Trade Adjustment Dynamics and the Welfare Gains from Trade*

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Abstract
We build a general equilibrium model in which producers expand their export sales gradually by making export-specific investments. The model is calibrated to match salient features of producer and new exporter growth. The sluggishness in export expansion at the producer level leads to sluggishness in the aggregate response of exports to a change in tariffs, with a long-run trade elasticity that is 3.1 times the short-run trade elasticity. We estimate the welfare gains from trade from a cut in tariffs taking into account the transition period. While trade flows respond slowly, we find that consumption overshoots its new steady-state level, so the welfare gains exceed the change in steady state consumption by about 216 percent. A cut in tariffs that increases the long-run share of production exported from 8.8 to 24.1 percent increases welfare by 6.4 percentage points. Models without this dynamic export decision underestimate the gains to removing trade barriers, particularly when constrained to also match the sluggishness in aggregate trade flows.

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1 Introduction

The key determinant of the welfare gains from international trade is the trade elasticity. The trade elasticity measures how a change in trade barriers—such as tariffs or transportation costs—leads consumers and firms to substitute between local and imported goods. In static models, the trade elasticity is a well defined object, but in reality, matching this elasticity with its counterpart in the data is fraught with complications. One of the most challenging aspects of measuring the aggregate trade elasticity is that it is not constant: The time horizon over which it is measured is a key determinant of the aggregate elasticity, with long-run elasticities commonly measured to be several times larger than short-run elasticities.[1] The variance in elasticities measured over different periods is a reflection of the slow response of aggregate trade flows to changes in trade barriers. Addressing the dynamic response of trade flows to trade barriers requires an explicitly dynamic model, which we construct in this study. With a model that can account for the dynamics that follow trade liberalization—as disciplined by measures of the trade elasticity at varying horizons—we show that accounting for the dynamic response of trade flows greatly increases the gains from liberalization.

Measures of the aggregate trade elasticity vary with trade liberalization episode (Yi 2003) and horizon considered (Gallaway, McDaniel, and Rivera 2003). Surveying the literature, Ruhl (2008) finds estimates of the trade elasticity that vary from 1 to 15. The conventional view is that trade responds slowly to changes in trade barriers or relative prices, so that the trade elasticity is low in the short run and high in the long run. It is commonly claimed that the long-run elasticity is 5 to 10 times larger than the short-run elasticity. Not surprisingly, the behavior of aggregate trade flows is closely tied to the behavior of trade flows at the producer level. The literature focused on producer-level data documents that exporting is a persistent activity (Das, Roberts, and Tybout 2007) and that new exporters take time to mature (Ruhl and Willis 2008). Figure 1a, from Ruhl and Willis (2008), plots the average export-total sales ratio of new exporters in Colombia. The average continuing exporter ships 13 percent of its output abroad. A new exporter ships about 6 percent of total sales abroad in its first year as an exporter, and it takes 5 years for the new exporter to reach the same

[1] Industry level estimates of the response of trade to changes in exchange rates tend to find substantial differences between short-run and long-run trade response (Gallaway, McDaniel, and Rivera 2003).

export intensity as the existing exporters. If trade liberalization induces some producers to begin exporting, the impact on aggregate trade flows will initially be quite small, but will grow in importance as new exporters sales abroad increase with time.

The trade elasticity is in part determined by the decisions of heterogeneous producers to start or stop exporting, and the intensity with which producers export over their life-cycle. We build a model in which sluggish aggregate trade growth is the result of sluggish producer-level export growth. Producers are subject to persistent idiosyncratic productivity shocks, and—in addition to an export entry cost—must make continual investments that boost future export sales. Our producer-level model nests several technologies used in the literature, including Krugman (1991) and Das, Roberts, and Tybout (2007). In our model, the producer-level details have large quantitative effects on the gains from trade: The welfare gains from an 10 percent cut in tariffs are more than 3 times larger in the model with sluggish producer-level dynamics than in the model in which all producers export.

The technology for exporting we consider generates sluggish export expansion. This technology is a straightforward generalization of that used in standard theories of trade with heterogeneous plants. In those theories, producers can reduce their per unit cost of trade from infinity[2] to some lower level by incurring a fixed cost: This is export entry. In dynamic variations of this theory (such as Das, Roberts, and Tybout 2007), by incurring a second, smaller fixed cost the producer can maintain access to this low iceberg cost. If an exporter does not incur this fixed cost, its iceberg cost increases back to infinity and it must pay the higher fixed cost to re-enter. In our theory, investing in export technology only gradually lowers the iceberg cost. This formulation is much better able to capture the key dynamics of new exporter growth. The slow growth in the export intensity of a new exporter in the model mimics the sluggish producer-level trade growth in the data.

