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WORKING PAPER NO. 11-19/R

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July 2012

RESEARCH DEPARTMENT, FEDERAL RESERVE BANK OF PHILADELPHIA

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

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First Version: July 2007

This Version: July 2012

Abstract

We study the effects of tariffs in a dynamic variation of the Melitz (2003) model, a monopolistically competitive model with heterogeneous establishments and fixed costs of exporting. With costs of starting to export that are substantially larger than the costs of continuing to export, the model matches both the size distribution of exporters and annual transition in and out of exporting of US manufacturers. The tariff equivalent of these fixed costs is 30 percentage points. The calibrated model is used to estimate the effect of reducing tariffs on welfare, trade, and export participation. We find sizeable gains to moving to free trade of 1.03 percent of steady state consumption. Along the transition, economic activity overshoots its steady state so that steady state changes in consumption understate the welfare gain to trade reform. Models that abstract from exporter dynamics generate smaller gains to trade and very different aggregate transition dynamics.

JEL classifications: E31, F12.

Keywords: Sunk cost, fixed cost, establishment heterogeneity, tariff, welfare.

*The views expressed here are those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Philadelphia or the Federal Reserve System. This paper is available free of charge at www.philadelphiafed.org/research-and-data/publications/working-papers/. Alessandria thanks the National Science Foundation for support. We thank Andy Atkeson, Roc Armenter, Yan Bai, Sam Kortum, Amatrya Lahiri, Marc Melitz, Virgiliu Midrigan, Alex Monge, Fabrizio Perri, Esteban Rossi-Hansberg, Kim Ruhl, Mike Waugh, Daniel Xu, and Kei-Mu Yi for useful comments. We also thank seminar participants at the Berkeley, University of Chicago, University of Texas, Tulane, NYU, Science Po, Stanford, SUNY-Albany, 2006 Philadelphia Fed International Trade Workshop, 2006 Minneapolis Fed Macroeconomics Without Frontiers Conference, Vancouver SED Meetings, Stanford Institute for Theoretical Economics in 2007, 2009 Frontier Research on Markets with Frictions, 2010 NY/Philly Fed Quantitative Macro Conference, 2011 Yale conference on New Perspectives on International Trade, Development, and Macroeconomics.

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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.[1] In this theory, tariffs and trade barriers reduce the value of exporting and discourage some relatively productive establishments from exporting. This lowers trade flows and shifts production 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] However, recent work by Arkolakis, Demidova, Klenow, and Rodriguez-Clare, 2008, and Arkolakis, Costinot, and Rodriguez-Clare, 2011, has cast doubt on the novelty of this mechanism showing that under certain conditions heterogeneity and fixed costs do not change the gains from international trade. In this paper, we evaluate quantitatively the impact of reducing tariffs on welfare, trade, and the organization of production in a dynamic variation of the Melitz model that captures key cross-sectional and dynamic elements of US establishments and exporters. We find that when the cost of starting to export exceeds the cost of continuing to export, so that exporting is a dynamic decision, the gains to trade from

[1] Many 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).

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

cutting tariffs are about 2.5 times larger than in simpler models of trade.

Before examining the aggregate implications of tariffs though, our first goal is to determine whether the cross-plant distribution of export participation[3] 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 allow plant-level dynamics.[5] First, plants face persistent idiosyncratic productivity shocks. Second, establishments face a large up-front cost of starting to export and a smaller period-by-period cost of continuing to export. Following the literature, the startup cost is described as being *sunk* since the investment has no residual value when a plant stops exporting. Third, following Das, Roberts, and Tybout (2007), there are temporary idiosyncratic shocks to the fixed export costs. In the presence of idiosyncratic shocks to technology and fixed export costs, non-exporters 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. It is important to match both the high persistence of

[3] Eaton, Kortum, and Kramarz (forthcoming) 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.

[4] Alessandria and Choi (2007) and Irarrazabal and Opromolla (2007) also develop general equilibrium models with sunk export costs and persistent idiosyncratic productivity differences. In Irarrazabal and Opromolla, 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.

[5] Atkeson and Burstein (2010) study innovation and trade in a model with firm dynamics.

exporting and the substantial dispersion in the size of exporters among US manufacturing establishments. It also implies that the distribution of exporters and non-exporters are state variables of the economy.

Our calibration provides an estimate of the precise nature of US trade costs divided between variable, startup, and continuation costs. Consistent with the common view in the theoretical work of Dixit (1989) and Baldwin and Krugman (1989) as well as the empirical findings by Das, Roberts, and Tybout (2007) of the export behavior of 136 Colombian plants, we find large costs of starting to export. For US manufacturers, the average cost of starting to export is roughly 3.7 times the average cost of continuing to export, or $745,000 ($1992). To put these into perspective, the average startup cost incurred is about 1 year (4 years) of the export profits of the average (median) exporter. In the aggregate, the resources devoted to startup costs and continuation costs account for about 25 and 28 percent, respectively, of export profits.[6] Without fixed costs, to generate the same aggregate trade, variable trade costs must increase from 45.1 percent to 75.7 percent. The high tariff equivalent of these fixed trade costs explains, in part, why direct measures of trade costs are so much lower than model-based measures inferred from trade flows (Anderson and van Wincoop, 2004).

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.

[6]The near equal importance of continuation costs in the aggregate is a result of the low entry and exit rates in and out of exporting. Most exporters are continuing exporters that pay the continuation cost.

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. This increases the duration of each exporting spell from 5.9 to 9.1 years. In total, the model predicts a 92.3 percent increase in trade (or 3.6 percentage points of GDP) and 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. This overshooting occurs even though trade grows slowly in response to a trade liberalization, so that the trade elastictiy is not constant, as it takes time to build up the stock of exporters. 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 startup cost, continue exporting longer and thus 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 exporting. The transition is slowed further when plant productivity is entirely determined at birth.

Having estimated the aggregate response to a trade reform in our benchmark model, we then ask: Do models that abstract from the key empirical features of exporter dynamics approximate the findings of our more general model? A natural reference is a model without fixed trade costs so that all establishments producing tradables export. If we calibrate this version of the Krugman (1980) model to generate the same long-run change in trade as in our benchmark model, we find a welfare gain of only 40 percent of our benchmark model. If we consider a move to autarky, which requires a different calibration of the trade elasticity, we find that the welfare loss is 1.5 times larger in the sunk cost model than in the Krugman model. These differences across models arise because transition dynamics and the long-run effects of trade are quite different. Thus, we find that the nature of trade costs and plant heterogeneity do matter for the welfare gain and trade response to a change in tariffs.

Our finding that the nature of trade costs and plant heterogeneity matter for the welfare gains to tariff reductions contrasts with the recent work by Arkolakis et al. (2008, 2011) that shows analytically under certain parametric assumptions the gains from reducing trade costs, but not necessarily tariffs, are the exact same across models with and without fixed costs of exporting. While there is no reason to expect these theoretical results to 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 of exporting 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. We also find that when there are cuts in iceberg costs, a less relevant policy tool, the gap between the benchmark and the Krugman model is substantially smaller.

A final methodological contribution of this paper is to apply quantitative methods to the study of the aggregate response to changes in tariffs in a dynamic general equilibrium model with heterogeneous producers and endogenous exporting. This approach allows us to consider a more general shock process for individual plant dynamics and different structure of trade costs than commonly employed in the largely static theoretical literature. These methods permit us to solve for the first time the transition dynamics following a trade liberalization in a GE model with sunk export costs and plant dynamics.[7] Our finding that transition dynamics, the nature of trade costs, and plant heterogeneity determine the aggregate response to trade policies suggests that quantitative methods offer an important complement to the analytical approach more commonly employed.

This paper is related to four lines of research. First, Eaton and Kortum (2002), Bernard, Eaton, Jensen, and Kortum (2003), and Alvarez and Lucas (2007) also consider the welfare gains to trade.[8] These papers evaluate the aggregate consequences of a trade liberalization in parsimonious, static, multicountry Ricardian models with productivity heterogeneity, tariffs, and transportation costs. Unlike these papers, our paper considers a dynamic model of exporting subject to sunk costs and allows for capital accumulation. The second line of research studies how trade costs influence the international transmission of business cycles.

[7] Chaney (2005) discusses the dynamics of trade and establishment dynamics following a trade liberalization without plant dynamics or a sunk aspect of exporting but does not solve for the transition path.

[8] Baldwin 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.

Baldwin and Krugman (1989) and Dixit (1989) develop partial equilibrium models of sunk costs of exporting to rationalize the non-constant trade elasticity 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 non-linear trade response to an exchange rate depreciations. These partial equilibrium studies cannot evaluate welfare or the aggregate effect of tariffs on the organization of production. Ruhl[9] (2003), Alessandria and Choi (2007), and Ghironi and Melitz (2005) study how fixed costs affect international business cycle fluctuations in two-country GE models. In a companion paper (Alessandria and Choi, 2011) we use the model developed here to evaluate the source of US export growth from 1987 to 2007. We find that sunk costs are necessary to match the non-linear relationship between aggregate export growth and the observed changes in trade costs. Third, we contribute to the macroeconomic literature that studies the impact of producer-level non-convexities in labor, capital, and price adjustment for aggregate outcomes.[10] Last, 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. Similarly, our finding of a large sunk cost implies that a substantial fraction of export profits are actually a return on the investment in building export capacity rather than a return on building a plant. Exporters are a durable asset that can be accumulated and tariffs are a tax that distorts the

[9] Ruhl is close in spirit to our work 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 that 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 exporting. Moreover, we explicitly consider the transition dynamics following a tariff reduction, while Ruhl considers the change in the stationary steady state.

