.61	0.71	1.76	0.70	0.70	0.51
SS Consumption relative to Autarky**	1.60	3.78	2.45	3.91	1.17	0.71	1.12

Note: Welfare gains are measured as the value of x that satisfies $\sum_{t=0}^{\infty} \beta^t U(C_{-1}(1+x)) = \sum_{t=0}^{\infty} \beta^t U(C_t)$, where C_{-1} is the initial steady state consumption. * By autarky we mean raising tariffs to lower the level of trade to 1 percent of our calibrated level.

* Tariff rate to achieve 0.01 percent of the trade share of GDP.

**New steady state (0 tariff rate) consumption relative to autarky.

Table 6: Percent Changes in Steady State from Eliminating 8 Percent Tariff with Same
Trade Response by Changing θ

	Sunk- Cost	No- Cost	Fixed- Cost	Permanent (shock)	No- Capital	No- Materials
New θ	5.00	9.16	6.79	7.87	5.00	5.09
Consumption	0.84	0.58	0.63	0.54	0.58	0.00
Trade to GDP ratio	92.31	92.31	92.31	92.31	92.31	92.31
Capital stock	1.06	0.89	0.91	0.83	-	0.37
Production labor	-0.26	-0.04	-0.15	-0.09	-0.20	-0.16
Non-tradable variety	-0.45	-0.30	-0.38	-0.33	-0.39	-0.47
Domestic tradable variety	-2.19	1.19	-0.74	0.02	-2.13	-3.19
Total tradable variety	11.13	1.19	5.34	3.47	11.20	10.22
Starter ratio	63.84	-	32.17	18.13	63.84	65.08
Stopper ratio	-35.51	-	-11.60	-6.30	-35.51	-36.02
Exporter ratio	74.66	-	33.57	18.95	74.66	76.01
Output premium	-1.97	-	7.31	8.46	-1.97	-1.92
Productivity premium	-10.30	-	-3.16	-2.48	-10.30	-10.41

Figure 1a: Establishment Distribution

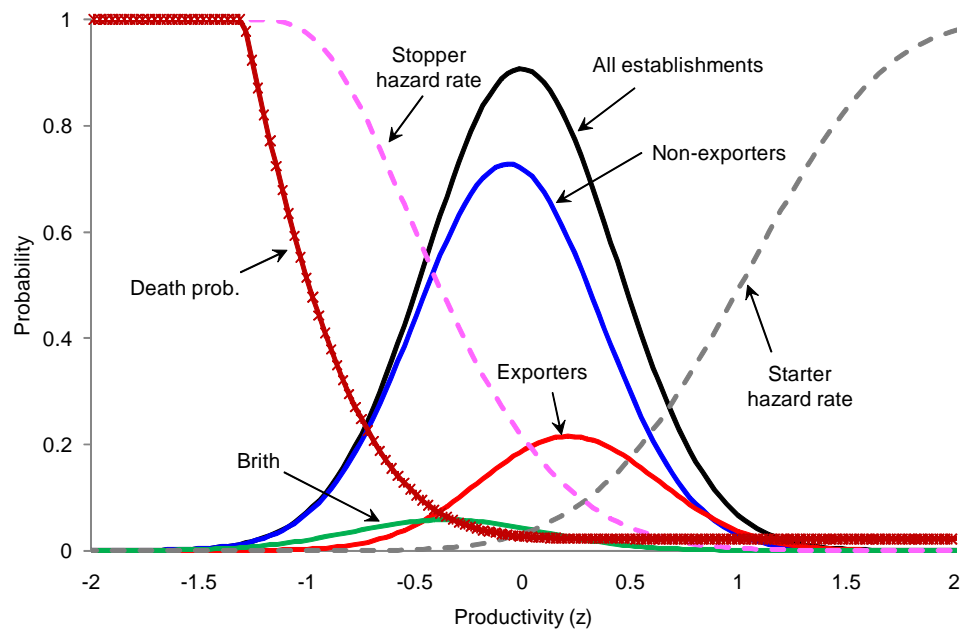
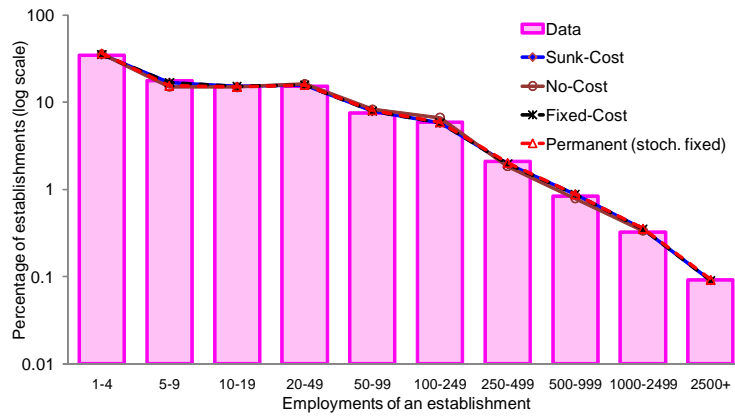
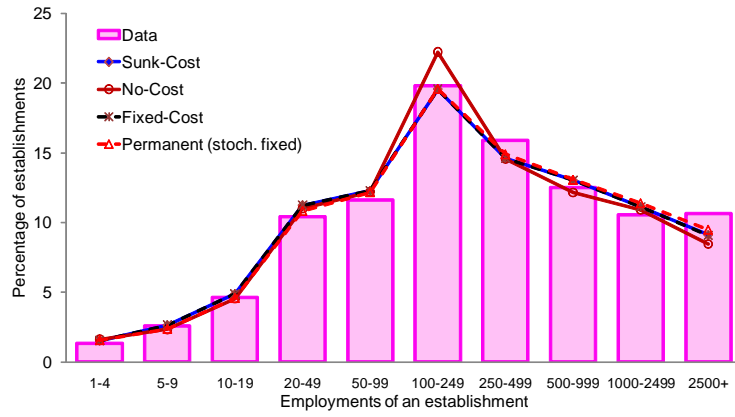