Specifically, we develop a model with producers that are subject to persistent idiosyncratic shocks to productivity. To start exporting, producers must pay a fixed cost, and to continue exporting producers pay fixed continuation costs. To capture the slow growth of new exporters, we assume that when a producers begins to export it faces a high marginal

[2]In models with CES demand the non-exporter iceberg cost must be infinite to get no exports. In models with non-CES demand lower iceberg costs can drive demand to zero.

cost of shipping their products overseas. With time, as long as the producer maintains its presence in the foreign market by paying the continuation cost, the marginal cost of shipping falls. When a producer stops exporting it loses access to the technology for exporting at a low marginal cost. To regain it, the producer must go through the same costly growth process.

We calibrate our model to the salient producer and exporter dynamics of US establishments. We then use our model to evaluate the effect of an unanticipated cut in tariffs on trade and welfare. Following a cut in tariffs of 10 percent, we find that trade expands gradually with a short-run elasticity that is 1/3 the long-run elasticity. Unlike trade, consumption responds more sharply, and even overshoots the new steady state. Including this transition leads welfare to exceed the change in steady-state consumption by about 216 percent. The overshooting is quite surprising given the trade response and physical capital accumulation. It primarily arises because the tariffs lead to an overaccumulation of establishments in the initial equilibrium relative to the free trade equilibrium. Along the transition, these establishments can be relatively quickly converted into exporters and this frees resources to produce more goods.

Our focus on understanding the aggregate effects of trade barriers in the presence of producer heterogeneity is related to previous work by Bernard, Eaton, Jensen, and Kortum (2003), Alvarez and Lucas (2007), and Alessandria and Choi (2011). Of these, only Alessandria and Choi (2011) explicitly consider the gains when exporting is a dynamic decision. Unlike that paper, we consider the lifecycle of exporting. Drozd and Nosal (2011) and Engel and Wang (2011) also develop general equilibrium models of the short-run and long-run trade elasticity. Drozd and Nosal (2011) emphasize matching frictions between producers and consumers that depend on the accumulation of market specific marketing capital. Engel and Wang (2011) attribute differences in the short-run and long-run trade elasticity to adjustment costs in trade flows. Unlike these two papers, the aggregate sluggishness here is disciplined by observed producer-level sluggishness in trade flows.

We also examine how well models without this endogenous form of sluggishness in producer level export growth compare to the baseline model. Specifically, we consider the welfare gains in a variation of the Krugman (1991) model of trade calibrated to match the long-run

trade response in our dynamic model. We find that the change in steady state consumption in this model is 203 percent of our benchmark model. However, when we include the transition period, and introduce an adjustment cost to match the sluggishness of export growth, we find this model predicts welfare gains that are just 32 percent of our dynamic model (6.4 percent vs 2.0 percent).

The next section develops the model. Section 3 discusses the calibration. Section 4 presents the results. Section 5 presents some sensitivity analysis, and section 6 concludes.

2 Model

We develop a dynamic general equilibrium model that captures both the lifecycle of plants and exporters. We assume there are two symmetric countries, *home* and *foreign,* and that each country is populated by a unit mass of identical, infinitely lived consumers that inelastically supply L units of labor.

In each country, competitive final good producers purchase differentiated intermediate inputs from establishments active in that country. The final good is used for consumption, investment, and as an input into production. There exists a one-period nominal bond denominated in units of the home final good. 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. The home final good is the numeraire so that its price, $P_t = 1$. We focus on a symmetric economy with symmetric policies and thus the foreign price level, $P_t^* = 1$.

Intermediate good producers in each country are characterized by their productivity, fixed export cost, and iceberg trade cost. Productivity is stochastic. Iceberg costs have an endogenous and stochastic element while fixed cost are endogenous. The shocks generate movements of establishments into and out of exporting. Unproductive establishments exit and new establishments enter.

All intermediate good producers sell to their own country, but only some export. Exporting requires some fixed and variable costs. All exporters face the same ad valorem tariff,

τ, but differ in their iceberg transportation cost, ξ,[3] and fixed export costs. The tariff is a policy variable, and the revenues collected from the tariff are rebated lump-sum to the household. The transportation cost is a feature of technology: Fraction ξ of an export shipment is destroyed in transit.

To make the problem most tractable, we assume there are three possible iceberg costs $\xi \in \{\xi_L, \xi_H, \xi_\infty\}$ with $\xi_L \leq \xi_H < \xi_\infty = \infty$ and two possible fixed export costs $f \in \{f_L, f_H\}$, $f_L \leq f_H$.[4] We now explain how the fixed export costs are related to the variable iceberg costs. Producers with an iceberg cost of $\xi = \infty$ are non-exporters. A non-exporter can lower its next-period iceberg cost to ξ_H by paying a cost f_H. An exporter with iceberg costs $\xi_t = \{\xi_L, \xi_H\}$ can incur a cost f_L to draw its next period iceberg cost. We assume the transition probabilities are Markovian and that the probability of drawing the low iceberg costs, ξ_L, is lower for a an exporter with a high iceberg cost than a producer with a low iceberg cost (i.e $\rho_\xi(\xi_L|\xi_H) \leq \rho_\xi(\xi_L|\xi_L)$). If an exporter does not pay f_L, its next period iceberg cost rises to $\xi = \infty$. The fixed export costs f are in units of domestic labor. This formulation of fixed and iceberg costs clearly nests the most common approaches to modeling the export decision. When $f_L < f_H$ there is a sunk cost of exporting. When $f_L = f_H$ and $\xi_L = \xi_H$ exporting is a static decision.