[10] Hopenhayn and Rogerson (1993) consider firing taxes. Caballero and Engel (1999) and Khan and Thomas (2008) consider fixed adjustment costs in investment. Golosov and Lucas (2007) and Midrigan (forthcoming) consider fixed costs of price adjustment.

accumulation of these exporters. Thus, with a sunk cost, exporters and establishments are substitutes, while without the sunk cost, they are complements.

The paper is organized as follows. The next section develops a two-country dynamic general equilibrium model with a dynamic export decision. In section 3 we calibrate the model and present estimates of trade costs. Section 4 discusses the steady state relationship between tariffs, exporter characteristics, trade, and welfare. In Section 5, we examine the transition dynamics following an unanticipated worldwide elimination of tariffs. In Section 6, considers 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

We now develop a model that contains the key features of the Melitz model: producer heterogeneity and fixed export costs.[11] The Melitz model is 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 along with startup and continuation export costs. This allows us to capture the main aspects of exporter characteristics and transitions.[12]

Given our focus on plant dynamics, we assume there are two symmetric countries, *home* and *foreign*. Each country is populated by a unit mass of identical, infinitely lived consumers that inelastically supply L units of labor. Each period a mass of existing establishments

[11] Unlike the Melitz model, our model does not have fixed production costs. Instead, we capture the higher exit rates of small establishments in the shock process. By allowing the survival probability to vary with size we can capture how exit rates vary with size without relying on large shocks to fixed operating costs. Additionally, the assumption of exogenous exit implies that in the steady state the ergodic productivity distribution of plants is exogenous.

[12] Ruhl and Willis (2008) study how the persistence and intensity of exporting vary with the duration in a panel of Colombian manufacturers. Eaton, Eslava, Kugler, and Tybout (2008) study similar issues using transaction-level data from nearly the universe of Colombian firms over a different period. In the appendix, we show that the model can be made consistent with changes in the intensity of continuing exporters.

is distributed over countries, sectors, productivity, fixed export costs, and export status. Productivity and fixed export costs are stochastic and generate movements of establishments in and out of exporting. Unproductive establishments exit and new establishments enter.

In each country there are two intermediate good sectors, tradable and non-tradable. In each sector, a large number of monopolistically competitive establishments each produce 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.[13] In each sector, establishments differ in terms of total factor productivity, the size of their exporting fixed cost, and the markets they serve.

All tradable establishments sell to their own country, but only some export. Exporting incurs fixed and variable costs. There is an ad valorem tariff, τ, and an ad valorem transportation cost, ξ.[14] The fixed export cost depends on the establishment's current export status and an idiosyncratic shock. There is an up-front cost $f_0 e^v$ to start exporting. Here, v is an idiosyncratic shock that an establishment draws each period and shifts the startup cost. In subsequent periods, to continue exporting, establishments incur a lower, but non-zero continuation cost $f_1 e^v < f_0 e^v$. If an establishment does not pay this continuation cost it no longer exports. To resume exporting requires incurring the entry cost $f_0 e^v$ again, where ν is a new draw.[15] These costs are valued in units of domestic labor. The fixed costs of exporting imply that the available set of goods differ across countries and changes over time. Fixed

[13] We 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.

[14] Transportation costs are "iceberg" so $1+\xi$ units should be shipped for one unit to arrive. In the appendix we consider the case where the iceberg cost differs across producers and falls stochasitically over time.

[15] In the appendix we consider a case in which former exporters may resume exporting at cost $f_R \leq f_0$.

costs are paid in the period prior to exporting so that the stock of foreign varieties is fixed at the start of each period. Domestic consumers own establishments.

Any potential establishment makes an irreversible decision to enter either the tradable or non-tradable sector by hiring f_E domestic workers. Entrants produce 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, is $\varphi_{T,t}(z, v, m)$. The measure of home country non-tradable establishments with technology z is $\varphi_{N,t}(z)$. The distribution of establishments over technology, fixed cost shock, exporting status and sector is part of the aggregate state. The evolution of this distribution is central to our quantitative results.

In each country, competitive final good producers purchase intermediate inputs from establishments active in that country. Final goods are used for consumption and investment. There exists a one-period nominal bond denominated in the home currency. Money here is only a unit of account. Let B_t denote the home consumer's holding of bonds purchased in period t. Let B_t^* denote 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 subject to the sequence of budget constraints,

$$\begin{aligned} V_{C,0} &= \max \sum_{t=0}^{\infty} \beta^t U(C_t), \\ P_t C_t + P_t K_t + Q_t B_t &\leq P_t W_t L_t + P_t R_t K_{t-1} + (1-\delta) P_t K_{t-1} + B_{t-1} + P_t \Pi_t + P_t T_t, \end{aligned}$$

where $\beta \in [0,1]$ is the subjective time discount factor; P_t is the price of the final good; C_t is final consumption; K_{t-1} is the capital available in period t; 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 real dividends from home producers; and T_t is the real lump-sum transfer of local tariff revenue.

The foreign consumer's problem is analogous. Foreign prices and allocations are represented with an asterisk. The foreign budget constraint is:

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

where e_t is the nominal exchange rate with home currency as numeraire.

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

$$\begin{aligned}
Q_t &= \beta \frac{U_{C,t+1}}{U_{C,t}} \frac{P_t}{P_{t+1}} = \beta \frac{U_{C,t+1}^*}{U_{C,t+1}^*} \frac{P_t^*}{P_{t+1}^*}, \\
1 &= \beta \frac{U_{C,t+1}}{U_{C,t}} (R_{t+1} + 1 - \delta) = \beta \frac{U_{C,t+1}^*}{U_{C,t}^*} \left(R_{t+1}^* + 1 - \delta\right)
\end{aligned}$$

where $U_{C,t}$ denotes the derivative of the utility function with respect to its argument.

B. Final Good Producers

Final goods are produced by combining home and foreign intermediate goods. A home final good producer purchases inputs from all home intermediate good producers and those foreign tradable good producers exporting to the home market. Production is Cobb-Douglas in 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 intermediates, respectively. The aggregation technology is a CES function

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

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 home tradable intermediate 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, and the price of inputs, the final good producer solves the following problem,

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

subject to the production technology (1), (2), and (3). 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 producers with (z, v, m), foreign tradable good producers with $(z, v, 1)$, and non-tradable good producers with z, respectively. Solving the problem in (4) yields the input demand functions,

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

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

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

where the price indices are defined as

$$\begin{aligned} P_{T,t} = \Bigg\{ & \sum_{m=0}^{1} \int_v \int_z P_{H,t}(z,v,m)^{1-\theta} \varphi_{T,t}(z,v,m)\, dzdv \\ & + \int_v \int_z [(1+\tau) P_{F,t}(z,v,1)]^{1-\theta} \varphi_{T,t}^{*}(z,v,1)\, dzdv \Bigg\}^{\frac{1}{1-\theta}}, \end{aligned} \tag{8}$$

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

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

C. Intermediate Good Producers

All the intermediate good producers produce their differentiated good using capital and labor. Tradable producers also use tradable 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 $z,\ z' \in (\underline{z},\ \overline{z})$. An entrant draws productivity next period from the distribution $\phi_E(z')$. Each period tradable good producers draw their 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) $y_{N,t}(z) = e^{z} k_{N,t}(z)^{\alpha} l_{N,t}(z)^{1-\alpha}$

to solve

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

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

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

Tradable Good Producers

A tradable good producer is described by its technology, fixed cost shock, and export status, (z, v, m). Each period, it chooses current prices for each market, $P_{H,t}(z, v, m)$ and $P^*_{H,t}(z, v, m)$, labor, $l_{T,t}(z, v, m)$, capital $k_{T,t}(z, v, m)$, materials $x_t(z, v, m)$, and next period's export status, m'. Total materials, $x_t(z, v, m)$, are a CES of intermediate goods,

$$\begin{aligned}(14) \quad x_t(z, v, m) \quad = \quad & \left[\sum_{\mu=0}^{1} \int_{\varpi} \int_{\zeta} x^d_{H,t}(\zeta, \varpi, \mu, z, v, m)^{\frac{\theta-1}{\theta}} \varphi_{T,t}(\zeta, \varpi, \mu) d\zeta d\varpi \right. \\ & \left. + \int_{\varpi} \int_{\zeta} x^d_{F,t}(\zeta, \varpi, 1, z, v, m)^{\frac{\theta-1}{\theta}} \varphi^*_{T,t}(\zeta, \varpi, 1) d\zeta d\varpi \right]^{\frac{\theta}{\theta-1}},\end{aligned}$$

where $x^d_{H,t}(\zeta, \varpi, \mu, z, v, m)$ and $x^d_{F,t}(\zeta, \varpi, 1, z, v, m)$ are inputs of intermediate goods purchased from home tradable good producers with state (ζ, ϖ, μ) and foreign tradable exporters with state $(\zeta, \varpi, 1)$. Input demand equals

$$
\begin{aligned}
(15) \quad x^d_{H,t}(\zeta, \varpi, \mu, z, v, m) &= \left[\frac{P_{H,t}(\zeta, \varpi, \mu)}{P_t}\right]^{-\theta} \left(\frac{P_{T,t}}{P_t}\right)^{\theta} x_t(z, v, m), \\
(16) \quad x^d_{F,t}(\zeta, \varpi, 1, z, v, m) &= \left[\frac{(1+\tau) P_{F,t}(\zeta, \varpi, 1)}{P_t}\right]^{-\theta} \left(\frac{P_{T,t}}{P_t}\right)^{\theta} x_t(z, v, m).
\end{aligned}
$$