Figure 2: Employment Distributions

(a) Establishment Share



(b) Employment Share



(c) Export Participation

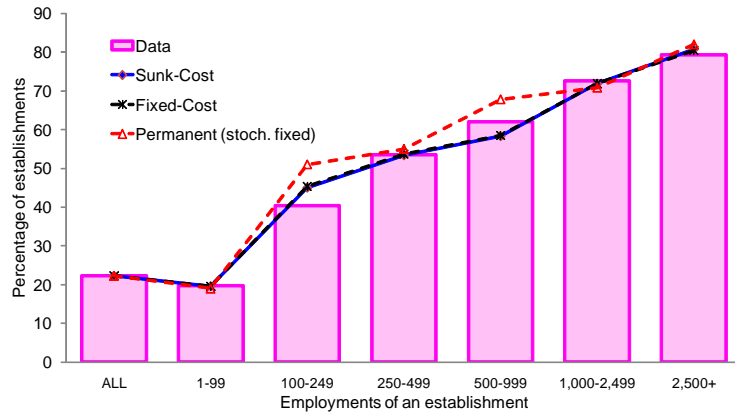


Figure 3: Steady State Establishment Characteristics and Tariffs

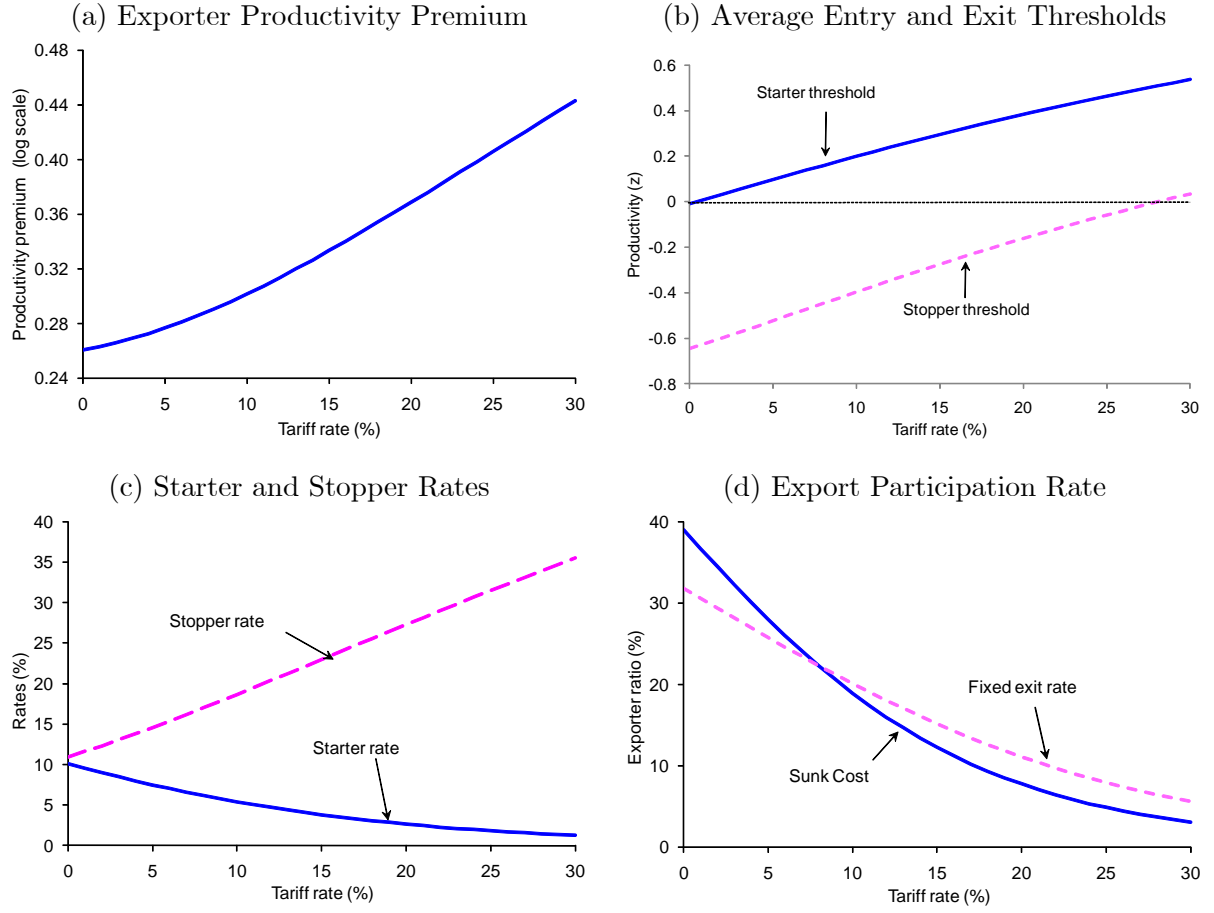


Figure 4: Steady State Aggregates and Tariffs

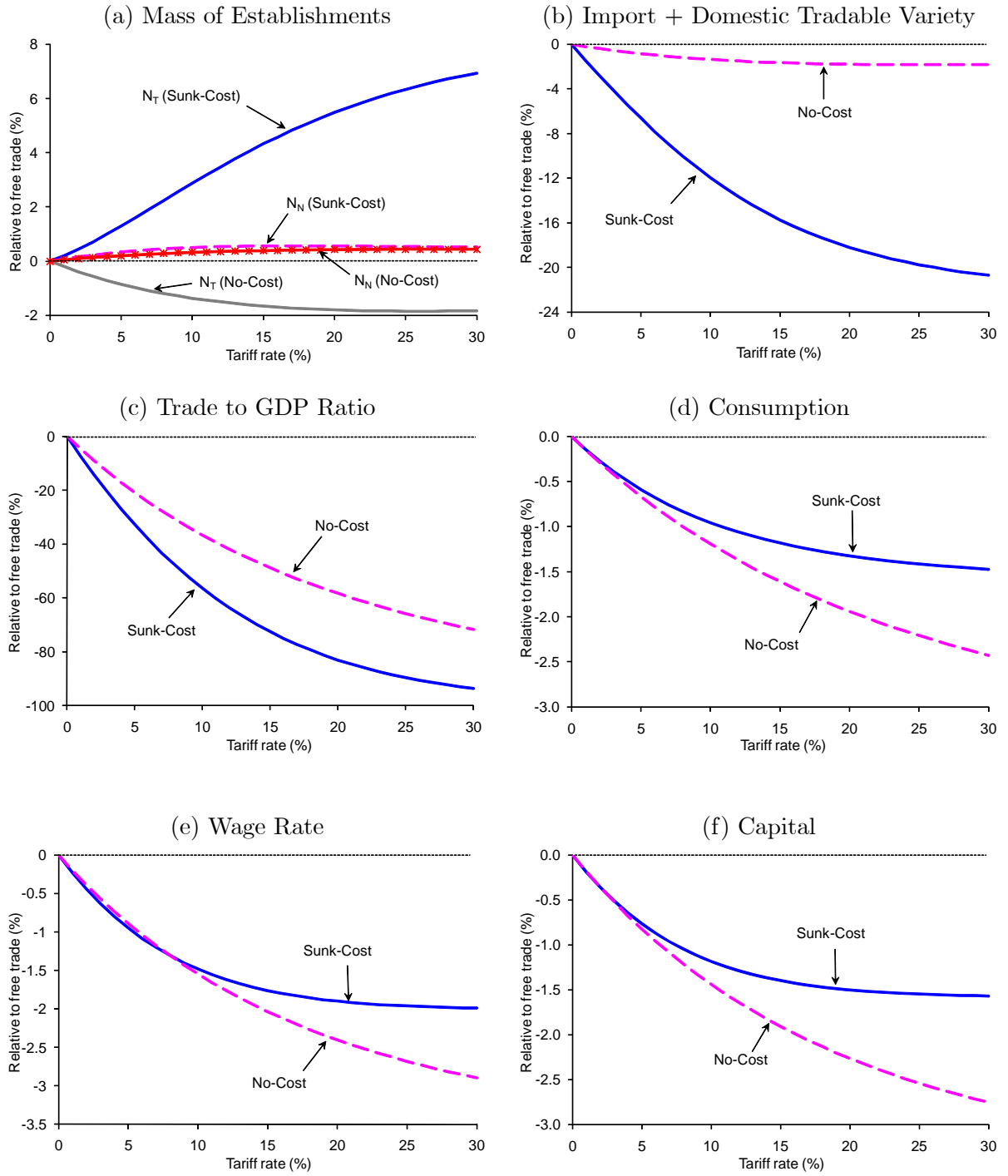