Figure 2a shows that the average export intensity, measured as teh ratio of export revenue to total revenue, will rise with the time since a producer started exporting. Figure 2b shows that the survival rate of exporters into the next period is initially quite low and rises with time. These two figures are consistent with evidence from Ruhl and Willis (2008). Figure 2c shows the ratio of net profits to gross profits of a surviving marginal starter (i.e. producer that does not exit and continues to export). The ratio is low, or negative, initially and rises gradually through time. In the figure, the marginal starter expects to make losses in its first 3 years of exporting as its revenue from exporting is initially low compared to the costs of staying in the market. As time goes on and foreign sales expand, net profits turn positive..

Any potential establishment enters by hiring f_E domestic workers. Entrants produce

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

[4] For notational convenience, we set $f_\infty = 0$.

from the following period on. The measure of country $j \in \{H, F\}$ establishments with technology, z, and iceberg costs, ξ, is $\varphi_{j,t}(z, \xi)$.

2.1 Consumers

Home consumers choose consumption, investment, and bonds to maximize utility subject to the sequence of budget constraints,

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

where $\beta \in (0,1)$ is the subjective time discount factor; 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. Investment is defined as $I_t = K_t - (1-\delta) K_t$.

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

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

where all prices are quoted in units of the home final good.

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

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

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

2.2 Final Good Producers

Final goods are produced by combining home and foreign intermediate goods. The aggregation technology is a CES function

$$(1) \quad D_t = \left\{ \sum_{\xi \in \{\xi_L, \xi_H, \infty\}} \int_z y_{H,t}^d (z,\xi)^{\frac{\theta-1}{\theta}} \varphi_{H,t}(z,\xi)\, dz + \sum_{\xi \in \{\xi_L, \xi_H\}} \int_z y_{F,t}^d (z,\xi)^{\frac{\theta-1}{\theta}} \varphi_{F,t}(z,\xi)\, dz \right\}^{\frac{\theta}{\theta-1}},$$

where $y_{j,t}^d(z,\xi)$ are inputs of intermediate goods purchased from country j intermediate producers. The elasticity of substitution between intermediate goods is $\theta > 1$.

The final goods market is competitive. Given the price of inputs, the final good producer chooses purchases of intermediate inputs, $y_{j,t}^d$, to solve

$$(2) \quad \max \Pi_{F,t} = D_t - \sum_{\xi \in \{\xi_L, \xi_H, \infty\}} \int_z P_{H,t}(z,\xi)\, y_{H,t}^d(z,\xi)\, \varphi_{H,t}(z,\xi)\, dz - (1+\tau) \sum_{\xi \in \{\xi_L, \xi_H\}} \int_z P_{F,t}(z,\xi)\, y_{F,t}^d(z,\xi)\, \varphi_{F,t}(z,\xi)\, dz$$

subject to the production technology (1). Here, $P_{j,t}(z,\xi)$ are the home-country prices of intermediate goods produced in country j establishments. Solving the problem in (2) yields the input demand functions,

$$(3) \quad y_{H,t}^d(z,\xi) = [P_{H,t}(z,\xi)]^{-\theta} D_t,$$

$$(4) \quad y_{F,t}^d(z,\xi) = [(1+\tau) P_{F,t}(z,\xi)]^{-\theta} D_t,$$

where the final good price is defined as

$$(5) \quad P_t = \left\{ \sum_{\xi \in \{\xi_L, \xi_H, \infty\}} \int_z P_{H,t}(z,\xi)^{1-\theta} \varphi_{H,t}(z,\xi)\ dz + \sum_{\xi \in \{\xi_L, \xi_H\}} \int_z [(1+\tau) P_{F,t}(z,\xi)]^{1-\theta} \varphi_{F,t}(z,\xi)\ dz \right\}^{\frac{1}{1-\theta}},$$

2.3 Intermediate Good Producers

An intermediate good producer is described by its technology and iceberg costs, (z, ξ). It produces using capital k, labor l, and materials x according to a Cobb-Douglas production technology,

$$(6) \quad y_t(z,\xi) = e^z \left[k_t(z,\xi)^{\alpha} l_t(z,\xi)^{1-\alpha}\right]^{1-\alpha_x} x(z,\xi)^{\alpha_x}.$$