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

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

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),

$$
(20) \quad y^{d*}_{H,t}(z, v, m) = m\gamma \left[\frac{(1+\tau) P^*_{H,t}(z, v, m)}{P^*_t}\right]^{-\theta} \left(\frac{P^*_{T,t}}{P^*_t}\right)^{\theta-1} D^*_t,
$$

and demand by intermediate good producers, so that

$$\begin{aligned}
(21) \quad y_{H,t}(z,v,m) &= y^d_{H,t}(z,v,m) + \sum_{\mu=0}^{1} \int_{\varpi} \int_{\zeta} x^d_{H,t}(z,v,m,\zeta,\varpi,\mu)\, \varphi_{T,t}(\zeta,\varpi,\mu)\, d\zeta d\varpi, \\
(22) \quad y^*_{H,t}(z,v,m) &= y^{d*}_{H,t}(z,v,m) + m \sum_{\mu=0}^{1} \int_{\varpi} \int_{\zeta} x^{d*}_{H,t}(z,v,m,\zeta,\varpi,\mu)\, \varphi^*_{T,t}(\zeta,\varpi,\mu)\, d\zeta d\varpi.
\end{aligned}$$

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

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

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

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

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

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

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, v, and the aggregate state. Moreover V^1_T intersects V^0_T from below as long as there are some establishments that do not export.[16] Hence, it is possible to solve for the establishment productivity at which an establishment is indifferent between exporting and not exporting. This level of establishment productivity differs by the establishment's current export status and fixed cost shock. The critical level of

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

technology for exporters and non-exporters $z_{m,t}(v)$ satisfies

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

if there exists $z^*_{m,t}(v)$ and $z^{**}_{m,t}(v)$ such that $V^1_{T,t}\left(z^*_{m,t}(v), v, m\right) < V^0_{T,t}\left(z^*_{m,t}(v), v, m\right)$ and $V^1_{T,t}\left(z^{**}_{m,t}(v), v, m\right) > V^0_{T,t}\left(z^{**}_{m,t}, v, m\right)$.[17]

D. Entry

New establishments are created by hiring f_E workers in the period prior to production. Establishments draw their productivity from the distribution $\phi_E(z')$. Tradable entrants cannot export in their first productive period. The entry conditions in two sectors are

$$\begin{aligned}
(26) \quad V^E_{T,t} &= -W_t f_E + Q_t \left(\frac{P_{t+1}}{P_t}\right) \int_{v'} \int_{z'} V_{T,t+1}(z', v', 0)\, \phi_E(z')\, \phi_v(v')\, dz' dv' \leq 0, \\
(27) \quad V^E_{N,t} &= -W_t f_E + Q_t \left(\frac{P_{t+1}}{P_t}\right) \int_{z'} V_{N,t+1}(z')\, \phi_E(z')\, dz' \leq 0.
\end{aligned}$$

The mass of entrants in the tradable and non-tradable good sectors in period t is $N_{TE,t}$ and $N_{NE,t}$, while the mass of incumbents in the tradable and non-tradable good sectors is denoted as $N_{T,t}$ and $N_{N,t}$. The mass of exporters equals $N_{1,t} = \int_v \int_z \varphi_{T,t}(z, v, 1)\, dz dv$, the mass of non-exporters equals $N_{0,t} = \int_v \int_z \varphi_{T,t}(z, v, 0)\, dz dv$, and the mass of establishments in the tradable good sector equals $N_{T,t} = N_{1,t} + N_{0,t}$. 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 equals $N_{N,t} = \int_z \varphi_{N,t}(z)\, dz$.

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,

[17] If $V^1_{T,t}(z, v, m) < V^0_{T,t}(z, v, m)$ for all $z \in (\underline{z},\ \overline{z})$, all the producers with v will not pay the fixed cost. In that case, we set $z_{m,t}(v) = \overline{z}$. If $V^1_{T,t}(z, v, m) > V^0_{T,t}(z, v, m)$ for all $z \in (\underline{z},\ \overline{z})$, all the producers with v pay the fixed cost. In that case, we set $z_{m,t}(v) = \underline{z}$. Note that if $\overline{z} = \infty$, for any v there exists $\widetilde{z} \in (\underline{z},\ \overline{z})$ such that $V^1_{T,t}(\widetilde{z}, v, m) = V^0_{T,t}(\widetilde{z}, v, m)$ if there exists $z^* \in (\underline{z},\ \overline{z})$ such that $V^1_{T,t}(z^*, v, m) < V^0_{T,t}(z^*, v, m)$.

and the stopper ratio, the fraction of exporters who stop exporting among surviving establishments, are, respectively

$$n_{0,t+1} = \frac{\int_v \int_{z_{0,t}(v)}^{\overline{z}} n_s(z)\,\varphi_{T,t}(z,v,0)\,dzdv}{\int_v \int_z n_s(z)\,\varphi_{T,t}(z,v,0)\,dzdv}, \quad n_{1,t+1} = \frac{\int_v \int_{\underline{z}}^{z_{1,t}(v)} n_s(z)\,\varphi_{T,t}(z,v,1)\,dzdv}{\int_v \int_z n_s(z)\,\varphi_{T,t}(z,v,1)\,dzdv}, \tag{28}$$

and evolutions of the mass of establishments are

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

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

Note that for each type of good there is a distribution of establishments in each country. For exposition, we wrote these distributions separately by country and type of establishment. We can 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 establishments are indexed by their origin and sector. The exogenous evolution of technology and fixed costs as well as the endogenous exporting and entry decisions determine the evolution of this distribution.

E. Government and aggregate variables

The government collects tariffs and redistributes the revenue lump sum to domestic consumers. The government's budget constraint is

$$(29)\quad T_t = \tau \int_v \int_z \left[\frac{P_{F,t}(z,v,1)}{P_t} \right] y_{F,t}(z,v,1)\, \varphi^*_{T,t}(z,v,1)\, dzdv.$$

Nominal exports and imports equal

$$\begin{aligned} (30)\quad EX_t^N &= \int_v \int_z e_t P^*_{H,t}(z,v,1)\, y^*_{H,t}(z,v,1)\, \varphi_{T,t}(z,v,1)\, dzdv, \\ (31)\quad IM_t^N &= \int_v \int_z P_{F,t}(z,v,1)\, y_{F,t}(z,v,1)\, \varphi^*_{T,t}(z,v,1)\, dzdv, \end{aligned}$$

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 $TR_t = \frac{EX_t^N + IM_t^N}{2Y_t^N}$. Production labor, $L_{P,t}$, equals

$$(32)\quad L_{P,t} = \sum_{m=0}^{1} \int_v \int_z l_{T,t}(z,v,m)\, \varphi_{T,t}(z,v,m)\, dzdv + \int_z l_{N,t}(z)\, \varphi_{N,t}(z)\, dz.$$

The domestic labor hired by exporters to cover the fixed costs of exporting, $L_{X,t}$, equals

$$(33)\quad L_{X,t} = f_0 \int_v \int_{z_{0,t}(v)}^{\overline{z}} e^v \varphi_{T,t}(z,v,0)\, dzdv + f_1 \int_v \int_{z_{1,t}(v)}^{\overline{z}} e^v \varphi_{T,t}(z,v,1)\, dzdv.$$

From (33), we see that the trade cost, measured in units of domestic labor, depends on the exporter status from the previous period. Aggregate profits measured as the difference between profits and fixed costs equal

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

F. Equilibrium Definition

In an equilibrium, variables satisfy several resource constraints. The final goods market clearing conditions are $D_t = C_t + I_t$, and $D_t^* = C_t^* + I_t^*$. Each individual goods market clears; the labor market clearing conditions are $L = L_{P,t} + L_{X,t} + f_E\left(N_{TE,t} + N_{NE,t}\right)$, and the foreign analogue; the capital market clearing conditions are $K_{t-1} = \sum_{m=0}^{1} \int_v \int_z k_{T,t}\left(z,v,m\right) \varphi_{T,t}\left(z,v,m\right) dzdv + \int_z k_{N,t}\left(z\right) \varphi_{N,t}\left(z\right) dz$, and the foreign analogue. The government budget constraint is given by (29) 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, writing the budget constraints in units of 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 decisions 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

In this section we calibrate the model and examine its fit along targeted and non-targeted dimensions. We then discuss the magnitude of trade costs necessary to capture the characteristics and dynamics of exporters and non-exporters.

