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DYNAMICS, AND THE EFFECTS OF
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Establishment Heterogeneity, Exporter Dynamics, and the Effects of Trade Liberalization *

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Abstract

We study a variation of the Melitz (2003) model, a monopolistically competitive model with heterogeneity in productivity across establishments and fixed costs of exporting. We calibrate the model to match the employment size distribution of US manufacturing establishments. Export participation in the calibrated model is then compared to the data on US manufacturing exporters. With fixed costs of starting to export about 3.9 times as large as costs of continuing as an exporter, the model can match both the size distribution of exporters and transition into and out of exporting. The calibrated model is then used to estimate the effect of reducing tariffs on welfare, trade, and export participation. We find sizeable gains to moving to free trade. Contrary to the view that the gains to lowering tariffs are larger in models with export decisions, we find that steady state consumption increases by less in our benchmark model of exporting than in a similar model without fixed costs. However, we also find that comparisons of steady state consumption understate the welfare gains to trade reform in models with fixed costs and overstate the welfare gains in models without fixed costs. With fixed costs, tariffs lead to an overaccumulation of product varieties which can be used more effectively along the transition to the new steady state. Thus, following trade liberalizations economic activity overshoots its steady state, with the peak in output coming 10 years after the trade reform. Finally, we explore the impact of the key modelling assumptions in the theoretical literature for quantitative results.

JEL classifications: E31, F12.

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

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1. Introduction

Recent evidence of substantial differences between exporters and non-exporters has led Melitz (2003) to develop a theory of international trade that emphasizes productive heterogeneity across many monopolistically competitive establishments facing fixed costs of exporting. This theory is consistent with the evidence that the biggest, most productive establishments do the bulk of exporting and empirical estimates of large fixed costs of exporting (Das, Roberts and Tybout 2007). In this theory, tariffs and trade barriers reduce the value of exporting and thus discourage some relatively productive establishments from paying the fixed cost and exporting. This lowers trade flows and shifts production away from relatively productive establishments toward relatively unproductive non-exporters. Reducing tariffs encourages entry into export markets by relatively productive establishments and reallocates production toward these relatively productive exporters. Melitz (2003), Eaton and Kortum (2002), and Alvarez and Lucas (2006) emphasize that this reallocation increases the welfare gains to lowering trade barriers compared to models without this margin.¹ In this paper, we evaluate the impact of lowering tariffs on welfare and trade in a particular variation of the Melitz model.

Before examining the aggregate implications of trade reform, our first goal is to find out whether the cross-plant distribution of export participation 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 make two modifications to the Melitz model to allow for richer establishment and exporter dynamics.² First, we subject plants to persistent, idiosyncratic technology shocks. Second, consistent with the evidence of Das, Roberts and Tybout (2007), we assume individual establishments face a large,

¹The Eaton and Kortum (2002) model is a multicountry version of the Dornbusch-Fisher-Samuelson model with a continuum of goods and idiosyncratic differences across producers. The model is competitive and has no fixed costs of trade.

²Atkeson and Burstein (2006) develop a model of firm dynamics to study the relation between innovation and trade.

up-front sunk cost of entering a foreign market and a smaller, period-by-period cost of continuing in that market. In the presence of idiosyncratic technology shocks, nonexporting establishments start exporting only when the expected value of exporting covers the entry 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 at only home, and it is important in getting the model to match the dispersion in export participation among US manufacturing establishments in the data.

Since the model can generate exporter characteristics and movements into and out of exporting that match US manufacturing plant-level data, our second goal is to use the calibrated model to see how tariffs affect entry, export participation, trade, and welfare. We find that a global reduction of tariffs from 8 percent to free trade increases the total number of tradable varieties available by 13 percent but lowers the number of non-tradable varieties by 0.5 percent. The increase in tradable varieties is a result of a 1.9 percent fall in the number of domestic tradable establishments and a near doubling of export participation from 22.3 percent of establishments to 41.3 percent. The duration of each exporting spell rises from 5.9 years³ to 10 years. In total, the model predicts an 82 percent increase in trade. These changes in export participation and establishments result in a sizeable 1.07 percent rise in steady state consumption. Perhaps surprisingly, however, we find that consumption rises by substantially less in our model of exporting than a similar model without the export margin. We view this result as sensible. After all, in the model with an export decision there is one additional margin to adjust economic activity than the model in which all establishments export.

³This is calculated as the inverse of the annual rate of exit from exporting.

Our dynamic model is also well suited to study the transition dynamics following an unanticipated move to free trade. Considering these transitions, we find that steady state consumption understates the welfare gain by almost 15 percent, since along the transition to the new steady state the economy overshoots considerably, with consumption peaking 10 years after the reform at 0.3 percent above its long-run level. The boom in economic activity occurs because tariffs lead to the creation of too many establishments and not enough exporters. When tariffs are lowered, existing establishments can now be used effectively to produce new varieties by incurring the startup export cost. In addition, current exporters, which have already incurred the big startup cost, find it worthwhile to 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.

Our final goal is to provide some guidance to modelers of the quantitative implications of some common modelling assumptions. By changing certain parameters in our benchmark model we can study the role of four common assumptions: no capital, identical startup and continuation export costs, permanent idiosyncratic productivity, and no intermediate inputs. First, we find that abstracting from capital accumulation lowers the welfare gain to moving to free trade by about one-quarter, but has no noticeable impact on either export participation or trade flows. Without capital the economic expansion following a trade liberalization is much more muted, with output peaking 6 years earlier and about 23 percent below the peak in the benchmark model, as capital is useful for smoothing out the benefits of trade liberalization. Second, we find that the structure of fixed costs matters for both the trade and export participation response to tariffs but less so for welfare. When the startup cost is constrained to be the same as the continuation cost of exporting, the trade and export participation increase is, respectively, 12 and 25 percent less than in the benchmark model. The alternate model generates a smaller response of trade and exporting because the threshold for

entry and exit is identical and there are fewer establishments affected by changes in this threshold than in the benchmark model. Third, we find that the structure of idiosyncratic shocks matters for both welfare and trade. When establishment productivity is constant, we find that steady state consumption overstates the welfare gains to free trade as the model does not generate any overshooting along the transition. Additionally, the increase in trade and export participation is less than in our benchmark model. Finally, we find the welfare results are quite sensitive to the use of intermediate inputs in the production of tradable varieties. Without intermediates, the welfare gains to trade reform are about 20 percent of our benchmark model.

This paper is related to three lines of research. First, our focus on the welfare gains to trade liberalization is similar to the work by Eaton and Kortum (2002), Bernard, Eaton, Jensen and Kortum (2003) and Alvarez and Lucas (2006). These papers evaluate the welfare gains to trade liberalization in static, multicountry Ricardian models with productivity heterogeneity, tariffs, and transportation costs. Unlike these papers, we consider a dynamic model with entry and exit subject to fixed costs and allow for capital accumulation under a monopolistically competitive market environment. Chaney (2005) discusses the dynamics of trade and establishment dynamics following trade liberalization in the Melitz model.⁴ The second line of research uses models with fixed costs of trade to understand international business cycle fluctuations (see Ruhl (2003), Alessandria and Choi (2007), and Ghironi and Melitz (2005)). Finally, there is a third, partial equilibrium literature that studies the export decisions of establishments. Baldwin and Krugman (1989) and Dixit (1989) develop models of export decisions with an exogenous exchange rate process. Das, Roberts and Tybout (2007) develop these models further and use them to estimate the sunk costs of exporting. As partial equilibrium studies these papers cannot evaluate welfare.

⁴Baldwin 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.

The paper is organized as follows. The next section develops a two-country dynamic general equilibrium model with endogenous export penetration and sunk costs of exporting. Section 3 discusses the calibration of the model and the distribution of establishments and export participation. Section 4 discusses the relationship between tariffs, exporter characteristics, trade and welfare in the steady state of the model. In Section 5 we examine the transition dynamics following an unanticipated worldwide elimination of tariffs. In Section 6, we investigate how the quantitative results are sensitive to alternative structures of models. Section 7 concludes.

2. The Model

In this section, we develop a model that contains the key features of the Melitz model, producer heterogeneity and fixed costs of exporting.⁵ Each period there is a mass of existing establishments distributed over sectors, productivity, countries, and export status. Productivity is stochastic and generates movements of establishments into and out of exporting. Unproductive establishments also shutdown, and new establishments are created by incurring a sunk cost.

There are two countries, *home* and *foreign*. Each country is populated by a continuum of identical, infinitely lived consumers with mass of one. Each period, consumers are endowed with fixed L units of labor and supply them inelastically in the labor market.

In each country there are two intermediate good sectors, tradable and non-tradable. In each sector, there is a large number of monopolistically competitive establishments, each producing a differentiated good. The mass of varieties in the tradable and non-tradable goods sectors are $N_{T,t}$ and $N_{N,t}$, respectively. A non-tradable good producer uses capital and labor inputs to produce its variety, whereas a tradable good producer uses capital, labor, and material inputs to produce its variety.⁶ In each sector, establishments differ in terms of total factor productivity, capital, and the

⁵Unlike the Melitz model we do not have fixed costs of continuing to produce. Instead, we capture the higher exit rates of small establishments in the shock process we consider.

⁶We introduce materials into the tradable sector to be consistent with the observation that trade as a share of gross

markets they serve.

All establishments sell their product in their own country, but only some establishments in the tradable good sector export their goods abroad. When an establishment in the tradable good sector exports goods abroad, the establishment incurs some international trading cost. The establishment has to pay tariffs to the government of the destination country with an ad valorem tariff rate of τ in addition to an ad valorem transportation cost with the rate of ξ .⁷ Additionally, the establishment has to pay some fixed costs to export its goods abroad. The size of the cost depends on the producer's export status in the previous period. There is a (relatively) high up-front sunk cost $f_0 > 0$ that must be borne to gain entry into the export market next period. In subsequent periods, to continue exporting in the following period, establishments incur a lower but nonzero period-by-period fixed continuation cost $f_1 < f_0$. If an establishment does not pay this continuation cost, then it ceases to export. In future periods, the establishment can begin exporting only by incurring the entry cost f_0 again. These costs are valued in units of labor in the domestic country. The cost of exporting implies that the set of goods available to consumers and establishments differs across countries and is changing over time. We assume that the fixed costs must be incurred in the period prior to exporting. This implies that the set of foreign varieties is fixed at the start of each period. All the establishments are owned by domestic consumers.