Figure 5: Transition Dynamics from 8 Percent Tariff to Free Trade

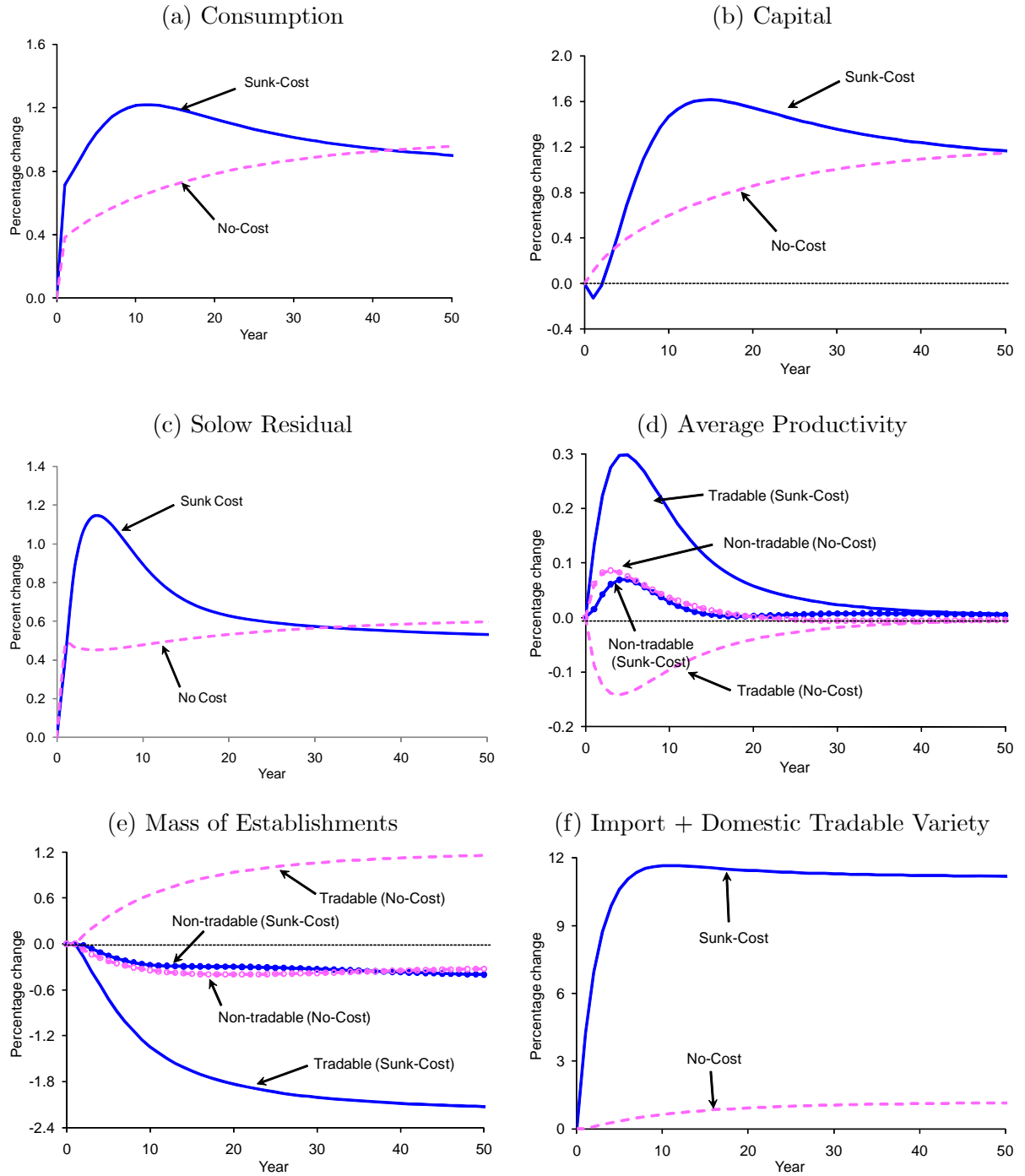
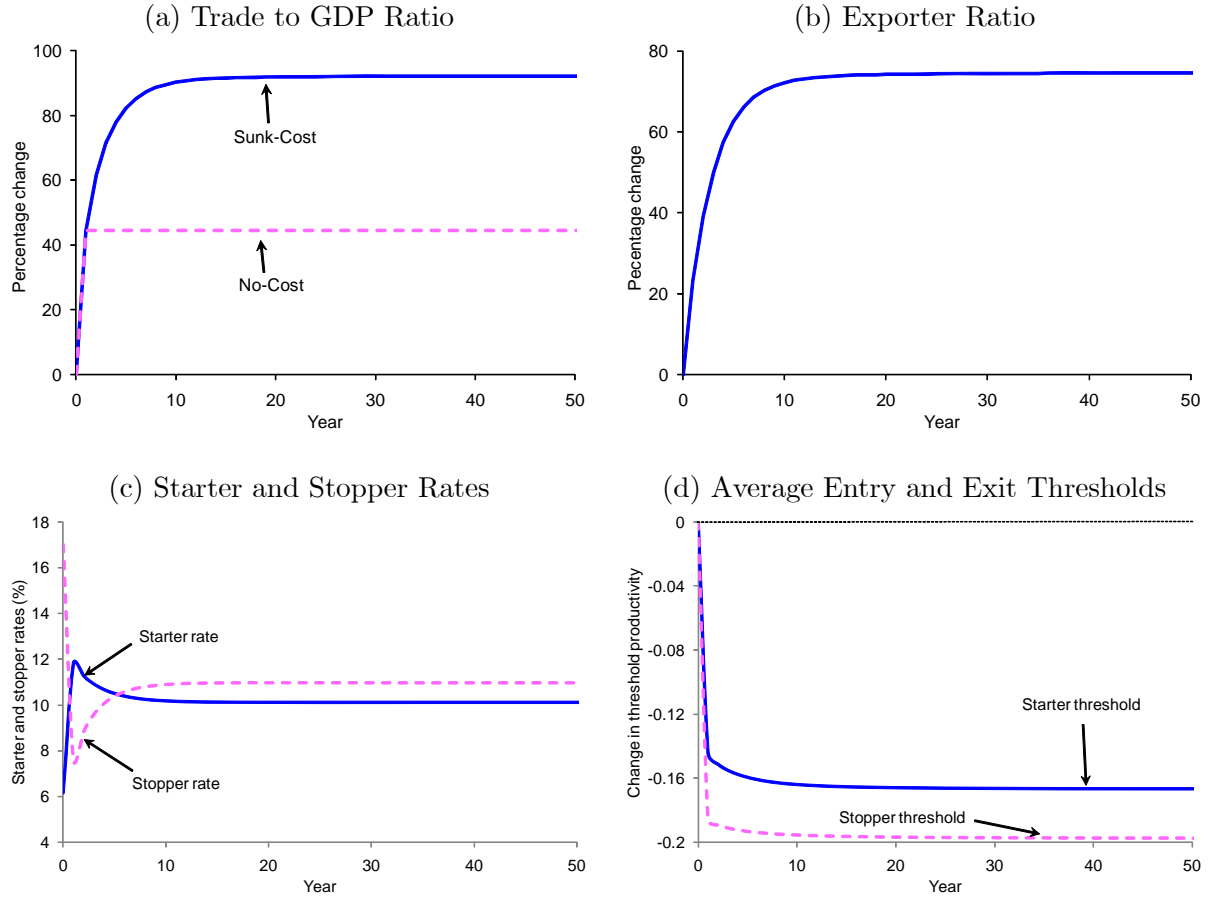


Figure 6: Transition Dynamics from 8 Percent Tariff to Free Trade



Note: The average productivity is normalized with the steady state distribution to have zero-mean and unit-variance.

Figure 7: Transitions with Variations