We first 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 discount factor, β, depreciation rate, δ, and risk-aversion, σ, are standard, $\beta = 0.96$, $\delta = 0.10$, and $\sigma = 2$. Labor supply is normalized to 1.

The distribution of establishments is determined by the structure of shocks. An incumbent's productivity has an autoregressive component ($\rho < 1$) of $z' = \rho z + \varepsilon$, $\varepsilon \overset{iid}{\sim} N(0, \sigma_\varepsilon^2)$. With an AR(1) shock process, the conditional distribution is normal, $\phi(z'|z) = N(\rho z, \sigma_\varepsilon^2)$, and the unconditional distribution is $N\left(0, \frac{\sigma_\varepsilon^2}{1-\rho^2}\right)$. This log normal distribution of US manufacturing plants is consistent with the evidence of Rossi-Hansberg and Wright (2007) and is a departure from the Pareto formulation of the model.[18]

Entrants draw productivity based on the unconditional distribution $z' = \mu_E + \varepsilon_E$, $\varepsilon_E \overset{iid}{\sim} N\left(0, \frac{\sigma_\varepsilon^2}{1-\rho^2}\right)$, where we assume that $\mu_E < 0$ to match the observation that entrants start out small relative to incumbents. Establishments receive an exogenous death shock that depends on an establishment's last period productivity, z, so that the probability of death is $n_d(z) = 1 - n_s(z) = \max\left\{0, \min\left\{\lambda e^{-\lambda e^z} + n_{d0}, 1\right\}\right\}$. Each period, tradable good producers

[18] We consider a Pareto distribution in the appendix.

draw a fixed cost shock from $v \overset{iid}{\sim} N(0, \sigma_v^2)$.

The parameter θ determines both the producer's markup and the elasticity of substitution across varieties. We set $\theta = 5$, which yields a producer markup of 25 percent and is consistent with the US trade-weighted import elasticity of 5.36 estimated by Broda and Weinstein (2006).[19] 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.[20] We set the tariff rate to 8 percent to include the direct measure of tariffs and half of the 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 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 $\alpha_x = 0.804$. Entry cost, f_E, is set to normalize the total

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

[20] 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 (2007) calibrate their model to 11 percent tariffs.

mass of establishments, $N_{T,t}+N_{N,t}$, to 2. The mean tradable establishment size is normalized to the US in 1992.

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 observations:

1. An exporter rate of 22.3 percent (1992 Census of Manufactures (CM)).
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 (Dunne et al. 1989).
4. Entrants' labor share of 1.5 percent reported in Davis et al. (1996) based on the ASM.
5. Shut down establishments' labor share of 2.3 percent (Davis et al. 1996).
6. Establishment employment size distribution as in the 1992 CM.
7. Establishment export participation rate distribution by size as in the 1992 CM.

The first two targets relate exporters to the population of establishments. The next three targets help to pin down the establishment creation, destruction, and growth process. Newborn establishments and dying establishments tend to have few employees. Moreover, newborns have high failure rates. Atkeson and Kehoe (2005) show that these features of the plant life cycle are important determinants of the economy's stock of organizational capital.

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 between the data and the model's implied distributions of establishments, employment size, and export participation rates.[21] The parameter values are reported in Table 1 and the fit of the benchmark model, dubbed *Sunk-Cost*, and some variations are summarized in Table 2.

Three variations of the model help to isolate the role of the structure of fixed costs and idiosyncratic shocks. These variations require us to give up on one or more of our calibration targets. We 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.

The first variation, *Fixed-Cost*, constrains $f_0 = f_1$ so that the startup and continuation costs are identical. There is no exporter hysteresis so we give up on matching transitions in and out of exporting. In our second variation, *Permanent*, $f_0 = f_1$, and we assume that establishments draw their technology at birth. With constant plant-level 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. We also eliminate the lag in the export decision so that the export decision is static. In our third variation, *No-Cost*, there are no fixed export costs. This is the Krugman (1980) model with a plant lifecycle. To match trade flows in the No-Cost model we increase the iceberg trade cost.

A. 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 targeted the establishment and employment size distribution in manufactur-

[21] Specifically, we target 10 bins for employment sizes and 6 bins for export participation rates. See the technical appendix for details.

ing 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 and the fixed-cost model 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. Some sense of the benefit of modelling the differences between export startup and continuation costs is apparent in that our calibration implies that startup costs are 3.7 times continuation costs and the standard deviation of shocks to fixed costs is substantially smaller (1.1 vs. 4.2).

Figure 1a plots the distribution of plants, exporters, non-exporters, and newborn plants by productivity level in the 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 endogenous. To match the low employment share and high shutdown rate of entrants, newborn productivity starts out on average about 35 percent lower than that of the average incumbent. Because of the idiosyncratic shocks to fixed export costs, the likelihood of starting (stopping) increases (decreases) in the plant's productivity. Because of the relatively high startup costs, the average productivity threshold for starting to export exceeds the productivity threshold to stop exporting by 63 percent (in logs). Table 2 shows that these different thresholds imply a large range of exporter hysteresis as the mean (median) new exporter will have 171 (60) employees, while the mean (median) exporter that stops exporting has 13 (5.0) employees in steady state. In contrast, in the fixed cost model the mean starter has 84 employees and the mean stopper has 51 employees.

Figures 1b and 1c plot the distribution of establishments and employment by employment size in the data and the model. The share of establishments is decreasing in size in the data and all the models we consider. 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 1 we see that the sunk-cost and fixed cost models generate the lowest root mean squared errors of 0.38 and 0.34 percent relative to the establishment distribution and 0.76 and 0.86 percent, respectively, relative to the employment share distribution.

Figure 1d plots export participation in the data and the three models with an export decision. 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 3.2 percent for the *Fixed Cost* model and 2.8 percent for the model with permanent productivity differences. Note that only the *Sunk-Cost* model can generate highly persistent exporters. The *Fixed-Cost* and *Permanent* models generate a stopper rate of 70 percent.

B. Plant-Level Growth and Export Transitions

Our calibration has focused on matching the characteristics of exporters and non-exporters as well as the transitions across export status. We next consider some other non-targetted dynamic moments. Specifically, we 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 US manufacturing plants. We find that the sunk cost model gets 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 a sunk cost gets the qualitative nature of plant growth and changes in export status about right as well but is off quantitatively.

Define the growth rate of a variable X as $\%\Delta X_{iT} = \frac{1}{T}(\ln X_{iT} - \ln X_{i0})$. Bernard and Jensen (1999) run the following regressions

$$\%\Delta X_{iT} = \alpha + \beta_1 Start_{iT} + \beta_2 Both_{iT} + \beta_3 Stop_{iT} + \gamma Size_{i0} + \varepsilon_{iT}$$

where $\text{Start}_{iT} = 1$ if $(m_0, m_T) = (0, 1)$, $\text{Both}_{iT} = 1$ if $(m_0, m_T) = (1, 1)$, $\text{Stop}_{iT} = 1$ if $(m_0, m_T) = (1, 0)$, and Size_{i0} is a measure of the initial employment of the plant. 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.[22] We focus on the average growth rate of employment and sales.[23,24]

Table 3 reports how plant-level growth relates to changes in export status in the data and our benchmark sunk cost model and 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 70 percent. In the second variation, *Fixed-high persistence*, the shock process is calibrated to generate a stopper rate of 17 percent.

In the data, at all horizons, relative to continuing non-exporters, starters grow slightly faster than continuing exporters, while stoppers tend to shrink. The gaps become smaller over

[22] Note 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.

[23] We average these responses since they are indistinguishable in our model.

[24] These regressions are run on different waves (1984-88 & 1989-92) of the ASM as well as on the plants in both waves. This panel of US manufacturing plants is very heavily weighted toward the largest manufacturing plants, particularly in the regressions over longer horizons. Large plants (>250 employees) are sampled with certainty, while small plants are sampled randomly. Moreover, non-certainty 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. To take this into account, we construct a sample of tradable plants from our ergodic distribution based on a size cutoff in both years.

longer horizons. For instance, the annualized growth rate premium for starters is 7.4 percent at one year and falls to 2.8 percent at 8 years. The sunk and fixed cost models capture these salient features; however, statistically, the sunk cost model is a better fit for these dynamic moments with a mean absolute deviation (MAD) of 1.5 percentage points compared to the fixed cost model's MAD of 6.2 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 the fixed cost model generates more than 4 times the churning of export status per year as in the data.

When the fixed cost model is calibrated to match the high persistence of exporting, it badly misses on both exporter characteristics and plant-level dynamics around changes in export status. Capturing the high persistence of exporting requires very persistent productivity shocks $(\rho = 0.96)$ and relatively small productivity and fixed cost shocks $(\sigma_{\varepsilon} = 0.14, \sigma_{\upsilon} = 0.13)$. With these idiosyncratic shocks too many medium to large plants export: all plants with 100-249 employees export in the model compared to only 40 percent in the data. The overall root-mean-squared error for the distribution of export participation is 48.7 percent compared to 2.4 percent in the benchmark model. Focusing on the plants with 10 or more employees,[25] we find a MAD of 30.4 percent compared to 3.6 percent for the benchmark sunk cost model. The fixed-high persistence model misses out badly on plant dynamics because current productivity is much more highly correlated with the productivity that led 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.