Any potential establishment can enter either the tradable or non-tradable sector by hiring f_E domestic workers. New entrants can actively produce goods and sell their products from the following period on.

Establishments differ by their technology, export status, sector, and nationality. The measure of home country tradable establishments with technology z and export status, $m = 1$ for exporters

output is considerably smaller than trade as a share of value-added.

⁷The transportation costs are 'iceberg'. For one unit of good to be arrived at destination, $1 + \xi$ units should be shipped.

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

In each country, competitive final goods producers purchase intermediate inputs from those establishments actively selling in that country.⁸ The cost of exporting implies that the set of goods available to competitive final goods producers differs across countries. The entry and exit of exporting establishments implies that the set of intermediate goods available in a country is changing over time. The final goods are used for both domestic consumption and investment.

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

A. Consumers

Home consumers choose consumption, investment, and bond holdings to maximize their utility:

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

subject to the sequence of budget constraints,

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

⁸Final good production technology does not require capital or labor inputs. The final good production technology regulates a country's preferences over local and imported varieties.

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

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

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

where * denotes the foreign variables and e_t is the nominal exchange rate with home currency as numeraire.⁹

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

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

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

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

⁹ An increase in e_t means a depreciation of domestic currency.

B. Final Good Producers

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

The production technology of the establishment is given by a Cobb-Douglas function for tradable and non-tradable aggregate inputs, $D_{T,t}$ and $D_{N,t}$, with the tradable share γ

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

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

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

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

where $y_{H,t}^d(z, m)$, $y_{F,t}^d(z, 1)$, and $y_{N,t}^d(z)$ are inputs of intermediate goods purchased from a home tradable good producer with technology z and export status m , foreign tradable exporter with technology z , and home non-tradable good producer with technology z , respectively. The elasticity of substitution between intermediate goods within a sector is θ .

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

problem

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

subject to the production technology (1), (2), (3).¹⁰ Solving the problem in (4) gives the input demand functions,

$$\begin{aligned}
(5) \quad y_{H,t}^d(z, m) &= \gamma \left[\frac{P_{H,t}(z, m)}{P_t} \right]^{-\theta} \left(\frac{P_{T,t}}{P_t} \right)^{\theta-1} D_t, \\
(6) \quad y_{F,t}^d(z, 1) &= \gamma \left[\frac{(1 + \tau) P_{F,t}(z, 1)}{P_t} \right]^{-\theta} \left(\frac{P_{T,t}}{P_t} \right)^{\theta-1} D_t, \\
(7) \quad y_{N,t}^d(z) &= (1 - \gamma) \left[\frac{P_{N,t}(z)}{P_t} \right]^{-\theta} \left(\frac{P_{N,t}}{P_t} \right)^{\theta-1} D_t,
\end{aligned}$$

where the price indices are defined as

$$\begin{aligned}
(8) \quad P_{T,t} &= \left\{ \sum_{m=0}^1 \int_z P_{H,t}(z, m)^{1-\theta} \varphi_{T,t}(z, m) dz + \int_z [(1 + \tau) P_{F,t}(z, 1)]^{1-\theta} \varphi_{T,t}^*(z, 1) dz \right\}^{\frac{1}{1-\theta}}, \\
(9) \quad P_{N,t} &= \left[\int_z P_{N,t}(z)^{1-\theta} \varphi_{N,t}(z) dz \right]^{\frac{1}{1-\theta}}, \\
(10) \quad P_t &= \left(\frac{P_{T,t}}{\gamma} \right)^{\gamma} \left(\frac{P_{N,t}}{1-\gamma} \right)^{1-\gamma}.
\end{aligned}$$

The final goods are used for both consumption and investment.

C. Intermediate Good Producers

All the intermediate good producers produce their differentiated good using capital, labor and material inputs. We assume that an incumbent's productivity, z , follows a first order Markov

¹⁰Notice that the production function is defined only over the available products. It is equivalent to define the production function over all possible varieties but constrain purchases of some varieties to be zero.

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. An entrant draws productivity next period based on $\phi_E(z')$. We also assume that establishments receive an exogenous death shock that depends on an establishment's productivity, z , at the end of the period, $0 \leq n_d(z) \leq 1$.

Non-Tradable Good Producers

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

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

to solve

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

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

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

Tradable Good Producers

A producer in the tradable good sector is described by its technology and export status, (z, m) . Each period, it chooses current prices $P_{H,t}(z, m)$ and $P_{H,t}^*(z, m)$, and inputs of labor $l_{T,t}(z, m)$, capital $k_{T,t}(z, m)$, materials $x_t(z, m)$, and next period's export status, m' . Total materials, $x_t(z)$, is composed of tradable intermediate goods with a constant elasticity of substitution

function

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

where $x_{H,t}^d(\zeta, \mu, z, m)$ and $x_{F,t}^d(\zeta, 1, z, m)$ are inputs of intermediate goods purchased from a home tradable good producer with technology ζ and export status μ , and foreign tradable exporter with technology ζ , respectively, by the tradable good producer with technology z and export status m .

The CES aggregation function gives the input demand functions,

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

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

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

The producer has a Cobb-Douglas production technology,

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

and solves

$$(18) \quad V_{T,t}(z, m) = \max \Pi_{T,t}(z, m) - m'W_t [f_1 m + (1-m)f_0]$$

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

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

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

and demands by intermediate good producers

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

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

Let the value of the producer with z if it decides to export in period $t + 1$ be

$$(23) \quad V_{T,t}^1(z, m) = \max \Pi_{T,t}(z, m) - W_t [f_1 m + (1 - m)f_0] \\ + n_s(z) Q_t \int_{z'} V_{T,t+1}(z', 1) \phi(z'|z) dz',$$

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

$$(24) \quad V_{T,t}^0(z, m) = \max \Pi_{T,t}(z, m) + n_s(z) Q_t \int_{z'} V_{T,t+1}(z', 0) \phi(z'|z) dz'.$$

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

$$(25) \quad V_{T,t}(z, m) = \max \{V_{T,t}^1(z, m), V_{T,t}^0(z, m)\} \\ = \max \Pi_{T,t}(z, m) + \max \{-W_t [f_1 m + (1 - m)f_0] \\ + n_s(z) Q_t \int_{z'} V_{T,t+1}(z', 1) \phi(z'|z) dz', \\ n_s(z) Q_t \int_{z'} V_{T,t+1}(z', 0) \phi(z'|z) dz'\}.$$

Clearly the value of a producer depends on its export status and is monotonically increasing and continuous in z given m , and the states of the world. Moreover V_T^1 intersects V_T^0 from below as long as there are some establishments that do not export.¹¹ Hence, it is possible to solve for the establishment productivity at which an establishment is indifferent between exporting or not exporting; that is, the increase in establishment value from exporting equals the cost of exporting. This level of establishment productivity differs by the establishment's current export status. The critical level of technology for exporters and non-exporters, $z_{1,t}$ and $z_{0,t}$, satisfy

$$(26) \quad V_{T,t}^1(z_{1,t}, 1) = V_{T,t}^0(z_{1,t}, 1),$$

$$(27) \quad V_{T,t}^1(z_{0,t}, 0) = V_{T,t}^0(z_{0,t}, 0).$$

D. Entry

Each period, a new establishment can be created by hiring f_E workers. New establishments can enter either the tradable or non-tradable sector. Establishments incur these entry costs in the period prior to production. Once the entry cost is incurred, establishments receive an idiosyncratic productivity shock from the distribution $\phi_E(z')$. All the entrants are free from death shocks. New entrants into the tradable sector can not export in their first productive period. Thus the entry conditions in two sectors are given as

$$(28) \quad V_{T,t}^E = -W_t f_E + Q_t \int_{z'} V_{T,t+1}^0(z', 0) \phi_E(z') dz' \geq 0,$$

$$(29) \quad V_{N,t}^E = -W_t f_E + Q_t \int_{z'} V_{N,t+1}(z') \phi_E(z') dz' \geq 0.$$

Let the mass of entrants in the tradable and non-tradable good sectors who pay the entry cost in period t be $N_{TE,t}$ and $N_{NE,t}$, while the mass of incumbents in the tradable and non-tradable

¹¹If the difference between f_0 and f_1 is relatively large, the economy may have $V^1 > V^0$ for all $z \in (-\infty, \infty)$ for some periods.

good sectors be $N_{T,t}$ and $N_{N,t}$. The mass of exporters and non-exporters are given by

$$(30) \quad N_{1,t} = \int_z \varphi_{T,t}(z, 1) dz,$$

$$(31) \quad N_{0,t} = \int_z \varphi_{T,t}(z, 0) dz,$$

and the mass of establishments in the tradable good sector is given as

$$(32) \quad N_{T,t} = N_{1,t} + N_{0,t}.$$

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

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

$$(33) \quad N_{N,t} = \int_z \varphi_{N,t}(z) dz.$$

Given the critical level of technology for exporters and non-exporters, $z_{1,t}$ and $z_{0,t}$, we can measure the starter ratio, the fraction of establishments that start exporting among non-exporters, as

$$(34) \quad n_{0,t+1} = \frac{\int_{z_{0,t}}^{\infty} n_s(z) \varphi_{T,t}(z, 0) dz}{\int_z n_s(z) \varphi_{T,t}(z, 0) dz}.$$

Similarly, we can measure the stopper ratio, the fraction of exporters who stop exporting among surviving establishments, as

$$(35) \quad n_{1,t+1} = \frac{\int_{-\infty}^{z_{1,t}} n_s(z) \varphi_{T,t}(z, 1) dz}{\int_z n_s(z) \varphi_{T,t}(z, 1) dz}.$$