The markets that the firm serves in the current period are predetermined, so the firm maximizes current-period gross profits by choosing prices for each market, $P_{H,t}(z,\xi)$ and $P^*_{H,t}(z,\xi)$, labor, $l_t(z,\xi)$, capital $k_t(z,\xi)$, and materials $x_t(z,\xi)$, to solve

$$\begin{aligned}(7) \quad \Pi_t(z,\xi) = \max\, & P_{H,t}(z,\xi)\, y_{H,t}(z,\xi) + P^*_{H,t}(z,\xi)\, y^*_{H,t}(z,\xi) \\ & - W_t l_t(z,\xi) - R_t k_t(z,\xi) - P_t x_t(z,\xi)\end{aligned}$$

subject to the production technology (6), a constraint that supplies to home and foreign goods markets, $y_{H,t}(z,\xi)$ and $y^*_{H,t}(z,\xi)$, are feasible

$$y_t(z,\xi) = y_{H,t}(z,\xi) + (1+\xi)\, y^*_{H,t}(z,\xi),$$

and the constraints that supplies to home and foreign goods markets are equal to the demands from final good producers from (3) and its foreign analogue,

$$(8) \quad y_{H,t}(z,\xi) = y^d_{H,t}(z,\xi),$$

$$(9) \quad y^*_{H,t}(z,\xi) = y^{d*}_{H,t}(z,\xi).$$

Given its downward sloping demand curve, the monopolistic producer charges a constant markup over marginal cost in each market,

$$(10) \quad P_{H,t}(z,\xi) = \frac{\theta}{\theta-1} MC_t e^{-z}$$

$$(11) \quad P^*_{H,t}(z,\xi) = \frac{\theta}{\theta-1}(1+\xi)\, MC_t e^{-z},$$

where

$$MC_t = \alpha_x^{-\alpha_x}(1-\alpha_x)^{-(1-\alpha_x)}\left[\left(\frac{R_t}{\alpha}\right)^{\alpha}\left(\frac{W_t}{1-\alpha}\right)^{1-\alpha}\right]^{1-\alpha_x}.$$

The value of the producer with (z,ξ), if it decides to export in period $t+1$, is

$$(12)\quad V_t^1(z,\xi) = \max \Pi_t(z,\xi) - W_t f + n_s(z) Q_t \sum_{\xi' \in \{\xi_L, \xi_H\}} \int_{z'} V_{t+1}(z',\xi') \phi(z'|z) \rho_\xi(\xi'|\xi)\, dz',$$

and the value of the producer if it does not export in period $t+1$ is

$$(13)\quad V_t^0(z,\xi) = \max \Pi_t(z,\xi) + n_s(z) Q_t \int_{z'} V_{t+1}(z',\infty) \phi(z'|z)\, dz',$$

where $n_s(z)$ is the probability that the producer survives until the next period. Note that this probability varies with the productivity of the producer. The value of the producer can be defined as

$$(14)\quad V_t(z,\xi) = \max\left\{V_t^1(z,\xi), V_t^0(z,\xi)\right\}.$$

Clearly the value of a producer depends on its fixed cost, iceberg cost and productivity. Given that there are three possible levels of iceberg costs there are now three possible cutoffs, $z_{m,t}$, with $m \in \{L, H, \infty\}$. The critical level of technology for exporting, $z_{m,t}$ satisfies

$$(15)\quad V_t^1(z_{m,t}, \xi_m) = V_t^0(z_{m,t}, \xi_m).$$

It is straightforward to show that the threshold for exporting is largest for nonexporters and smallest for the low iceberg costs exporters ($z_{\infty,t} > z_{H,t} \geq z_{L,t}$).

2.4 Entry

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

$$V_t^E = -W_t f_E + Q_t \int_{z'} V_{t+1}(z', \infty)\, \phi_E(z')\, dz' \leq 0,$$

The mass of entrants in period t is $N_{E,t}$, while the mass of incumbents is N_t.

$$\begin{aligned} N_{L,t} &= \int_z \varphi_{H,t}(z, \xi_L)\, dz, \\ N_{H,t} &= \int_z \varphi_{H,t}(z, \xi_H)\, dz, \\ N_{\infty,t} &= \int_z \varphi_{H,t}(z, \infty)\, dz. \end{aligned}$$

The mass of exporters equals $N_{1,t} = N_{L,t} + N_{H,t}$, the mass of non-exporters equals $N_{0,t} = N_{\infty,t}$, and the mass of establishments equals $N_t = N_{1,t} + N_{0,t}$. The fixed costs of exporting imply that only a fraction $n_{x,t} = N_{1,t}/N_t$ of home intermediates are available in the foreign country in period t.