[25] Because 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 so we cannot run the same regressions on our model as in the data.

C. The Size of Trade Costs

Given that the model delivers the right plant characteristics and dynamics of exporters and non-exporters, we next use it to estimate the size and nature of trade costs. Das, Roberts, and Tybout (2007, DRT hereafter) also provide an estimate of these costs for 136 plants in three industries in Colombia. Similar to DRT, we find that the cost of starting to export is relatively high. In our calibration the startup cost is nearly 19 times the cost of continuing to export, while in DRT the ratio of startup to continuation costs is about 40 in the median industry. However, because of the shocks to these costs, we find that the mean (median) startup cost incurred is about 3.7 (4.7) times the mean (median) continuation cost incurred by a continuing exporter. In \$1992, the mean startup cost is about \$745,000, while the mean continuation cost is about \$203,000. To put these costs into perspective, the mean startup cost equals 0.99 (3.88) times the annual export profit of the mean (median) starter. In DRT, the mean startup cost is about 1.5 (8 to 9) times the mean (median) annual profit.[26]

In the aggregate, the resources devoted to startup and continuation costs are equal to 25 and 28 percent of gross export profits. This is much higher than the 17.6 percent share of export profits when productivity is permanent. Comparing the variable trade cost in our benchmark model (0.451) to that in the No-Cost model (0.757), we see that fixed 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).

A key benefit of splitting up trade costs is that we can get a sense of the division of

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

organizational capital in the economy. Organizational capital determines the size of payments, or organization rents, to plant owners. These rents compensate owners for the up-front costs of creating plants (or exporters) as well as the costs of waiting for plants to grow. When there is no sunk cost of exporting, the organizational rents from exporting are returns on the investment embodied in building plants. When there is a sunk cost of exporting, the rents from exporting are also a return on the investments in exporting. The substantial resources devoted to export costs in the sunk cost model point to substantial organizational rents from the export decision. In this respect, with sunk costs, tariffs are more a tax on the profits of exporters and less a tax on the profits of plants. Consequently, tariffs discourage the accumulation of exporters and lead to a substitution toward manufacturing plants. This mechanism is not present in previous work on international trade and heterogeneous plants and turns out to be key to understanding the aggregate consequences of tariffs on the economy.

4. Tariffs and Steady State

To shed light on how tariffs distort economic activity in the presence of non-convex costs of exporting and plant heterogeneity, we consider how the steady state depends on tariffs. We first explore the impact of tariffs on the characteristics of exporters vs. non-exporters and then consider aggregates such as consumption, investment, trade, and export participation.

A. Exporter Characteristics and Dynamics

Figure 2 depicts the relationship between exporter characteristics and tariffs ranging from 0 to 30 percent. Panel (a) shows that the exporter productivity premium in the stationary distribution of establishments is increasing in the tariff.[27] With free trade, exporters are on

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

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 increases with tariffs. As a result of these changes in thresholds, as tariffs increase, 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. Moving from 8 percent tariffs to free trade increases the duration of each export spell from 5.9 years to 9.1 years.[28] Finally, panel (c) 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 percent. 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 doubles the sensitivity of exporting to tariffs.[29]

B. Aggregates

To highlight the role of fixed export costs, we also report the results of the No-Cost model, which is nearly identical to our benchmark model except that all plants export. This comparison gives a sense as to how sunk costs and tariffs affect the structure of the economy. We are cautious about making welfare comparisons about the effects of international trade, since the models generate quite different trade responses. However, the comparison helps to clarify how well this simpler model approximates the properties of our richer model. In

[28] Since the plant-level productivity is persistent, the export spell is increasing in the plant-level productivity.

[29] This understates the role of the exit margin, since the exit margin determines the duration of exporting. A longer expected duration of exporting raises the expected value of exporting and increases entry.

Figure 2d to 2i, for exposition, all series are measured relative to the level under free trade.

We first consider how tariffs influence the stock of establishments in each model. From Figure 2d, in the *No-Cost* model the mass of tradable establishments, N_T, decreases with tariffs, while the mass of non-tradable establishments, N_N, increases with tariffs. Tariffs are effectively a tax on investment in tradable establishments and thus the economy substitutes toward non-tradable establishments. In contrast, in our benchmark *Sunk-Cost* model, the mass of both tradable and non-tradable establishments increases with tariffs. However, panel e shows 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 since export participation declines with tariffs. This effect is much stronger in the *Sunk-Cost* model than in 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 h). Second, higher tariffs strongly 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 i) 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, because of the reduced export participation, the net effect is to decrease the mass of available varieties by about

20.7 percent. Thus, tariffs encourage establishment creation[30] over capital accumulation and discourage investing in export capacity.

Panel (f) 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 percent to 6.8 percent.

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

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

cisions 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 from a move to free trade 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 an unanticipated[31] global cut in tariffs from 8 percent to free trade. This policy experiment provides some guide to the expected changes in the US and the rest of the world from moving to free trade. The long-run changes in the model are reported in Table 4, and the first 50 periods[32] of the transition[33] are plotted in Figure 3. We first

[31] This distinction is quite important in the sunk-cost model since an anticipated trade reform will generate a change in trade prior to the reform.

[32] The 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.

[33] With 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 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

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

respectively. Here, a is the steady state level of the 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 discuss the implications for trade and then consider aggregate implications.[34]

A. Trade and Exporters

Figures 3a-3c plot the evolution of trade-related variables along the transition to the new steady state. Panel a shows that the trade to GDP ratio in both the *Sunk-Cost* and *No-Cost* models 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. In the *Sunk-Cost* model, the trade expansion is drawn out. In the first period trade increases by 44.6 percent. After five years, 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. Thus, the trade elasticity is constant in the *No-Cost* model and increasing in the *Sunk-Cost* model.

The gradual increase in trade reflects a slightly more gradual increase in exporters (panel b). On impact, export participation rises 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 for a total increase of 74.6 percent. The increase in exporting occurs through a persistent increase (decrease) in the starter (stopper) ratio, both of which overshoot their long-run levels (panel c). The overshooting of the stopper and starter rates primarily reflects changes in the productivity distribution of exporters and non-exporters. When the policy is enacted, at the margin there are many relatively productive non-exporters 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, the exporter distribution is shifted toward relatively

transition, suggesting that the modification has only negligible effects on the results.

[34] We do not consider adjustment costs to capital or labor along the transition. These adjustment costs would slow down the transition in all the models considered.

productive establishments and this will contribute to overshooting in economic activity.

B. Welfare

From Table 4 we see that including the transition period the welfare gains 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 with sunk costs steady state consumption understates the true welfare gain 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.

From Figure 3 we see that the transition to the new steady state in the No-Cost model generates the gradual expansion 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 forgone consumption along the transition, and so steady state consumption overstates the true welfare gain.

In the benchmark model, the cut in tariffs leads to a sustained economic expansion that slightly overshoots the new steady state. From panel (d), consumption grows quite strongly, peaking 0.4 percent above the new steady state 10 years after the policy change. This overshooting is surprising given the strong consumption smoothing motive in the model and the gradual growth in trade. It largely reflects the economy's ability to better use existing assets, namely establishments, along the transition. This improved efficiency is captured in the dynamics of the Solow residual[35] in panel (f). By this measure, there are both permanent and persistent changes in the Solow residual. As with a persistent productivity shock in a

[35]The 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.

standard RBC model, agents accumulate capital (panel e) to smooth out consumption, and this contributes to the overshooting in consumption.

Unlike the Solow residual in an RBC model, here it reflects endogenous changes in the number of establishments and exporters as well as the productivity distribution. Given our finding that tariffs lead to an over-accumulation of establishments and under-accumulation of exporters, along the transition there are many establishments that can easily be converted into exporters. Thus, along the transition there is less investment in establishments (panel h) and more investment in exporters. The net effect is a rapid increase in the number of tradable varieties available, which also overshoots its long-run level (panel i). Because this expansion in variety occurs through an increase in exporters and a 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 existing establishments (panel g). This measure peaks 0.3 percent above its initial and long-run levels[36] in year 4. In contrast, in the *No-Cost* model, since the number of tradable producers increases, the average productivity of the plants in the tradable sector initially falls, and the Solow residual grows gradually.

6. Sensitivity

To make the model consistent with the data, we added a number of real-world features.[37] We now ask whether abstracting from these features of plant and exporter characteristics and

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

[37] Some 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 (2011).

dynamics affect the relation between tariffs, trade, and welfare. We do this two ways: First, we consider the impact of a policy change holding the elasticity of substitution of varieties constant. This experiment essentially asks: how far off would one be if they used a simpler model to evaluate a prospective policy experiment. Second, following Arkolakis et al. (2011) we constrain the trade elasticity to be the same across models. This experiment obviously requires one to know the trade elasticity and should be viewed as evaluating a past policy. In terms of the nature of trade costs, we find that nearly all of the overshooting arises because of the sunk cost. When constraining the trade response to be identical, we find trade has a considerably larger welfare impact when there are sunk costs.