The evolutions of mass of establishments are given by

$$\begin{aligned}
\varphi_{T,t+1}(z', 1) &= \int_{z_{0,t}}^{\infty} n_s(z) \varphi_{T,t}(z, 0) \phi(z'|z) dz + \int_{z_{1,t}}^{\infty} n_s(z) \varphi_{T,t}(z, 1) \phi(z'|z) dz, \\
\varphi_{T,t+1}(z', 0) &= \int_{-\infty}^{z_{0,t}} n_s(z) \varphi_{T,t}(z, 0) \phi(z'|z) dz + \int_{-\infty}^{z_{1,t}} n_s(z) \varphi_{T,t}(z, 1) \phi(z'|z) dz \\
&\quad + N_{TE,t} \phi_E(z'), \\
\varphi_{N,t+1}(z') &= \int_z n_s(z) \varphi_{N,t}(z) \phi(z'|z) dz + N_{NE,t} \phi_E(z').
\end{aligned}$$

E. Government

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

$$(36) \quad T_t = \tau \int_z \left[\frac{P_{F,t}(z, 1)}{P_t} \right] y_{F,t}(z, 1) \varphi_{T,t}^*(z, 1) dz.$$

F. Aggregate Variables

The investment, I_t , is given by the law of motion for capital

$$(37) \quad I_t = K_t - (1 - \delta) K_{t-1}.$$

Nominal exports and imports are given as

$$(38) \quad EX_t^N = \int_z e_t P_{H,t}^*(z, 1) y_{H,t}^*(z, 1) \varphi_{T,t}(z, 1) dz,$$

$$(39) \quad IM_t^N = \int_z P_{F,t}(z, 1) y_{F,t}(z, 1) \varphi_{T,t}^*(z, 1) dz,$$

respectively. Nominal GDP of the home country is defined as the sum of value added from non-

tradable, tradable and final goods producers,

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

The trade to GDP ratio is given as

$$(40) \quad TR_t = \frac{EX_t^N + IM_t^N}{2Y_t^N}.$$

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

$$(41) \quad L_{P,t} = \sum_{m=0}^1 \int_z l_{T,t}(z, m) \varphi_{T,t}(z, m) dz + \int_z l_{N,t}(z) \varphi_{N,t}(z) dz.$$

The domestic labor¹² hired by exporters, $L_{X,t}$, is given by

$$(42) \quad L_{X,t} = f_0 \int_{z_{0,t}}^{\infty} \varphi_{T,t}(z, 0) dz + f_1 \int_{z_{1,t}}^{\infty} \varphi_{T,t}(z, 1) dz.$$

From (42), we see that the trade cost, measured in units of domestic labor, depends on the exporter status from the previous period.

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

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

For each type of good, there is a distribution of establishments in each country. For the sake of exposition we have written these distributions separately by country and type of establishment.

It is also possible to rewrite the world distribution of establishments over types as $\varphi : R \times \{0, 1\} \times$

¹²Entry costs are measured in units of labor to ensure a balanced growth path.

$\{H, F\} \times \{T, NT\}$, where now we have indexed establishments by their origin and their sector. The exogenous evolution of establishment technology as well as the endogenous export participation and entry decisions determines the evolution of this distribution. The law of motion for this distribution is summarized by the operator T , which maps the world distribution of establishments and entrants into the next period's distribution of establishments,

$$\varphi' = T(\{\varphi, N_{TE}, N_{NE}, N_{TE}^*, N_{NE}^*\}).$$

G. Equilibrium Definition

In an equilibrium, variables satisfy several resource constraints. The final goods market clearing conditions are given by $D_t = C_t + I_t$, and $D_t^* = C_t^* + I_t^*$. Each individual goods market clears; the labor market clearing conditions are $L = L_{P,t} + L_{X,t} + f_E(N_{TE,t} + N_{NE,t})$, and the foreign analogue; the capital market clearing conditions are $K_{t-1} = \sum_{m=0}^1 \int_z k_{T,t}(z, m) \varphi_{T,t}(z, m) dz + \int_z k_{N,t}(z) \varphi_{N,t}(z) dz$, and the foreign analogue. The government budget constraint is given by (36) and the foreign analogue. The profits of establishments are distributed to the shareholders, Π_t , and the foreign analogue. The international bond market clearing condition is given by $B_t + B_t^* = 0$. Finally, our decision to write the budget constraints in each country in units of the local currency permits us to normalize the price of consumption in each country as $P_t = P_t^* = 1$.

An equilibrium of the economy is a collection of allocations for home consumers C_t, B_t, K_t ; allocations for foreign consumers C_t^*, B_t^*, K_t^* ; allocations for home final good producers; allocations for foreign final good producers; allocations and prices for home non-tradable good producers; allocations and prices for foreign non-tradable good producers; allocations, prices, and export policies for home tradable good producers; allocations, prices and export decisions for foreign tradable good producers; labor used for exporting costs at home and foreign; labor used for entry costs; transfers T_t, T_t^* by home and foreign governments; real wages W_t, W_t^* , real rental rates of capital R_t, R_t^* , real and

nominal exchange rates q_t and e_t ; and bond prices Q_t that satisfy the following conditions: (i) the consumer allocations solve the consumer's problem; (ii) the final good producers' allocations solve their profit maximization problems; (iii) the non-tradable good producers' allocations and prices solve their profit maximization problems; (iv) the tradable good producers' allocations, prices, and export decisions solve their profit maximization problems; (v) the entry conditions for tradable and non-tradable sectors hold; (vi) the market clearing conditions hold; and (vii) the transfers satisfy the government budget constraint.

3. Calibration

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

The instantaneous utility function is given as

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

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

The establishment size distribution is largely determined by the underlying structure of shocks. An incumbent's productivity follows

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

The assumption that establishment technology follows an AR(1) with shocks drawn from an iid normal distribution implies that this conditional distribution follows a normal distribution $\phi(z'|z) = N(\rho z, \sigma_\varepsilon^2)$. We assume that entrants draw productivity based on the unconditional distribution

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

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

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

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

The parameter θ determines both the producer's markup as well as the elasticity of substitution across varieties. We set $\theta = 5$, which gives the producer's markup of 25 percent. This value of θ is consistent with the US trade-weighted import elasticity of 5.36 estimated by Broda and Weinstein (2006) for the period 1990-2001.¹³ 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.¹⁴ We set the tariff rate to 8 percent, near the midpoint of the sum of tariff and non-tariff barriers. The transportation cost parameter, ξ , is set to match the exporters' export sales to the total sales ratio of 13.3 percent from the 1992 Census of Manufactures. Given the tariff rate and elasticity of substitution, this implies $\xi = 0.451$. In total, our calibration implies that tariffs and transportation costs increase the per unit cost by 57 percent. Anderson and van Wincoop (2004) find slightly larger costs of 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

¹³ Anderson and van Wincoop survey elasticity estimates from bilateral trade data and conclude $\theta \in [5, 10]$.

¹⁴ Tariff measures can vary. For instance, Yi (2003) reports a tariff on manufactured goods of 4.5 percent in the US in 1992. Similarly, US tariff revenue in 1992 was equal to 3.3 percent of imports. The World Bank reports an unweighted average tariff of 6.4 percent. For comparison Alvarez and Lucas (2006) calibrate their model to 11 percent tariffs.

mining for the US from 1987 to 1992. The labor share parameter in the production, α , is set to match the labor income to GDP ratio of 66 percent. The share of materials in production, α_x , determines the ratio of gross output to value-added in manufacturing. For the period 1987 to 1992, in the US this ratio averages 2.75 and implies that $\alpha_x = 0.804$.

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

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

1. A exporter rate of 22.3 percent (1992 Census of Manufactures).
2. Exporter output premium (the average exporter shipments relative to the average non-exporter shipments) of 5.6 as in Bernard et al. (2003) based on 1992 Census of Manufactures.
3. A stopper rate of 17 percent as in Bernard and Jensen (1999) based on the Longitudinal Research Database (LRD) of the Bureau of the Census 1984-1992.
4. Entrants' labor share of 1.5 percent reported in Davis et al. (1996) based on the Annual Survey of Manufactures (ASM).
5. Shutdown establishments' labor share of 2.3 percent (Davis et al. 1996).
6. Five-year exit rate of entrants of 37 percent based on plants that first began producing (Dunne et al. 1989).
7. Establishment employment size distributions (fractions of establishments and fractions of em-

ployment given the employment sizes) as in the 1992 Census of Manufactures.

The first three targets relate exporters to the population of establishments. As is well known, not all establishments export. Those that do are much bigger than the average establishment. There is also substantial churning in the export market, with the typical exporter exiting after six years of exporting.

The next three targets help to pin down the establishment creation, destruction, and growth process. New establishments and dying establishments tend to be small, respectively accounting for only 1.5 percent and 2.3 percent of employment. Moreover, new establishments have high failure rates, with a 37 percent chance of exiting in the first five years.

Since the establishment employment size distributions cannot be perfectly matched given the limited number of parameters, we use the following procedures. First, for a given value of σ_ε we choose the remaining six parameters to match the first 6 moments. Then we compute the sum of squared residuals from the data and the model's implied distribution of establishment employment size.¹⁵ Finally, we search for the value of σ_ε that minimizes the sum of squared residuals.¹⁶ The parameter values are reported in Table 1 and the fit of the benchmark model, dubbed *Sunk-Cost*, and some variations, is summarized in Table 2.

We also consider three other variations of the model to isolate the role of the structure of fixed costs and idiosyncratic technology shocks for exporter characteristics and aggregate results. In the first variation, which we call *Fixed-Cost*, we constrain $f_0 = f_1$ so that the startup cost and the continuation cost are identical. In this parameterization, the entry and exit thresholds are identical and so there is no hysteresis. In our second variation, called *Permanent*, we shut down the variation

¹⁵Specifically, we use the following 10 bins for employment sizes: 1-4, 5-9, 10-19, 20-49, 50-99, 100-249, 250-499, 500-999, 1000-2499, and 2500 and more employees.

¹⁶The model is solved by discretizing the idiosyncratic shock process and then using value function iteration to solve for the marginal starters and stoppers.

in idiosyncratic shocks over time and instead assume that establishments draw their technology at birth. With no plant-level uncertainty, 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. In our third variation, we also calibrate an alternate model with no fixed costs of exporting, which we call the *No-Cost* model. To make this model comparable with the other three, we calibrate the trade cost so that total trade flows are the same as in our benchmark model with sunk costs.