Given the critical level of technology for exporters and non-exporters, $z_{m,t}$ the starter ratio, the fraction of establishments that start exporting among non-exporters, and the stopper ratio, the fraction of exporters who stop exporting among surviving establishments, are, respectively

$$(16)\quad n_{0,t+1} = \frac{\int_{z_{\infty,t}}^{\infty} n_s(z)\, \varphi_{H,t}(z, \infty)\, dz}{\int_z n_s(z)\, \varphi_{H,t}(z, \infty)\, dz}, \quad n_{1,t+1} = \frac{\sum_{m \in \{L,H\}} \int_{-\infty}^{z_{m,t}} n_s(z)\, \varphi_{H,t}(z, \xi_m)\, dz}{\sum_{m \in \{L,H\}} \int_z n_s(z)\, \varphi_{H,t}(z, \xi_m)\, dz},$$

and evolutions of the mass of establishments are

$$\begin{aligned}
\varphi_{t+1}(z',\infty) &= \sum_{m\in\{L,H,\infty\}} \int_{-\infty}^{z_{m,t}} n_s(z)\,\varphi_{H,t}(z,\xi_m)\,\phi(z'|z)\,dz + N_{E,t}\phi_E(z'),\\
\varphi_{t+1}(z',\xi_H) &= \sum_{m\in\{L,H,\infty\}} \rho_\xi(\xi_H|\xi_m) \int_{z_{m,t}}^{\infty} n_s(z)\,\varphi_{H,t}(z,\xi_m)\,\phi(z'|z)\,dz,\\
\varphi_{t+1}(z',\xi_L) &= \sum_{m\in\{L,H,\infty\}} \rho_\xi(\xi_L|\xi_m) \int_{z_{m,t}}^{\infty} n_s(z)\,\varphi_{H,t}(z,\xi_m)\,\phi(z'|z)\,dz.
\end{aligned}$$

2.5 Government and aggregate variables

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

$$(17)\quad T_t = \tau \sum_{\xi\in\{\xi_L,\xi_H\}} \int_z P_{F,t}(z,\xi)\,y_{F,t}(z,\xi)\,\varphi_{F,t}(z,\xi)\,dz.$$

Nominal exports and imports equal

$$\begin{aligned}
(18)\quad EX_t^N &= \sum_{\xi\in\{\xi_L,\xi_H\}} \int_z P^*_{H,t}(z,\xi)\,y^*_{H,t}(z,\xi)\,\varphi_{H,t}(z,\xi)\,dz,\\
(19)\quad IM_t^N &= \sum_{\xi\in\{\xi_L,\xi_H\}} \int_z P_{F,t}(z,\xi)\,y_{F,t}(z,\xi)\,\varphi_{F,t}(z,\xi)\,dz,
\end{aligned}$$

respectively. Home nominal GDP is the sum of value added from intermediate and final goods producers, $Y_t^N = P_t D_t + EX_t^N - IM_t^N$. The trade to GDP ratio is $TR_t = \frac{EX_t^N + IM_t^N}{2Y_t^N}$. Let IMD_t be the expenditure on imported goods relative to that on home goods

$$(20)\quad IMD_t = \frac{(1+\tau_t)\sum_{\xi\in\{\xi_L,\xi_H\}}\int_z P_{F,t}(z,\xi)\,y_{F,t}(z,\xi)\,\varphi_{F,t}(z,\xi)\,dz}{\sum_{\xi\in\{\xi_L,\xi_H,\infty\}}\int_z P_{H,t}(z,\xi)\,y_{H,t}(z,\xi)\,\varphi_{H,t}(z,\xi)\,dz}.$$

We define the share of expenditures on domestic goods as

$$(21)\quad \lambda_t = \frac{1}{1+IMD_t},$$

and the trade elasticity as

$$(22)\quad \varepsilon_t = -\frac{\ln\left(IMD_t/IMD_{-1}\right)}{\ln\left(\left(1+\tau_t\right)/\left(1+\tau_{-1}\right)\right)}.$$

Production labor, $L_{P,t}$, equals

$$(23)\quad L_{P,t} = \sum_{\xi\in\{\xi_L,\xi_H,\infty\}} \int_z l_t\left(z,\xi\right)\varphi_{H,t}\left(z,\xi\right)dz.$$

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

$$(24)\quad L_{X,t} = \sum_{m\in\{L,H\}} f_L \int_{z_{m,t}}^{\infty} \varphi_{H,t}\left(z,\xi_m\right)dz + f_H \int_{z_{\infty,t}}^{\infty} \varphi_{H,t}\left(z,\infty\right)dz.$$

From (24), 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

$$(25)\quad \Pi_t = \sum_{\xi\in\{\xi_L,\xi_H,\infty\}} \int_z \Pi_t(z,\xi)\varphi_{H,t}\left(z,\xi\right)dz - W_t L_{X,t} - W_t f_E N_{E,t}.$$