Specifically, we study 5 variations of our benchmark model. In addition to the *Permanent* and *Fixed-Cost* models, we include models with no capital, called *No-Capital*, no material inputs, called *No-Materials,* and more persistent exporters, called *Sunk-High.* Table 1 reports the parameters and fit for these variations. We again consider eliminating an 8 percent tariff. Table 4 summarizes the long-run effects and Figure 4 plots transitions.

The *Fixed-Cost* model shows that the structure of fixed costs matters for both the trade and export participation response but less so for welfare. With only a fixed cost of exporting, the trade and export participation increase is, respectively, 58 and 12 percent of the benchmark model. The smaller response of trade and exporting arises because there are fewer establishments affected by changes in this threshold than in the benchmark model. Also, we see that exporters and establishments are complement with just the fixed cost as the mass of plants increases 0.59 percent compared to the 2.2 percent drop in our benchmark. 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 4 panel (f) we see that these exporter dynamics eliminate the overshooting of consumption following trade liberalization, implying that welfare gains are 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 the *Permanent* model, we see that removing the 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 12 percent and 59 percent, respectively, as much as in the *Sunk-Cost* model.

From *No-Capital* we see that capital accumulation primarily matters for welfare. With capital, the welfare gain to moving to free trade is reduced 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 as a complement to exporting.

Eliminating material inputs reduces the welfare gain to 22 percent of our benchmark. Yi (2003) finds that intermediates magnify the 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 without intermediates is nearly identical to the benchmark.[38]

A. Targeting the Trade Elasticity

We next evaluate how well the *No-Cost* model approximates the welfare gain in the *Sunk-Cost* model when both models have the same long-run trade elasticity. This exercise is motivated by the findings of Arkolakis et al (2011, hereafter ACR) that the gains from trade are the same across a large class of static trade models when the trade elasticity is the same. With capital, materials inputs, and non-tradebles, we show in the appendix that the ACR formula for the welfare gain can be approximated as

$$\widehat{C} = -\frac{\gamma}{(1-\alpha_x)(1-\alpha)}\frac{\widehat{\lambda}_D}{\varepsilon},$$

where γ is the tradable share, α_x is the share of materials in production, α is labor share in production, $\widehat{\lambda}_D$ is the change in the share of domestic tradable goods in tradable absorption (a gross output concept), and ε is the elasticity of trade with respect to trade costs.

Matching the trade elasticity in the Sunk cost model requires recalibrating the elasticity of substitution, θ, in the No-Cost model so that it generates the same long-run growth in

[38] Yi (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. This back and forth is in our model in that when establishments choose to export they are selling goods overseas that then might be reimported in the goods of intermediates of foreign exporters. Adding materials does not magnify this effect because all of the changes come in the first stage of production with the change in range of varieties available.

trade from any policy.[39] The choice of θ will depend on the experiment since with a sunk cost the trade elasticity is not constant. Additionally, the trade elasticity along the transition will be smaller with a sunk cost. Changing θ affects the markup and consequently the income share of labor as well as the ratio of gross output to value added in manufacturing. To remain consistent with our targets, we must recalibrate (α, α_x). Table 5 reports our new parameters and the changes in the models from changes in tariffs and iceberg cost.

In short, following a cut in tariffs the welfare gain with a sunk cost is 2.4 times larger than in the *No-Cost* model. With a cut in iceberg cost the welfare gain is 1.3 to 1.5 times larger with a sunk cost. Ignoring transitions, steady state consumption rises 1.4 times more with a sunk cost from a cut in tariffs and 86 to 95 percent from a cut in iceberg costs. In the case of tariffs, we find that the larger increase in steady state consumption with sunk costs (0.83 vs 0.58) because output grows faster than in the *No-Cost* model (0.87 vs 0.64) even though the labor used in producing goods falls substantially more (-0.26 vs -0.04). We also consider an unanticipated move to autarky through increases in tariffs or iceberg costs. Now, the costs of moving to autarky are 1.3 to 2.1 times larger in the *Sunk-Cost* model.

These results may be surprising given the findings of ACR. However, their results hold only for zero tariffs and changes in iceberg cost. They do not hold for the sunk cost model or transitions. When we consider changes in iceberg costs with no tariffs, we find smaller differences in the change in steady state consumption across the models. However, interestingly enough, we find that while the ACR formula holds in this case for the *No-cost* model,

[39] Let * 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.

it overstates consumption growth in the *Sunk-Cost* model by almost 40 percent.

7. Conclusions

We find a generalized version of the Melitz model with plant-level uncertainty in technology and a relatively large up-front costs of starting to export can explain the cross-sectional and dynamic characteristics of US exporters. The size of the US sunk export cost is consistent with evidence for Colombia plants by Das, Roberts, and Tybout (2007) and implies export profits are largely rents to the organizational capital embodied in exporting rather than in establishment. With a sunk cost, exporters are durable assets, much like physical capital or establishments, and tariffs are more a tax on exporter capital than a tax on plant capital. Consequently, tariffs deter accumulating exporters and lead to a very strong substitution towards manufacturing plants. Static trade models lack this mechanism and it turns out to be key to understanding the aggregate consequences of a cut in tariffs.

We find that the nature of plant heterogeneity and trade costs matter for the gains to trade. Models that lack a sunk cost of exporting and plant-level uncertainty provide an imprecise estimate of the welfare gain in the full model, particularly when calibrated to match the aggregate trade response. Moreover, we find that the transition dynamics following a cut in tariffs depends on the nature of trade costs. With a sunk cost of exporting, the transition is much faster and may overshoot even though trade grows gradually. Without a sunk cost, the transition takes on the familiar gradual neoclassical transition and the trade response is immediate. Thus, the benefits to trade liberalization are much more immediate when costs are sunk even if it takes longer for trade to expand.

While we focus on symmetric policies in symmetric economies, our quantitative approach is well-suited to consider a range of alternative and asymmetric policies. For instance, we can study net exports and the real exchange rate following a unilateral change in trade policy. One would expect a unilateral cut in tariffs to generate a larger economic expansions as the reformer can borrow to finance investment. Our model can also be used to examine the aggregate implications of policies meant to encourage exporting, such as subsidies or corporate taxes, or policies targeted to assist workers following trade-related displacements.

Finally, we consider the implications of a popular theory that is consistent with a key set of cross-sectional and dynamic facts about exporters and non-exporters. Doing so, we find that when there is a dynamic aspect to exporting, the aggregate outcomes are quite different than with a static export decision. Exploring the aggregate consequences of additional aspects of the micro dynamics of exporting is likely to be an important area of future research.[40]

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Table 1: Parameter Values, Targets, and Fit

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 (iid fixed)	No-Capital	No-Materials	Sunk-High
α		0.286	0.281	0.283	0.223	0	0.304	0.286
λ		7.351	7.472	7.423	0	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..453	0.432	0.451	0.451	0.451
ρ		0.655	0.655	0.655	1.000	0.655	0.655	0.640
σ_ε		0.333	0.335	0.333	0.419	0.333	0.333	0.340
μ_E		-0.353	-0.368	-0.364	0	-0.353	-0.353	-0.355
f_E		1.652	1.685	1.675	3.192	1.258	1.195	1.678
σ_v		1.104	0	4.185	4.214	1.104	1.104	0.430
f_0		0.342	0	0.203	0.251	0.261	0.247	0.336
f_1		0.018	0	0.203	0.251	0.014	0.013	0.021
Target Moments								
	Data							
5-year exit rate	0.370	0.370	0.370	0.370	0.110	0.370	0.370	0.370
Startups' labor	0.015	0.015	0.015	0.015	0.023	0.015	0.015	0.015
Exiters' labor	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Stopper rate	0.170	0.170	-	0.700	0.700	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
Overall Fit		1.553	5.258	2.000	1.959	1.553	1.553	1.629
Establishments		0.376	1.065	0.339	1.186	0.376	0.376	1.131
Employment		0.762	1.162	0.856	1.633	0.762	0.762	0.721
Exporting		2.489	8.475	3.236	2.809	2.489	2.489	2.224

Note: For permanent, there is no idiosyncratic productivity over time but σ_ε determines the unconditional productivity distribution. Overall fit is defined as the root mean squared error of establishment and export participation bins.