A. Establishment Distribution

Our first aim is to evaluate whether the model can explain both the rate of export participation across plants and the churning in exporting. Our calibration strategy has been to target the establishment and employment size distribution in manufacturing plus a limited set of moments about export participation, transitions, and the exporter premium. 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. That the benchmark sunk-cost model generates the best fit with the data is perhaps not surprising, after all it is the most general of the models. Some sense of the benefit of modelling the difference between export startup and continuation costs is apparent in that our calibration implies startup costs are 3.9 times continuation costs.

Figure 1 plots the distribution of births, exporters, and non-exporters by productivity level for our benchmark model. We also plot the exit rate by productivity level along with the threshold to enter and exit the export market. To match the low employment share of entrants and high exit rate, mean new establishment productivity starts out about 33 percent lower than mean incumbent productivity. The model generates a productivity threshold for entry that exceeds the productivity threshold to exit by 63 percent (in logs). These thresholds imply a large range of exporter hysteresis as the marginal non-exporter that starts to export will have 80 employees, while the marginal

exporter that stops exporting has 7.2 employees in steady state.

The top two panels of Figure 2 plot our targets about the establishment and employment distribution by employment size. The first panel plots the share of establishments by employment size. The share of establishments is decreasing in size in the data and all the models we consider. The second panel plots the share of manufacturing employment accounted for by establishments in each employment category in the data and the models. The distribution 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. However, not surprisingly since it is the most general model, statistically the sunk-cost model provides the best fit to the data.

The last panel of Figure 2 plots export participation in the data and the three models with a decision to export. All three models have been calibrated to get the total participation rate correct but no other information about the distribution of participation has been used. In all three models export participation increases with establishment size, although more so than in the data. With regards to the distribution of exporter participation, the fixed-cost model provides a slightly better fit than the sunk-cost model. However, the fixed-cost model predicts substantially more churning in the export market with exporters spending slightly less than 2 years exporting compared to the 5.9 year spells we see in the data. When shocks are permanent, the model substantially overpredicts participation by big establishments and generates an exporter premium 3 times bigger than in the data.

4. Tariffs and Steady State

To gain some insight into how tariffs distort economic activity, we now study how the structure of the steady state economy depends on tariffs. We first explore the impact of tariffs on the characteristics of exporters vs. non-exporters. We then consider the relation between tariffs and aggregates such as consumption, investment, trade, and export participation. For exposition, all

series are measured relative to the level under free trade.

A. Exporter Characteristics and Dynamics

Figure 3 depicts the relationship between exporter characteristics and tariffs ranging from 0 to 30 percent. Panel (a) shows that the productivity cutoffs of the marginal starter, z_0 , and the marginal stopper, z_1 , are increasing in tariffs as the higher tariff lowers the value of exporting.

Panel (b) plots the exporter output and productivity premia in the stationary distribution of establishments against the tariff rate.¹⁷ For low tariffs, the exporter productivity premium is increasing with the tariff rate. We get this monotonic relationship between tariffs and the exporter productivity premium because the tariff alters the type of establishments that export. As we increase the tariff, we increase the productivity cutoffs to start and stop exporting. Thus, the average productivity of exporters increases relative to that of non-exporters. Unlike the exporter productivity premium, the output premium is U-shaped in the tariff rate. Absent tariffs, the output premium is increasing in the productivity premium. However, holding the productivity premium constant, the output premium is decreasing with tariffs as higher tariffs reduce exports of each establishment. For tariffs less than about 4 percent, the direct effect of tariffs on output dominates the indirect effect working through the productivity premium. For tariffs greater than 4 percent, the effect of tariffs on productivity dominates.

Panel (c) plots the equilibrium starter and stopper rates for each tariff level. As tariffs increase, we find that non-exporters start exporting less frequently and establishments that do export exit fairly frequently. The duration of exporting is inversely proportional to the stopper rate. With 8 percent tariffs, the model predicts that each export spell lasts about 5.9 years. Under free trade, the duration of each export spell rises to about 10.0 years.¹⁸

¹⁷The productivity premium is calculated as the difference between the average productivity of exporters and that of non-exporters in logarithm.

¹⁸Since the plant-level productivity is persistent, the export spell is increasing in the plant-level productivity.

Panel (d) plots the share of establishments in the tradable sector that are exporters. Moving from 8 percent tariffs to free trade increases export participation from 22.3 percent of the establishments to 41.3 percent as the thresholds to start and stop exporting are lowered. Similarly, as we increase tariffs above 8 percent, exporters exit foreign markets in droves. To get an idea of the importance of the exit margin for participation, we have also plotted the export participation rate that would have prevailed if we had held the exit threshold constant at the level with 8 percent tariffs. This partial equilibrium counterfactual implies that modelling the exit margin just about doubles the sensitivity of exporting to tariffs.¹⁹

B. Aggregates

We start our analysis of the aggregate effect of tariffs by considering trade-related variables. To highlight the role of fixed export costs, we also report the results of the *No-Cost* model, which is identical to our benchmark model except that there are no costs of exporting, $f_0 = f_1 = 0$.

We first consider the effect of tariffs on establishment creation in each model. From panel (a) of Figure 4, in *No-Cost* the mass of tradable establishments decreases with tariffs, while the mass of non-tradable establishments is increasing in tariffs. Tariffs are effectively a tax on tradable establishments and thus the economy substitutes toward non-tradable establishments. In the benchmark model, both tradable and non-tradable establishments are increasing in tariffs. However, from panel (b) we see that the mass of differentiated varieties available, measured as imports and domestic tradables, declines with tariffs as the increase in local tradable establishments is offset by a decline in foreign varieties as export participation declines with tariffs.

There are two reasons why increasing tariffs encourage establishment creation. First, tariffs raise the relative price of physical capital to establishments or export capacity, as physical capital

¹⁹Of course this understates the role of the exit margin, since it is the exit margin that determines the duration of exporting. A longer expected duration of exporting raises the expected value of exporting and increases entry.

is produced using labor, capital, and materials, while establishments and export capacity are produced just using labor whose price, the real wage rate, is decreasing in tariffs (panel e). Second, tariffs lower the benefits of investing in export capacity. When the tariff is raised, the return to producing additional varieties of goods by incurring the cost of exporting is reduced. We see that tariffs encourage savings through investment in establishments rather than capital (panel f), while discouraging saving through export capacity. Moving from free trade to 30 percent tariffs increases the mass of tradable varieties by about 7.4 percent. However, the net effect is to decrease the mass of available varieties by about 22 percent. Thus, tariffs encourage establishment creation²⁰ over capital accumulation and discourage investing in export capacity.

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

Despite the stronger trade response in the *Sunk-Cost* model, we see from panel (d) that lowering tariffs increases steady state consumption by more in the *No-Cost* model. For low tariffs, the gap between the two models is not too large and the *No-Cost* model provides a good approximation of the change in steady state consumption from a change tariffs in the *Sunk-Cost* model. For larger tariffs, the *No-Cost* model substantially overstates the change in steady state consumption from eliminating tariffs.

That tariffs distort steady state consumption by more in the model without export decisions may appear surprising. After all, the literature has emphasized that the gains to lowering trade barriers should be larger in models with export decisions, since the lower barriers attract more relatively productive exporters. We actually view this result as being sensible. In the model with

²⁰The pro-variety of tariffs is also found in the work by Baldwin and Forslid (2006).

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 a fixed cost has one additional margin with which to adjust and hence the impact on steady state consumption is smaller.

Now, a question arises: Are the welfare gains with transition dynamics similar to the steady state comparisons? To assess the costs or benefits of reducing tariffs carefully, it is necessary to consider the transition dynamics.

5. Transition Dynamics

In this section, we consider a move from a world in which both countries charge 8 percent tariffs to free trade. The results from this policy experiment provide some guide to the expected changes in the US and the rest of the world from moving to free trade. This change in policy is assumed to be completely unanticipated.²¹ The long-run changes in the model economy are reported in Table 3 and the first 50 periods²² of the transition²³ are plotted in Figures 5 and 6. We begin by discussing the aggregate implications and then consider the implications for the volume of trade and exporting.

²¹This distinction is quite important in the sunk-cost model, since an anticipated trade reform will generate a change in trade prior to the reform since the increase in the expected value of continuing to export will lead some relatively unproductive exporters to not exit.

²²The 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 are in the first 50 years.

²³With the fixed costs, a large change in policy can give rise to oscillations as a large mass of establishments can be created in a particular period. To reduce the oscillatory behavior with high frequency in the establishment creation during the transitions, we introduce small adjustment cost, which depends on the mass of new establishments relative to that of incumbents, rather than a constant cost. The modified costs of creating a new variety in the tradable and non-tradable sectors are given as

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

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

A. Welfare

From the last row of Table 3, which reports the change in welfare²⁴ taking into account the transition to the new steady state, we see, as expected, that the gains to lowering tariffs are about 1/3 larger in our model of exporting than in the *No-Cost* model (1.24 vs 0.90). In our benchmark model, steady consumption understates the true welfare gain of trade reform by 14 percent (1.07 vs 1.22). In contrast, in the *No-Cost* model steady state consumption overstates the true welfare gain by approximately 37 percent.

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

In the benchmark model, a trade liberalization leads to a sustained economic expansion that overshoots the new steady state along the transition. From panel (a) of Figure 5 we see that consumption grows quite strongly following the cut in tariffs, peaking 0.3 percent above the new steady state 10 years after the policy change. This overshooting is somewhat surprising given the strong consumption smoothing motive in the model, and largely reflects the economy's ability to better use existing assets, namely establishments, along the transition. This improved efficiency is captured in the dynamics of the Solow residual²⁵ in panel (c). By this measure, following a trade liberalization there are both permanent and persistent changes in total factor productivity. As with a persistent productivity shock in a standard real business cycle model, agents take advantage of this shock by investing in capital accumulation (panel b) and smoothing out consumption, and this

²⁴For a reference, in the model of Alvarez and Lucas (2006), the US gains 0.15 percent of consumption from a global elimination of tariffs.