2.6 Equilibrium Definition

In an equilibrium, variables satisfy several resource constraints. The final goods market clearing conditions are $D_t = C_t + I_t + X_t$, and $D_t^* = C_t^* + I_t^* + X_t^*$, where X_t the total material inputs in production given by

$$(26)\quad X_t = \sum_{\xi\in\{\xi_L,\xi_H,\infty\}} \int_z x_t(z,\xi)\varphi_{H,t}\left(z,\xi\right)dz.$$

. Each individual goods market clears; the labor market clearing conditions are $L = L_{P,t} + L_{X,t} + f_E N_t$, and the foreign analogue; the capital market clearing conditions are

$$(27)\quad K_{t-1} = \sum_{\xi\in\{\xi_L,\xi_H,\infty\}} k_t\left(z,\xi\right)\varphi_{H,t}\left(z,\xi\right)dz,$$

and the foreign analogue. The government budget constraint is given by (17) 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, prices, and export decisions for home intermediate producers; allocations, prices and export decisions for foreign intermediate 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^*, 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) intermediated good producers' allocations, prices, and export decisions solve their profit maximization problems; (iv) the entry conditions holds; (v) the market clearing conditions hold; and (vi) the transfers satisfy the government budget constraint.

3 Calibration

In this section we calibrate the model to match some features of the US economy. 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 $N\left(0, \frac{\sigma_\varepsilon^2}{1-\rho^2}\right)$. 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 $\mu_E < 0$ is chosen to match the observation that entrants are smaller than incumbents. Establishments receive an exogenous death shock that depends on an establishment's last period productivity, z, so that the probability of death is $n_d(z) = 1 - n_s(z) = \max\left\{0, \min\left\{\lambda e^{-\lambda e^z} + n_{d0}, 1\right\}\right\}$.

The parameter θ determines both the producer's markup and the elasticity of substitution across varieties. We set $\theta = 5$ to yield a producer markup of 25 percent. We set the tariff rate to 8 percent to include the direct measure of tariffs and half of the non-tariff barriers.

Recall that four parameters determine the dynamics of idiosyncratic transportation costs. The two iceberg costs $\{\xi_H, \xi_L\}$ and the transition probabilities, which we denote $\{\rho_L, \rho_H\}$. For simplicity we assume $\rho_L = 1$. We thus have 3 parameters to determine.

The labor share parameter in production, α, is set to match the labor income to GDP ratio of 66 percent. In the model, α_x determines the ratio of value-added to gross output in manufacturing. In the US this ratio averages 2.8 from 1987 to 1992 and implies that $\alpha_x = 0.810$. Entry cost, f_E, is set to normalize the total mass of establishments, N to 1. The mean establishment size is normalized to the US in 1992.

We have 10 parameters, $\{\lambda, n_d, \rho_z, \sigma_z^2, \mu_E, f_L, f_H, \xi_L, \xi_H, \rho_H\}$, which we choose to match the following observations:

1. Export intensity of 13.3 percent (1992 US Census of Manufactures, CM)
2. Initial export intensity of half of mean export intensity (Ruhl and Willis, 2008)
3. Export intensity in year six twice export intensity in initial year (Ruhl and Willis, 2008)
4. An exporter rate of 22.3 percent (1992 CM).
5. 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.
6. Five-year exit rate of entrants of 37 percent (Dunne, Roberts, and Samuelson 1989).
7. Entrants' labor share of 1.5 percent reported in Davis, Haltiwanger, and Schuh (1998) based on the ASM.

Table 1: Model parameters

Common parameters			
β	σ	δ	τ
0.96	2.0	0.10	0.10
Model parameters			
	Benchmark	Sunk-cost	No-cost
θ	5.00	5.00	13.46
α	0.142	0.142	0.279
α_m	0.810	0.810	0.700
λ	7.305	7.305	7.570
n_{d0}	0.022	0.022	0.022
ρ	0.656	0.656	0.688
σ_ε	0.331	0.331	0.105
μ_E	-0.349	-0.349	-0.117
f_E	6.393	6.497	2.531
f_H	0.195	0.374	0.000
f_L	0.179	0.100	0.000
ξ_H	0.718	0.430	0.096
ξ_L	0.084	0.430	0.096
ρ_H	0.952	1.000	1.000
ρ_L	1.000	–	–

8. Shut down establishments' labor share of 2.3 percent (Davis, Haltiwanger, and Schuh 1998).

9. Establishment employment size distribution as in the 1992 CM.

The first three targets summarize the dynamics of export intensity and determine the technology for shipping ($\xi_L, \xi_H\, \rho_H$). The next two targets relate exporters to the population of establishments and largely determine (f_L, f_H). The next three targets help to pin down the establishment creation, destruction, and growth process ($\rho, \sigma_z, \lambda, \mu_E, n_d$). Newborn establishments and dying establishments tend to have few employees. Moreover, newborns have high failure rates. Finally, we try to minimize the distance between the model and empirical distribution of US establishments.