Table 2: Additional Implications

	Sunk-Cost	Fixed-Cost	Permanent	Sunk-High
Exporter Premium	3.50	3.53	3.20	3.07
Starter (employment)				
Mean	171.29	84.02	70.32	439.60
Median	60.85	22.43	20.72	237.19
Stopper (employment)				
Mean	13.38	50.57	59.75	1.26
Median	4.96	12.64	17.64	0.82
Startup Cost (1992 $ mill.)				
Mean	0.75	0.09	0.08	2.108
Median	0.64	0.02	0.03	2.128
Continuation Cost (1992 $ mill.)				
Mean	0.20	0.16	0.19	0.223
Median	0.14	0.02	0.03	0.190
Costs (% of Gross Export Profits)	52.98	17.55	18.23	64.24
Startup	25.27	10.86	9.68	29.15
Continuation	27.71	6.69	8.55	35.09
Startup Cost (% of)				
Mean profits of starters	99.08	18.20	18.69	1.31
Median profits of starters	388.24	68.82	62.83	4.36

Table 3: US Micro Growth Rates: Data and Models

		Annual (1 year)			1989-1992 (3 years)			1984-1988 (4 years)			Long run (8 years)		
Data	MAD	Start	Stop	Both	Start	Stop	Both	Start	Stop	Both	Start	Stop	Both
Sales/Empl.		7.4	-2.1	4.8	4.7	-1.7	3.4	3.6	-0.8	2.6	2.8	-1.0	2.1
Model	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	6.2	30.4	-4.6	27.8	10.0	-0.2	9.8	7.0	-0.5	7.1	3.8	0.3	3.9
Fixed-High persistence	-	-	-	-	-	-	-	-	-	-	-	-	-
Model	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	11.4	45.6	-6.9	42.8	17.3	-0.6	16.9	12.8	-0.4	12.7	6.3	0.0	6.5
Fixed-High persistence	30.4	86.9	-39.3	63.1	42.2	-11.7	39.5	34.2	-7.6	33.7	20.0	-2.2	20.8

Note: Plant-level growth rates from data are from Bernard and Jensen (1999). MAD is the mean absolute deviation of the growth rates between the model's predictions and the data. In the Fixed-High Persistence all plants with 100+ employees in both years are exporters

Table 4: Effect of Eliminating 8 Percent Tariff

	Sunk-Cost	No-Cost	Fixed-Cost	Permanent (Stoch. fixed)	No-Capital	No-Materials	Sunk-High
Consumption	0.84	1.01	0.96	0.89	0.58	-0.01	0.80
Trade to GDP ratio	92.31	44.60	53.18	53.64	92.31	90.49	128.32
Capital stock	1.06	1.23	1.18	1.11	-	0.37	1.02
Production labor	-0.26	-0.09	-0.14	-0.13	-0.20	-0.16	-0.32
Non-tradable variety	-0.45	-0.28	-0.32	-0.32	-0.39	-0.47	-0.51
Domestic tradable variety	-2.19	1.21	0.59	0.61	-2.13	-3.13	-4.38
Total tradable variety	11.13	1.21	2.55	2.57	11.20	10.05	18.69
Starter ratio	63.84	-	10.27	10.29	63.84	63.84	152.87
Stopper ratio	-35.51	-	-3.41	-3.38	-35.51	-35.51	-86.25
Exporter ratio	74.66	-	10.65	10.65	74.66	74.66	132.33
Output premium	-1.97	-	5.29	5.62	-1.97	-1.97	-2.77
Productivity premium	-10.30	-	-1.39	-1.39	-10.30	-10.30	-12.01
Static welfare gains	0.84	1.01	0.96	0.89	0.58	-0.01	0.80
Transitional welfare gains	1.03	0.73	0.81	0.76	0.79	0.24	1.20
Tariff to get to Autarky*	0.70	2.61	1.81	1.79	0.70	0.70	0.51
SS Consumption relative to Autarky**	1.60	3.78	3.08	2.75	1.17	0.71	1.12

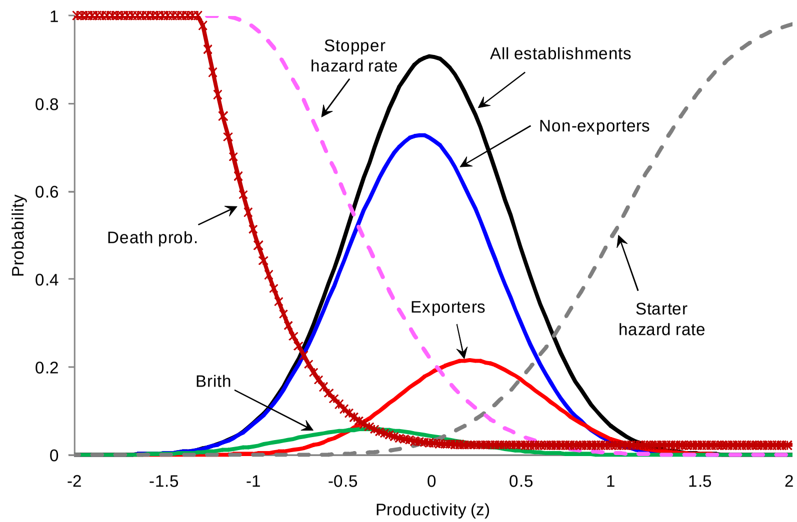
Note: Welfare gain is value of x that satisfies $\sum_{t=0}^{\infty}\beta^t U\left(C_{-1}\left(1+x\right)\right) = \sum_{t=0}^{\infty}\beta^t U\left(C_t\right)$, where C_{-1}. * Autarky means raising tariffs to lower trade share of GDP to 0.01 percent. **New steady state (0 tariff rate) consumption relative to autarky.

Table 5: Effect of Changing Tariffs and Iceberg Costs for Same Trade Elasticity

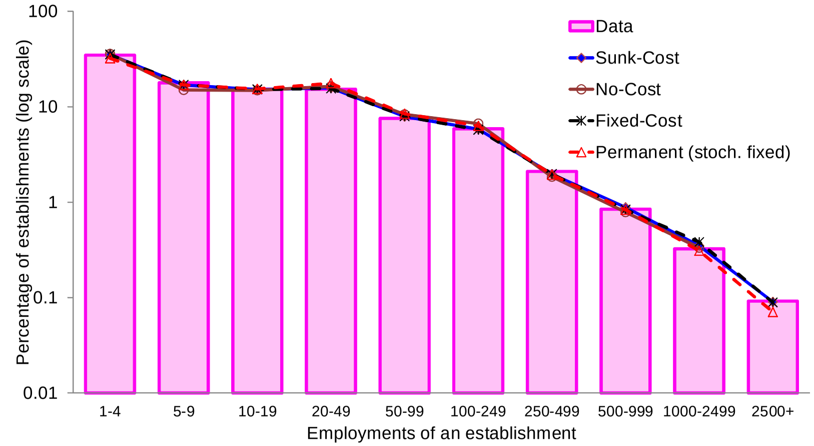
	Tariffs		Iceberg ($\tau > 1$)		Iceberg ($\tau = 1$)	
	Sunk-Cost	No-Cost	Sunk-Cost	No-Cost	Sunk-Cost	No-Cost
			*Trade Liberalization**			
Welfare Gain	1.027	0.427	1.195	0.920	0.993	0.669
ΔC^{SS} (%)	0.833	0.578	0.822	0.957	0.710	0.749
ACR formula (%)	1.113	0.815	1.084	0.812	1.000	0.749
$\widehat{\lambda}$ (%)	-6.067	-6.067	-5.417	-5.417	-4.983	-4.983
ε	-8.162	-8.162	-7.477	-7.477	-7.481	-7.481
α_x	0.804	0.722	0.804	0.729	0.804	0.729
α	0.286	0.312	0.286	0.309	0.288	0.311
$\Delta\ln(1+\text{marginal cost})$	-0.077	-0.077	-0.077	-0.077	-0.077	-0.077
Initial TR (%)	3.86	3.86	3.86	3.86	3.86	3.86
$\widehat{TR}$ (%)	65.39	65.39	51.48	51.48	52.59	52.59
			Trade to Autarky†			
Welfare Gain	-1.566	-1.163	-1.566	-0.962	-1.277	-0.586
ΔC^{SS} (%)	-0.752	-1.221	-0.752	-1.007	-0.598	-0.666
ACR formula (%)	-0.904	-0.613	-1.046	-0.726	-0.960	-0.666
$\widehat{\lambda}$ (%)	7.396	7.396	7.407	7.407	6.771	6.771
ε	-12.247	-12.247	-10.597	-10.598	-10.595	-10.595
α_x	0.804	0.695	0.804	0.704	0.804	0.704
α	0.286	0.321	0.286	0.318	0.288	0.320
$\Delta\ln(1+\text{marginal cost})$	0.456	0.456	0.570	0.570	0.568	0.568
Initial TR (%)	3.86	3.86	3.86	3.86	3.86	3.86
New TR (%)	0.01	0.01	0.01	0.01	0.01	0.01