²⁵The Solow residual is constructed as $z = \ln D - 0.34 \ln K - 0.66 \ln L$.

is what leads to the overshooting in consumption.

Unlike total factor productivity in a real business cycle model, the change in total factor productivity in our model is endogenous and reflects changes in the number of establishments and exporters, as well as in the productivity distribution of establishments. In the previous section we showed that tariffs lead to an overaccumulation of establishments and underaccumulation of exporters compared to free trade. Along the transition there are many establishments that can easily be converted into exporters. Thus along the transition the economy will invest less in establishments and invest more in creating exporters. The net effect is a rapid increase in the number of tradable varieties available, which also overshoots its long-run level (panel f). Because this expansion in variety occurs through an increase in exporters and decrease in the creation of establishments, the distribution of productivity over plants is also changing over time. Since entrants are generally less productive than incumbents, the decline in entry reduces the mass of relatively unproductive establishments, thereby raising the average productivity, measured as a simple average, of the existing establishments (panel d). This measure peaks 0.3 percent above its initial and long-run levels²⁶ in year 4.

B. Trade and Exporters

The four panels of Figure 6 plot the evolution of trade-related variables along the transition to the new steady state. Starting with the trade to GDP ratio (panel a), we see that in both the *Sunk-Cost* and *No-Cost* models trade expands substantially with tariff reductions. In the *No-Cost* model, the trade share jumps by 42.1 percent to its new long-run level right away since the trade-GDP ratio is determined by the tariff rate and transportation costs. In the *Sunk-Cost* model, the trade expansion is much more drawn out. In the first period trade increases by 44.1 percent since

²⁶Given that exit and productivity evolve exogenously, the distribution of establishments over productivity is identical across all steady states of the model.

existing varieties become less expensive. In the second period, trade expands another 21.5 percent as export participation increases. From then on, trade grows more gradually to its long-run value, which exceeds the initial level by 81.9 percent.

The gradual increase in trade reflects a slightly more gradual increase in export participation (panel b). On impact, export participation rises by 34.1 percent. In the next period it expands another 18.8 percent. From then on export participation grows gradually another 32.1 percent to its long-run level, which is greater than the initial level by 85.1 percent. The increase in exporting occurs through a persistent increase in the starter ratio and persistent decrease in the stopper ratio, both of which overshoot their long-run levels (panel c). From panel (d) we see that very little of the overshooting of the stopper and starter rates results in overshooting in the entry and exit thresholds, but instead reflects the fact that when the policy is enacted there are many relatively productive non-exporters at the margin and very few unproductive exporters. Given the large gap between the entry and exit threshold, this implies that along the transition, the mass of exporters clustered around the upper threshold is quite large relative to the steady state. So, just as the establishment distribution was shifted toward relatively more productive establishments, the exporter distribution is shifted toward relatively productive establishments. The change in exporter distribution contributes to the overshooting in economic activity.

6. Sensitivity

To make the model consistent with the data, we embedded a number of real-world features into our benchmark model, *Sunk-Cost*, that the theoretical literature on international trade commonly abstracts from.²⁷ We now investigate the quantitative implications of these abstractions on the relation between tariffs, trade, and welfare. In doing so, we highlight the key margins that

²⁷Some 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) and Baldwin and Forslid (2006).

matter in the model.

Specifically, we consider 4 variations of our benchmark model. In addition to the *Permanent* and *Fixed-Cost* model we already described, we include a model with no capital, called *No-Capital*, and another model in which tradable producers do not use intermediate goods, called *No-Materials*. The parameter values used for these variations are reported in Table 1. The calibration targets and the fit of the models are reported in Table 2. With these variations, we consider the effect of eliminating a tariff rate of 8 percent. The long-run effects are reported in Table 3 and transitions of some key variables are plotted in Figure 7.

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

From the *Fixed-Cost* variation, we see that the structure of fixed costs matters for both the trade and export participation response to tariffs but less so for welfare. When the startup cost is the same as the continuation cost of exporting, the trade and export participation increase is, respectively, 12 and 38 percent less than in the benchmark model. The alternate model generates a smaller response of trade and exporting because the threshold for entry and exit is identical and there are fewer establishments affected by changes in this threshold than in the benchmark model. With fixed costs, export capacity is no longer a durable asset and hence increasing export participation uses up more resources along the transition, while in the sunk-cost model the economy can use

existing exporters more effectively. These exporter dynamics imply less overshooting following trade liberalization and smaller welfare gains in the *Fixed-Cost* variation.

Eliminating the establishment idiosyncratic uncertainty reduces both the welfare gain and trade response to trade reform. With permanent shocks, the distribution of productivity over establishments is unaffected by the rate of new establishment creation. Thus, there is no overshooting and consumption grows much more gradually to its new steady state, and steady state consumption overstates the welfare gain. Additionally, now export participation and trade rise only 33 percent and 62 percent, respectively, as much as in the *Sunk-Cost* model.

Without intermediates, the welfare gains to trade reform are about 22 percent of our benchmark model. Yi (2003) also found that intermediates magnified the welfare costs of tariffs. Tariffs are more distortionary with materials because it is as if certain goods cross the border multiple times. However, the trade response is nearly identical to the *Sunk-Cost* model without intermediates.²⁸

7. Conclusions

We have studied the ability of the Melitz model to account for differences in US export participation among manufacturing establishments as well as the churning in exporting. We found that a model with plant-level uncertainty and fixed costs of starting to export 3.9 times as big as the cost of continuing in the export market matches up well with the distribution of export participation among US manufacturing plants. We then used the model to calculate the increase in trade and the gains to moving to free trade. They are both sizeable.

We find that tariffs have a smaller effect on steady state consumption in the Melitz model

²⁸Yi (2003) develops a model of trade in which intermediates move back and forth across borders in different stages of production and endogenizes the number of times goods cross the border. In some respects, there is some of this back and forth in our model in that when establishments choose to export they are selling goods overseas which then will be reimported in the goods of intermediates of foreign exporters. Adding materials does not magnify this effect because in our model all of the changes come in the first stage of production with the change in range of varieties available.

than in models without fixed costs of exporting, even though tariffs lower trade by more in the Melitz model. These paradoxical steady state results are sensible once one realizes that models without fixed costs of exporting are special cases of models with fixed costs and therefore have fewer margins on which to adjust. However, we also note that steady state consumption is not a good measure of welfare in either model, particularly when there is a large sunk component to exporting.

The model with fixed costs of exporting predicts that lowering tariffs should spur a substantial economic expansion that overshoots the new steady state after about 10 years. These transition dynamics imply that the welfare gains to trade reform are larger than measures based on steady state consumption. The structure of fixed export costs and idiosyncratic shocks determines the magnitude of the overshooting. When we shut down plant-level uncertainty and assume export costs are not sunk, the economy does not overshoot its new steady state.

The model was used to provide some guidance on the key margins that matter for trade and welfare in models with establishment heterogeneity. If one is mostly interested in trade flows, we find that models without sunk costs substantially understate the long-run increases in trade, since increases in export participation are much smaller. We also found that the dynamics of trade growth are more gradual in models with sunk costs. In terms of welfare, we found an important quantitative role for both capital and intermediate inputs in the production process of tradables.

We have studied only symmetric trade policies with two symmetric economies. However, the model is well suited to considering the impact of unilateral reforms as well. In particular, we can consider the impact on both net exports and the real exchange rate of a unilateral change in trade policies. One would expect that unilaterally lowering tariffs would generate somewhat larger economic expansions along the transitions to the new steady state as the reforming country can borrow to finance greater investment. We are currently exploring this topic.

Table 1: Parameter Values

Common Parameters

$$\beta = 0.96, \sigma = 2, \theta = 5, \delta = 0.10, \tau = 0.08$$

Benchmark (Sunk-Cost)

$$\alpha = 0.289, \lambda = 7.460, n_{d0} = 0.022, \alpha_m = 0.804, \gamma = 0.21, \xi = 0.451,$$

$$\rho = 0.625, \mu_E = 0.352, \sigma_\varepsilon = 0.355, f_E = 1.641, f_0 = 0.101, f_1 = 0.026$$

No-Cost

$$\alpha = 0.285, \lambda = 7.800, n_{d0} = 0.022, \alpha_m = 0.804, \gamma = 0.21, \xi = 0.662,$$

$$\rho = 0.625, \mu_E = 0.371, \sigma_\varepsilon = 0.370, f_E = 1.676, f_0 = f_1 = 0$$

No-Cost-No-Entry

$$\alpha = 0.087, \lambda = 0, n_{d0} = 0, \alpha_m = 0.804, \gamma = 0.21, \xi = 0.662,$$

$$\rho = 0.625, \mu_E = 0, \sigma_\varepsilon = 0.355, f_E \rightarrow \infty, f_0 = f_1 = 0$$

Fixed-Cost

$$\alpha = 0.296, \lambda = 7.527, n_{d0} = 0.022, \alpha_m = 0.804, \gamma = 0.21, \xi = 0.451,$$

$$\rho = 0.520, \mu_E = 0.362, \sigma_\varepsilon = 0.395, f_E = 1.644, f_0 = f_1 = 0.037$$

Permanent

$$\alpha = 0.223, \lambda = 0, n_{d0} = 0.023, \alpha_m = 0.804, \gamma = 0.21, \xi = 0.584,$$

$$\rho = 1, \mu_E = 0, \sigma_\varepsilon = 0.440, f_E = 3.177, f_0 = f_1 = 0.015$$

No-Capital

$$\alpha = 0, \lambda = 7.460, n_{d0} = 0.022, \alpha_m = 0.804, \gamma = 0.21, \xi = 0.451,$$

$$\rho = 0.625, \mu_E = 0.352, \sigma_\varepsilon = 0.355, f_E = 1.247, f_0 = 0.077, f_1 = 0.020$$

No-Materials

$$\alpha = 0.306, \lambda = 7.460, n_{d0} = 0.022, \alpha_m = 0, \gamma = 0.581, \xi = 0.451,$$

$$\rho = 0.625, \mu_E = 0.352, \sigma_\varepsilon = 0.355, f_E = 1.187, f_0 = 0.073, f_1 = 0.019$$