Our calibration provides an estimate of the technology of exporting. We find that the cost of starting to export is only about 10 percent larger than the cost of continuing to export (0.195 vs 0.179). We also find that the high iceberg cost ($1+\xi_H$) is about 63 percent larger than the low cost ($1+\xi_L$) (1.718 vs 1.084). We also find that the high iceberg cost is

quite persistent as $\rho_H = 0.952$. If we eliminate the variance in iceberg costs, $\xi_L = \xi_H$, then we are back to the traditional sunk cost model of (Das, Roberts, and Tybout 2007) studied by Alessandria and Choi (2011). In this case, we would find a the cost of starting to export is 3.74 times the cost of continuing and that the iceberg cost is 1.43. In the sunk cost model an important reason exporters stay in the market is to avoid paying the large upfront cost of re-entering. In our benchmark model, exporters stay in the market to maintain access to the good technology for exporting.

4 Results

We now consider the impact of a change in tariffs on the dynamics of trade and welfare. In particular, we consider an unanticipated elimination of the 10 percent tariff. Table 2 reports the change in welfare and trade. Figure 3 plots the dynamics of some key variables. Trade expands substantially, from about 8.8 percent of manufacturing shipments to 24.1 percent. This expansion takes time as the trade elasticity grows slowly. In the first year, the intensive margin operates so that the trade elasticity is equal to $\theta - 1$. With time as more exporters enter and mature, export shipments expand. Ten years after the policy change the endogenous part of the trade elasticity has only increased by 69 percent of its long run change. Thus trade is quite sluggish.

One way of measuring the sluggishness in trade is to measure the discounted average trade elasticity as

$$\bar{\varepsilon}_t = (1 - \beta) \sum_{t=0}^{\infty} \beta^t \varepsilon_t.$$

In our model the short-run elasticity is 4, the discounted trade elasticity is 10.3, and the long-run is 12.5.

This sluggish trade growth does not lead to very sluggish growth in consumption or output (see Figure 3). Consumption and output jump initially. Consumption has a hump shape, peaking 7 years after the policy change and 7.1 percentage points above the long-run change. Investment initially falls and then recovers strongly as the economy uses capital to smooth

Table 2: Effect of a cut in tariffs of 8 percentage points

Change	**Benchmark**	**Sunk-cost**	**No-cost**
Welfare gain	6.42	4.94	2.04
Discounted trade elasticity	10.34	7.03	10.36
Consumption	2.03	2.22	4.13
Trade elasticity	12.46	7.42	12.46

Note: Welfare gain is value of x that satisfies $\sum_{t=0}^{\infty}\beta^t U\left(C_{-1}e^x\right) = \sum_{t=0}^{\infty}\beta^t U\left(C_t\right)$, where C_{-1} is the consumption level in the initial steady state. The discounted trade elasticity is $\bar{\varepsilon} = \sum_{t=0}^{\infty}\beta^t\varepsilon_t$, where ε_t is the trade elasticity based on difference in trade between period t and the initial steady state. The longrun trade elasticity is $\lim_{t\to\infty}\varepsilon_t$.

out the benefits of the policy. Capital dynamics imply that output expands a bit more strongly than consumption. The number of establishments falls gradually to the new steady state. The desire to reduce the number of establishments following the policy change is key to the overshooting behavior in the model since it implies that more resources are available for production along the transition. The gradualness in the decline in establishments arises in large part to the adjustment costs we have included in entry costs.

5 Sensitivity

To evaluate the importance of matching micro dynamics of exporting we consider two variations of our benchmark economy. First, to examine the impact of producer level sluggishness for the results of trade reform, we eliminate the sluggishness in producer level export growth. This is a variation of the sunk cost model of Das, Roberts, and Tybout (2007). Next, we examine how well the results in our model are approximated by a model without an export decision that is calibrated to get the same aggregate export growth along the transition and in the new steady state. This allows us to explore how well the results from Arkolakis, Costinot, and Rodríguez-Clare (2012) extend to the dynamic environment we consider.

5.1 No Exporter Growth

We examine how important matching the slow export growth of producers is for the welfare and trade response to changes in trade barriers. In this case, we set $\xi_L = \xi_H = \xi$ so that intensity with which a producer exports does not change as long as it exports. New exporters

look just like old exporters in this model. This version of the model is recalibrated to match similar features of exporting and trade. The parameters are summarized in Table 1.

Table 2 summarizes the effect of abstracting from export intensity dynamics on aggregate outcomes. Figure 4 to 6 plots the transition to the new steady state.