Figure 1: Employment Distributions

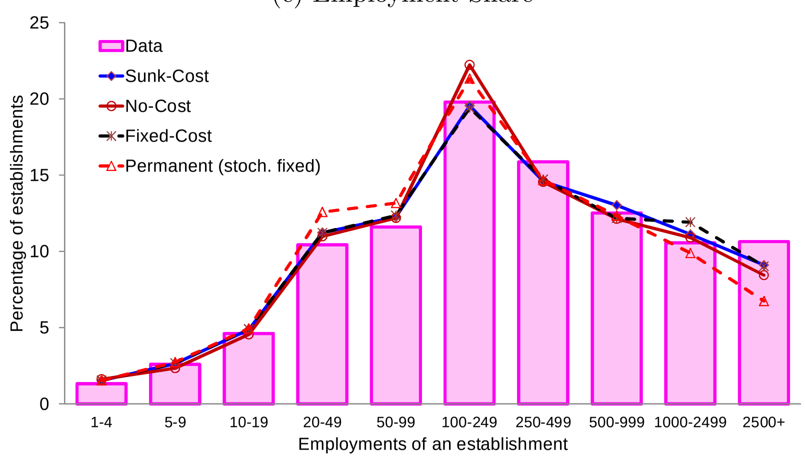
(a) Establishment Distribution



(b) Establishment Share



(c) Employment Share



(d) Export Participation

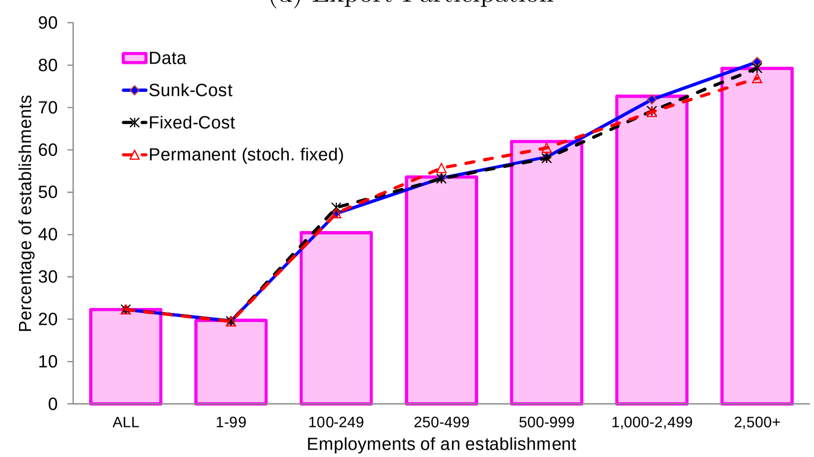
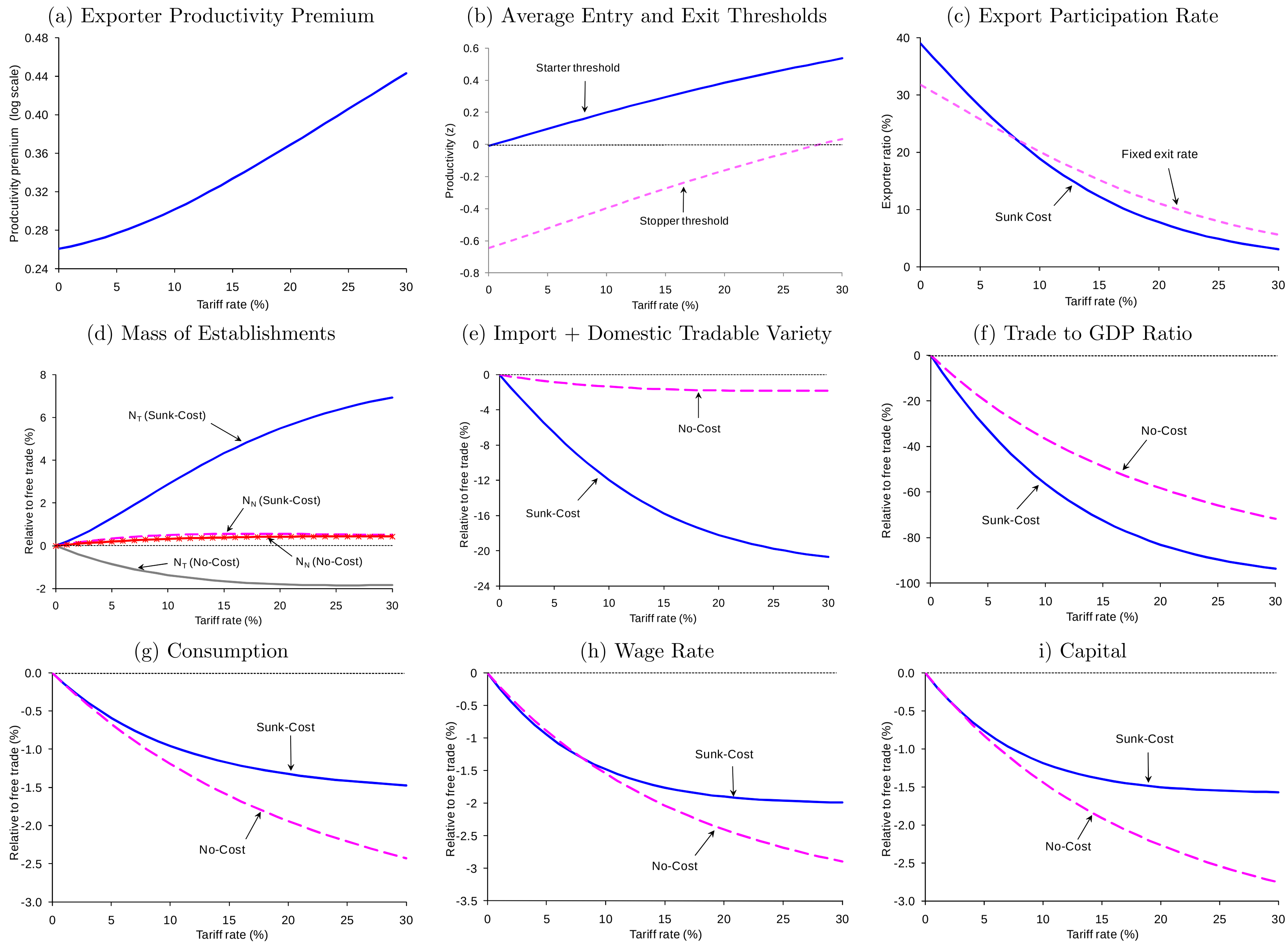
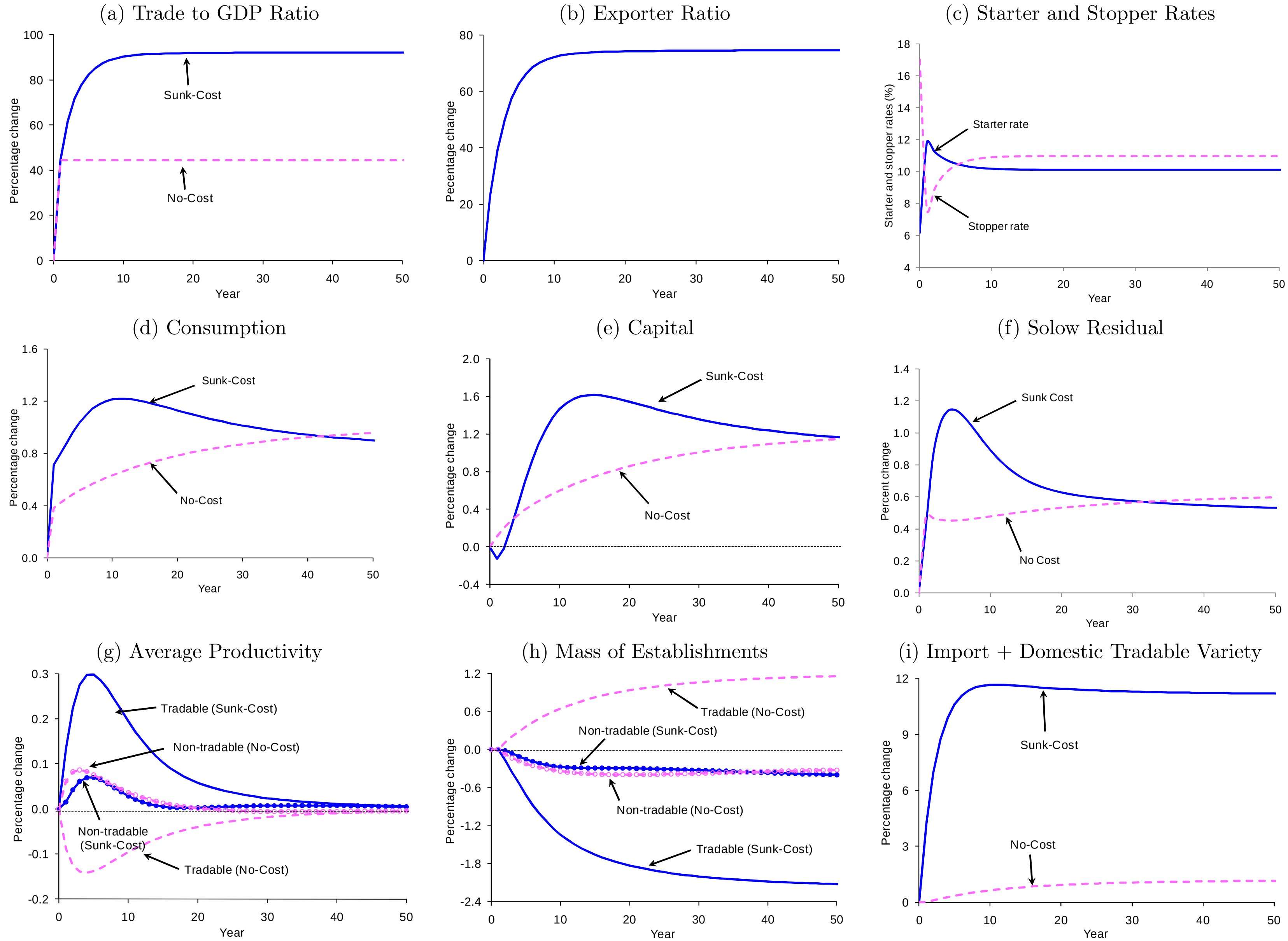


Figure 2: Steady State Establishment Characteristics, Aggregates, and Tariffs



Note:

Figure 3: 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 4: Transitions with Variations