Table 2: Target Moments

	Target value	Sunk- Cost	No- Cost	Fixed- Cost	Permanent	No- Capital	No- Materials
5-year exit rate	0.37	0.37	0.37	0.37	0.11	0.37	0.37
Startups' labor share	0.015	0.015	0.015	0.015	0.021	0.015	0.015
Shutdowns' labor share	0.023	0.023	0.023	0.023	0.023	0.023	0.023
Output Premium	5.60	5.60	-	5.60	18.28	5.60	5.60
Stopper rate	0.17	0.17	-	0.52	0.018	0.17	0.17
Exporter ratio	0.223	0.223	-	0.223	0.223	0.223	0.223
Trade Share	0.047	0.047	0.047	0.047	0.047	0.047	0.047
Squared sum of residuals (%)							
Establishments	0	0.84	3.70	2.31	2.58	0.84	0.84
Employment share	0	1.98	4.22	3.54	4.96	1.98	1.98
Export participation	0	33.45	-	28.16	87.21	33.45	33.45

Table 3: Percent Changes in Steady State and Transition Changes from Eliminating 8% Tariff

	Sunk- Cost	No- Cost	Fixed- Cost	Permanent	No- Capital	No- Materials
Consumption	1.07	1.24	1.13	1.09	0.74	0.03
Trade to GDP ratio	81.89	40.09	71.67	50.39	81.89	79.78
Capital stock	1.35	1.51	1.40	1.35	-	0.49
Production labor	-0.30	-0.12	-0.26	-0.12	-0.22	-0.17
Non-tradable variety	-0.52	-0.35	-0.49	-0.35	-0.45	-0.55
Domestic tradable variety	-1.88	1.48	-0.94	0.84	-1.81	-3.04
Total tradable variety	13.35	1.48	8.59	5.98	13.43	12.01
Starter ratio	67.87	-	49.16	62.43	67.87	67.87
Stopper ratio	-41.27	-	-19.19	39.31	-41.27	-41.27
Exporter ratio	85.11	-	52.74	27.81	85.11	85.11
Output premium	-0.82	-	4.45	3.38	-0.82	-0.82
Productivity premium	-10.33	-	-5.16	-3.50	-10.33	-10.33
Static welfare gains	1.07	1.24	1.13	1.09	0.74	0.03
Transitional welfare gains	1.22	0.90	1.16	0.89	0.94	0.26

Note: Welfare gains are measured as the value of x that satisfies $\sum_{t=0}^{\infty} \beta^t U(C_{-1}(1+x)) = \sum_{t=0}^{\infty} \beta^t U(C_t)$, where C_{-1} is the initial steady state consumption.

Figure 1: Establishment Distribution

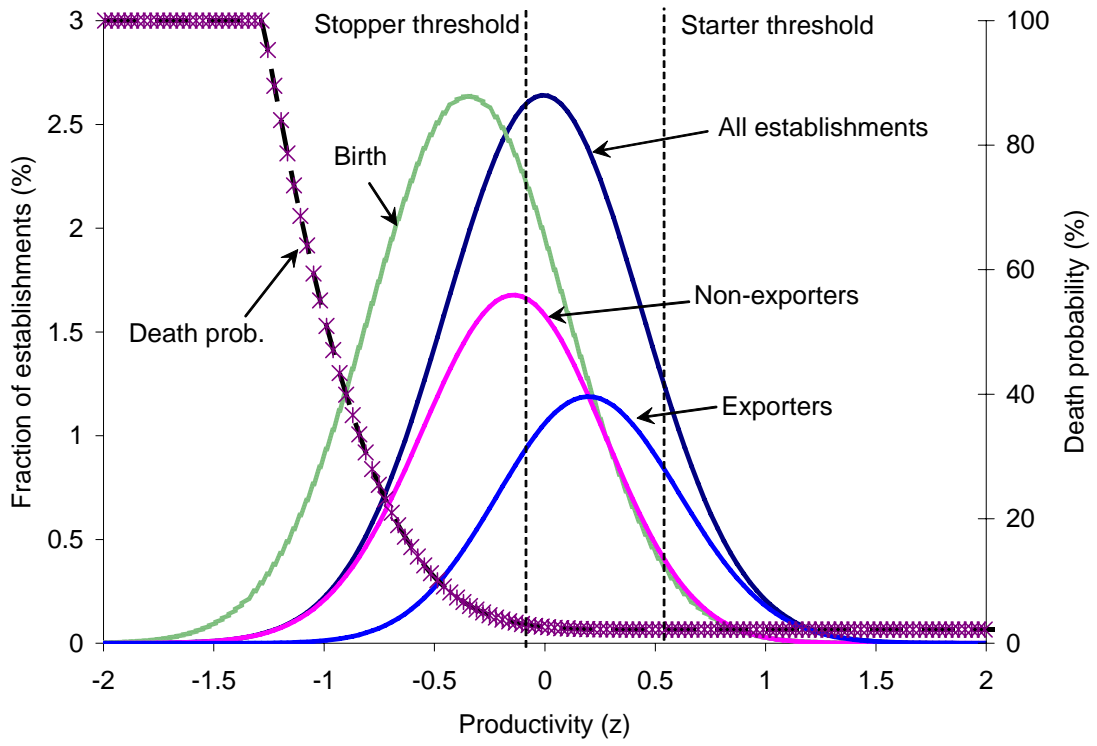
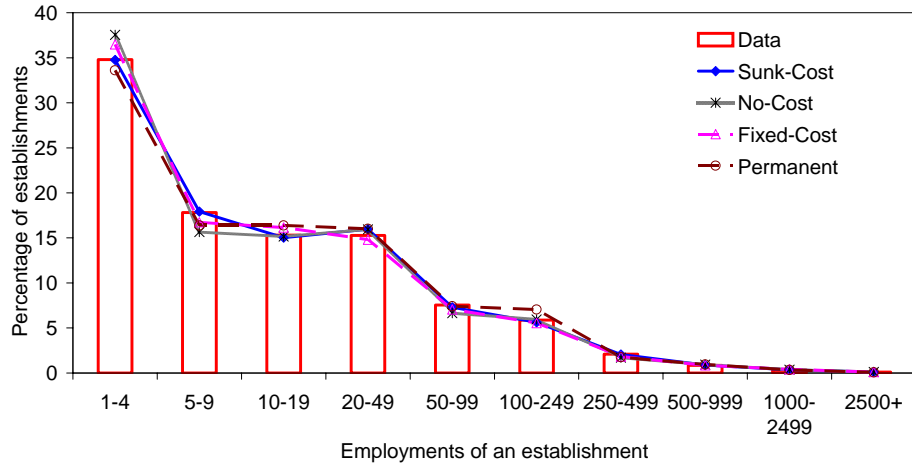
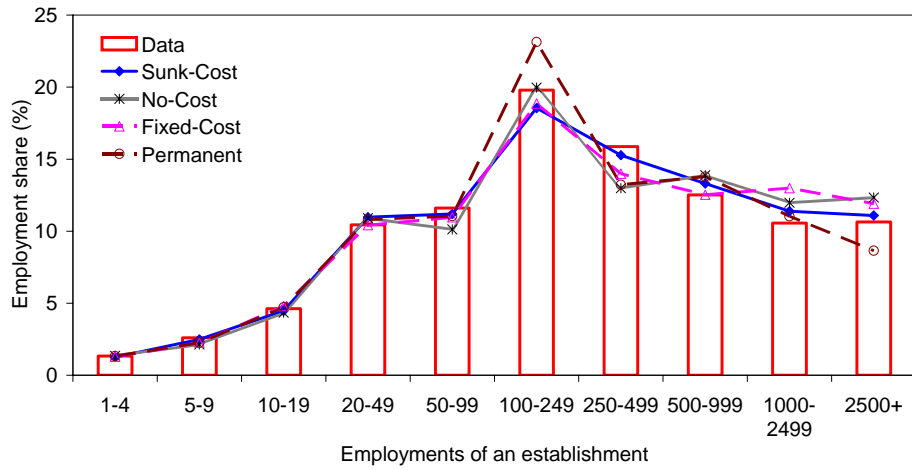


Figure 2: Employment Distributions

(a) Establishment Share



(b) Employment Share



(c) Export Participation

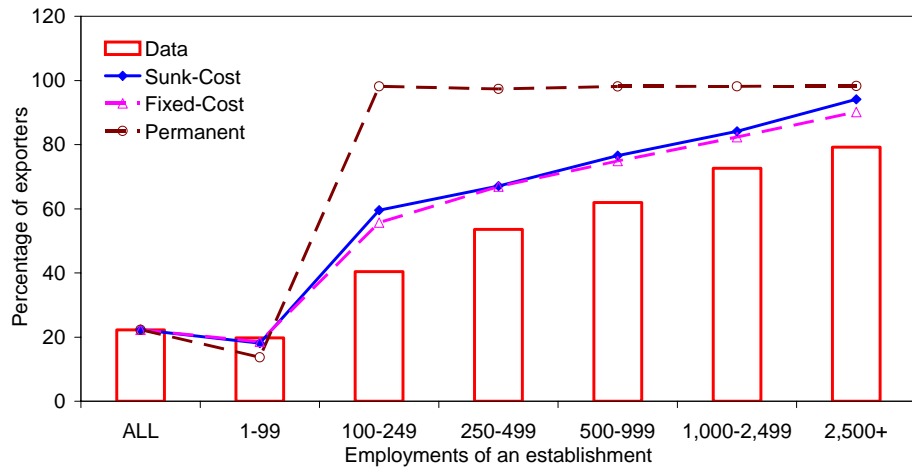


Figure 3: Steady State Establishment Characteristics and Tariffs

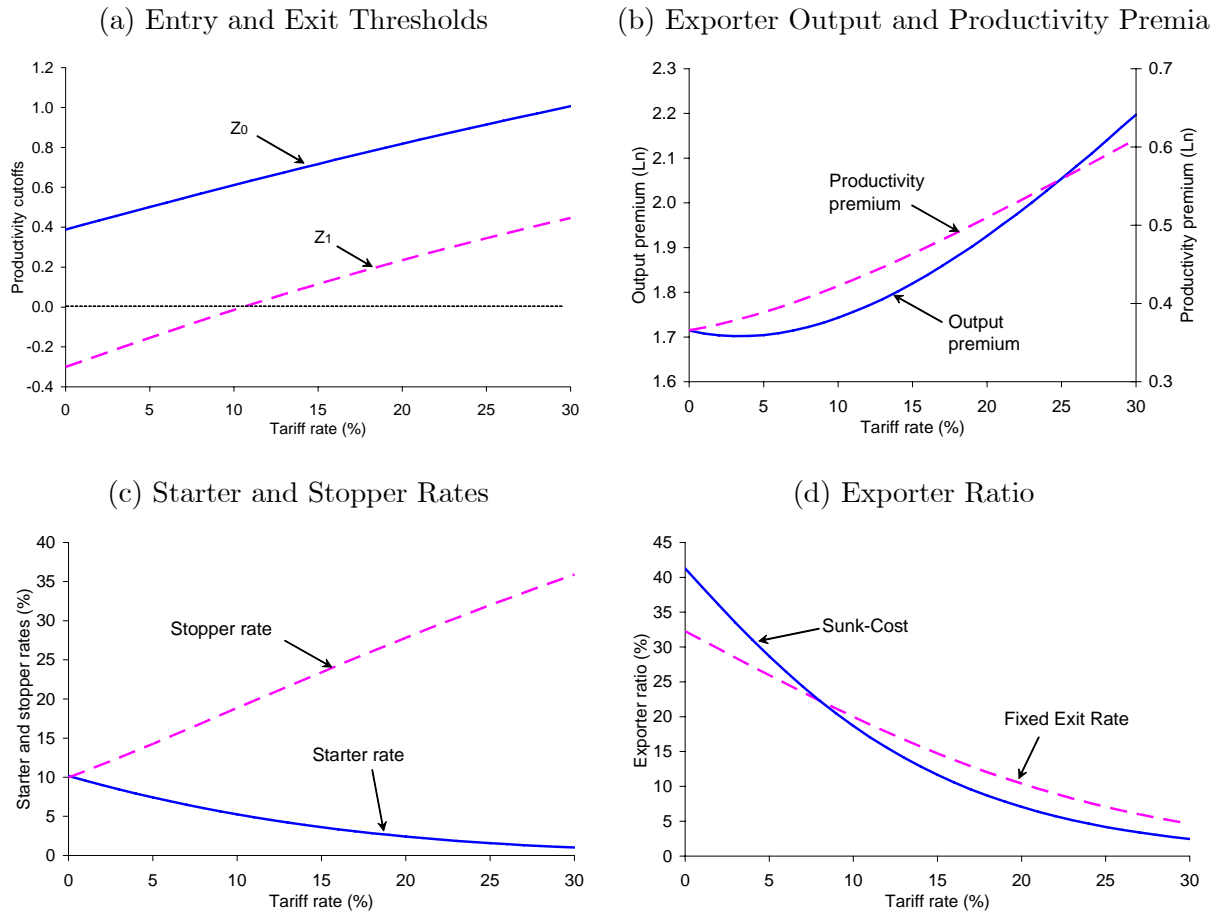


Figure 4: Steady State Aggregates and Tariffs

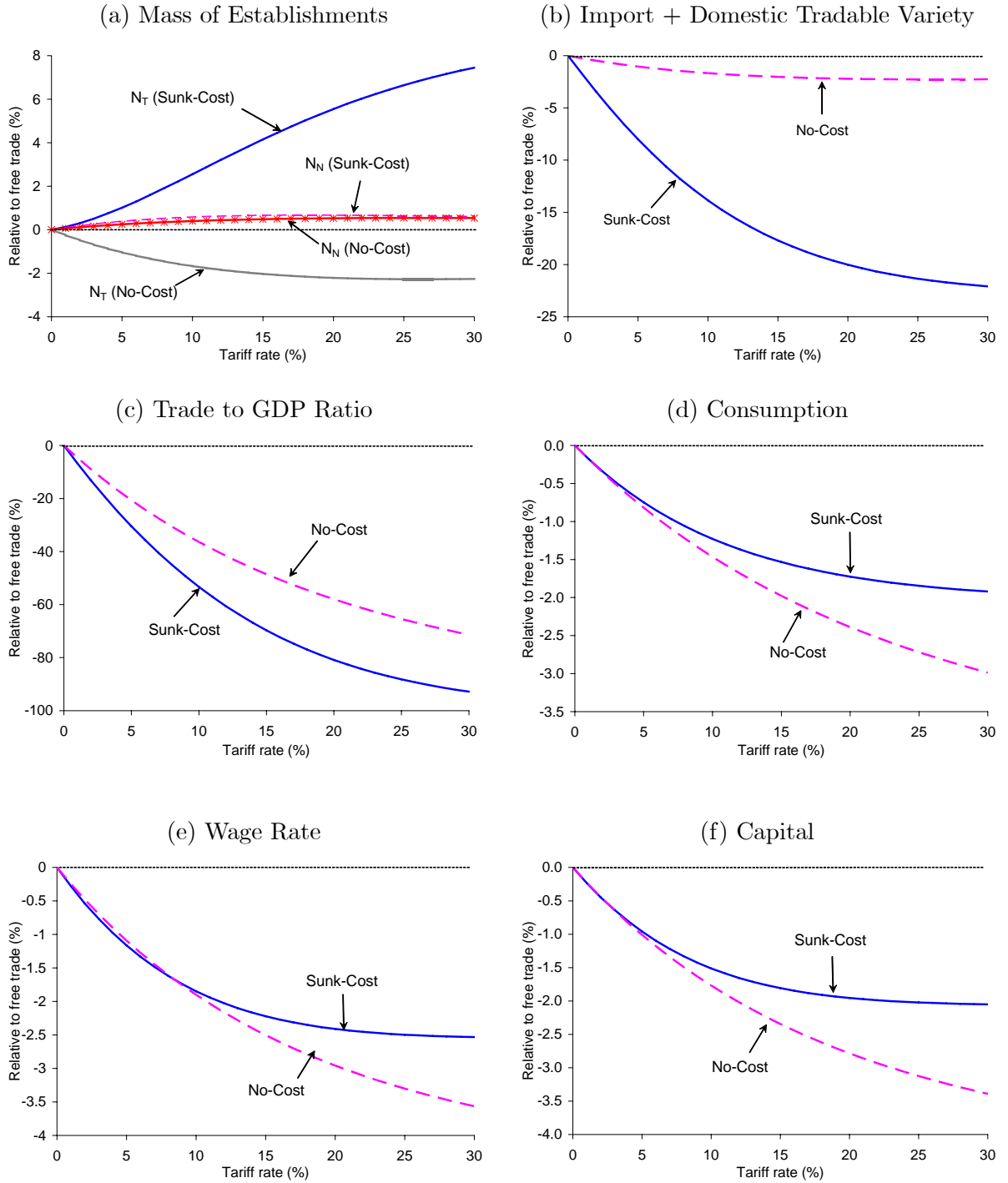


Figure 5: Transition Dynamics from 8 percent Tariff to Free Trade

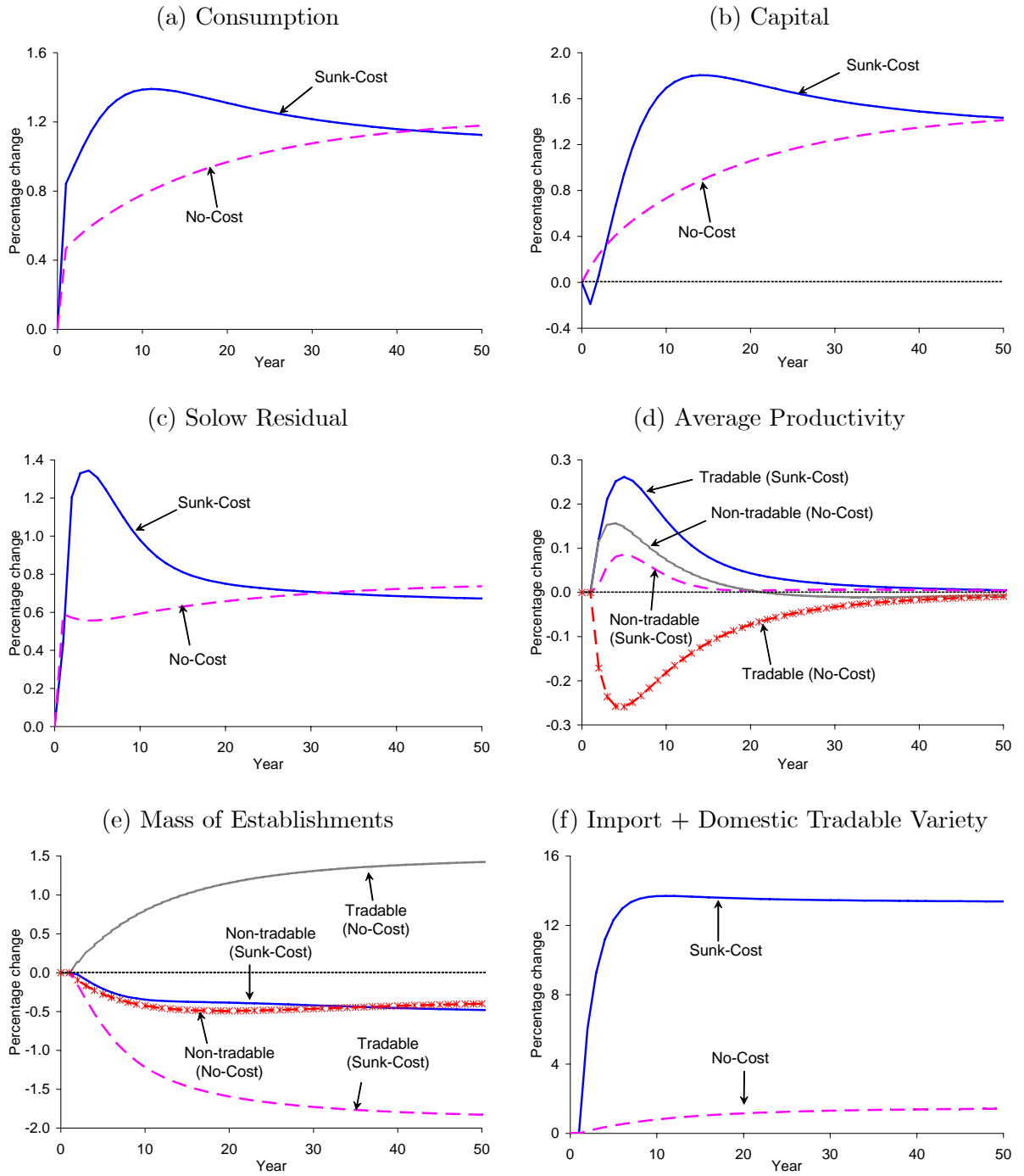
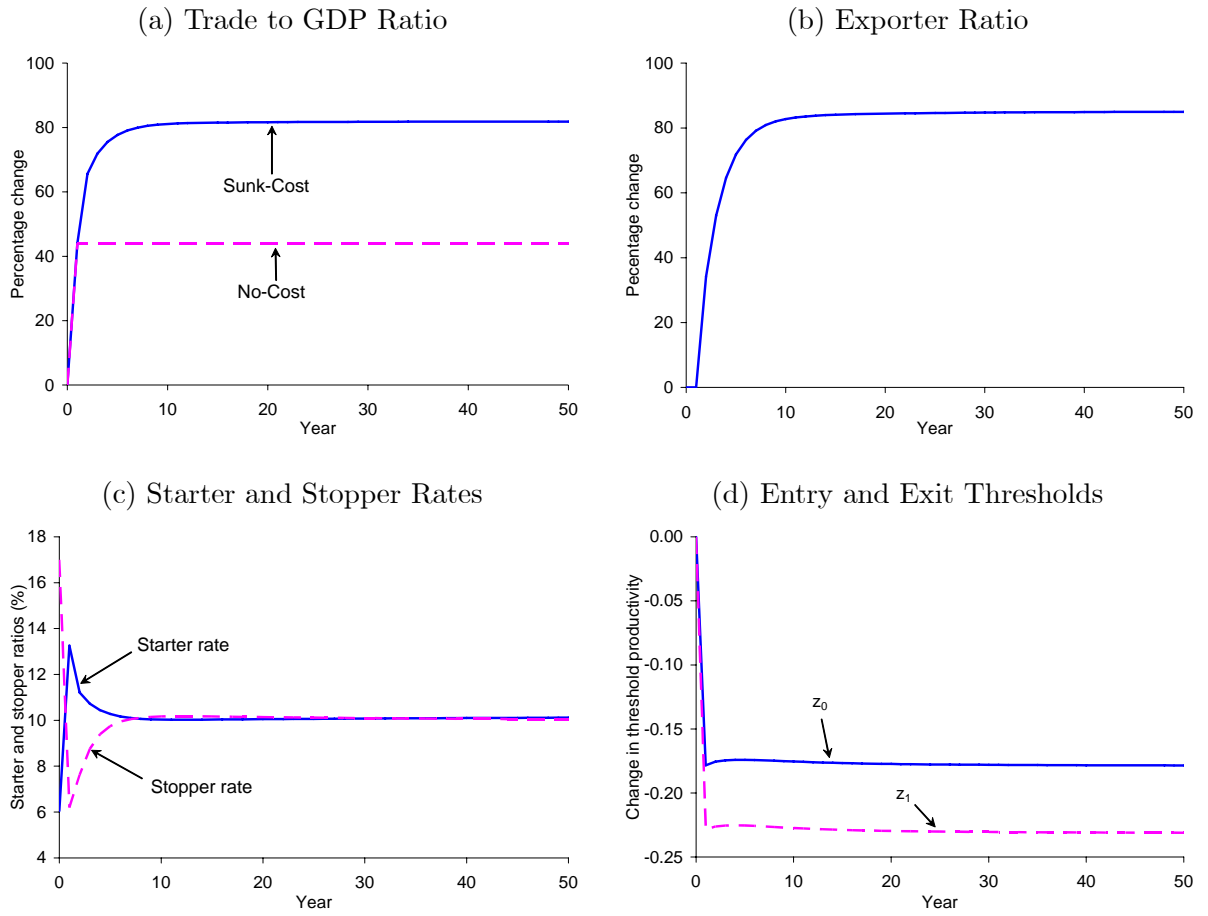
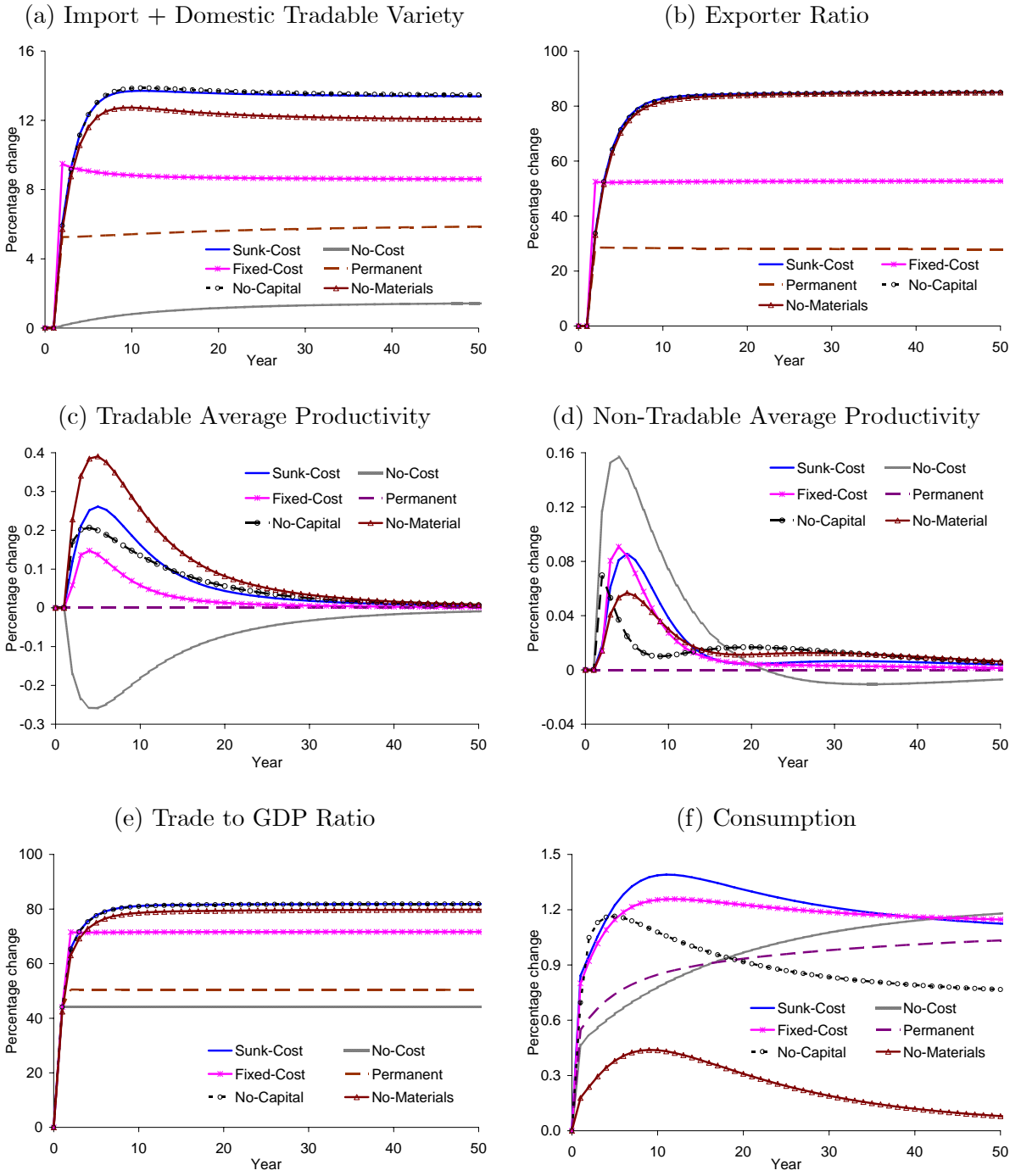


Figure 6: Transition Dynamics from 8 percent Tariff to Free Trade

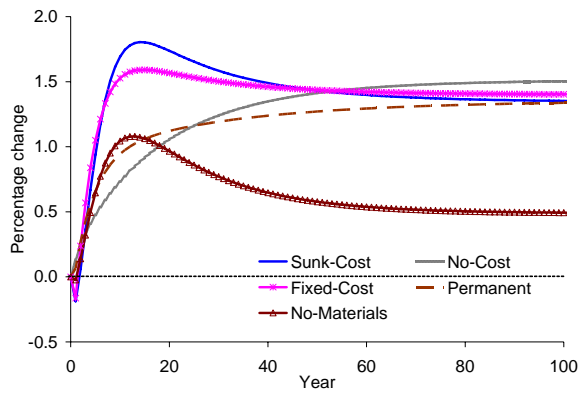


Note: The average productivity is normalized with the steady state distribution to have zero-mean and unit-variance.

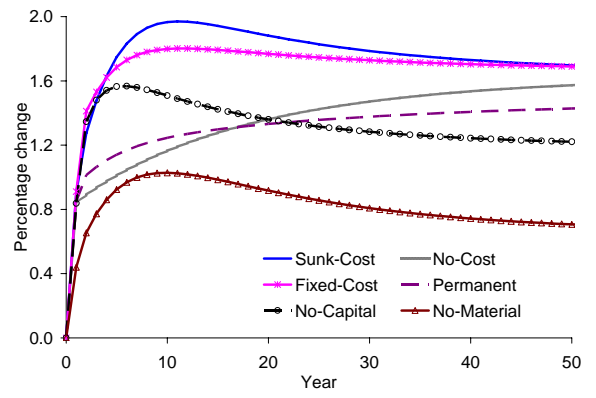
Figure 7: Transitions with Variations



(g) Capital Stock



(h) Wage Rate



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