The sunk cost model generates a smaller long-run expansion of trade than in our benchmark model. The trade elasticity is about 59 percent of the benchmark model (7.4 vs 12.5). The transition though is relatively faster as the discounted trade elasticity is about 68 percent of the benchmark model (7.0 vs 10.3). The sunk cost model generates a slightly larger change in steady state consumption than our benchmark model (2.2 vs 2.0) but a smaller welfare gain (4.9 percent vs 6.4). The benchmark model generates a larger welfare gain because overshooting is stronger in that model even as trade grows more slowly.

5.2 No Exporting Decision

We now consider a version of the model in which all establishments export from birth for free (i.e. there are no fixed export costs). To generate a sluggish trade elasticity as in our benchmark model we introduce an adjustment cost into the aggregation of intermediates by final good producers. Specifically, we use the following aggregator

$$D_t = \left[\int_z y_{H,t}^d(z)^{\frac{\theta-1}{\theta}}\varphi_t(z)\,dz + g_t\int_z y_{F,t}^d(z)^{\frac{\theta-1}{\theta}}\varphi_t^*(z)\,dz\right]^{\frac{\theta}{\theta-1}}, \tag{28}$$

$$g_t = g_{t-1}^{\rho_g}\left[\left(\frac{\lambda_t}{\lambda_{t-1}}\right)^{\upsilon}\right]^{1-\rho_g}, \tag{29}$$

where λ_t is the home intermediate goods' expenditure share. With $\upsilon > 0$, the term g_t implies that an increase in the import share will lower the weight on imports in the aggregator. This demand shifter is assumed to depend on aggregate imports and is external to the firm. It is a form of habit that only affects the transition and not the steady state. We set υ and ρ_g to minimizes the gap between the trade elasticity in benchmark model and this model which we call the No-Cost model

$$\left\{\upsilon^*,\rho_g^*\right\} = \arg\min_{\left\{\upsilon,\rho_g\right\}}\left\{\sum_{t=0}^{\infty}\left[\beta^t\left(\varepsilon_{\text{Benchmark},t}-\varepsilon_{\text{Nocost},t}\right)\right]^2\right\}. \tag{30}$$

This gives $\upsilon = 2.73$ and $\rho_g = 0.53$. Figure 5 plots the trade elasticity in the No-cost model.

To get this model to match the long-run trade elasticity we must increase the elasticity of substitution, θ, from 5 to 13.46. This lowers markups from 25 percent to about 8 percent. To maintain the same macro targets about labor share and materials usage, we thus need to adjust α_x, α accordingly. The capital share is roughly doubled from 14 percent to 28 percent and the material usage is lowered from 80 percent to 70 percent. The parameters are reported in Table 1. The column No-Cost in Table 2 summarizes the aggregate effects of the cut in tariffs considered in this alternative model and Figure 4 plots some aspects of the transition.

The key thing to focus on is the change in welfare. Just considering steady state changes in consumption, we find the gain is about 2.1 percentage points lower in our model of sluggish export growth (4.13 vs 2.03). Including the transition, we find the gains are 4.4 percentage points larger in the benchmark model (2.04 vs 6.42). This large gap in welfare occurs because consumption in our benchmark model overshoots the new steady state, while in the other model consumption grows quite gradually. This gradual consumption growth occurs because the economy deccumulates establishments only temporarily with much smaller magnitudes, and capital and trade grows gradually due to the adjustment cost in preferences. This suggests that focusing on the relationship between the trade elasticity and welfare is not sufficient to estimate the gains from trade.

6 Conclusions

We develop a model consistent with the evidence that trade is sluggish at the producer and aggregate levels. In our theory, it takes time and resources to lower the marginal cost of exporting. This implies that the distribution of iceberg costs is endogenous and reflects the investment decisions of producers. We estimate the effect of a cut in tariffs on trade and the gains from trade in a GE variation of our theory. Surprisingly, while we find that trade grows sluggishly we also find the benefits are more immediate. Including these transition periods boosts the welfare gain to changes from trade policy relative to the changes in steady state allocations by more than 3 times. Models without this dynamic export decision severely

underestimate the gains to removing trade barriers, particularly when constrained to also match the sluggishness in trade expansion.

We have developed a particular model of producer level sluggishness that is based on the technology for shipping being endogenous. This is a more general version of the standard fixed-variable cost tradeoff that the literature has emphasized. Other forms of sluggishness, such as building distribution networks or brand loyalty, are likely to be important. However, we suspect that these alternative explanations for sluggishness may generate similar micro and macro dynamics.

Finally, in our analysis the gap between the short-run and long-run aggregate trade elasticity is disciplined by evidence on producer level export dynamics. The dynamics of the aggregate trade elasticity following a trade reform is also likely to depend on general equilibrium considerations as the infrastructure for trade such as customs, ports, pipelines, and railroads, must be expanded to accommodate the increased flow of goods.

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Figure 1: Export Intensity Colombian Exporters

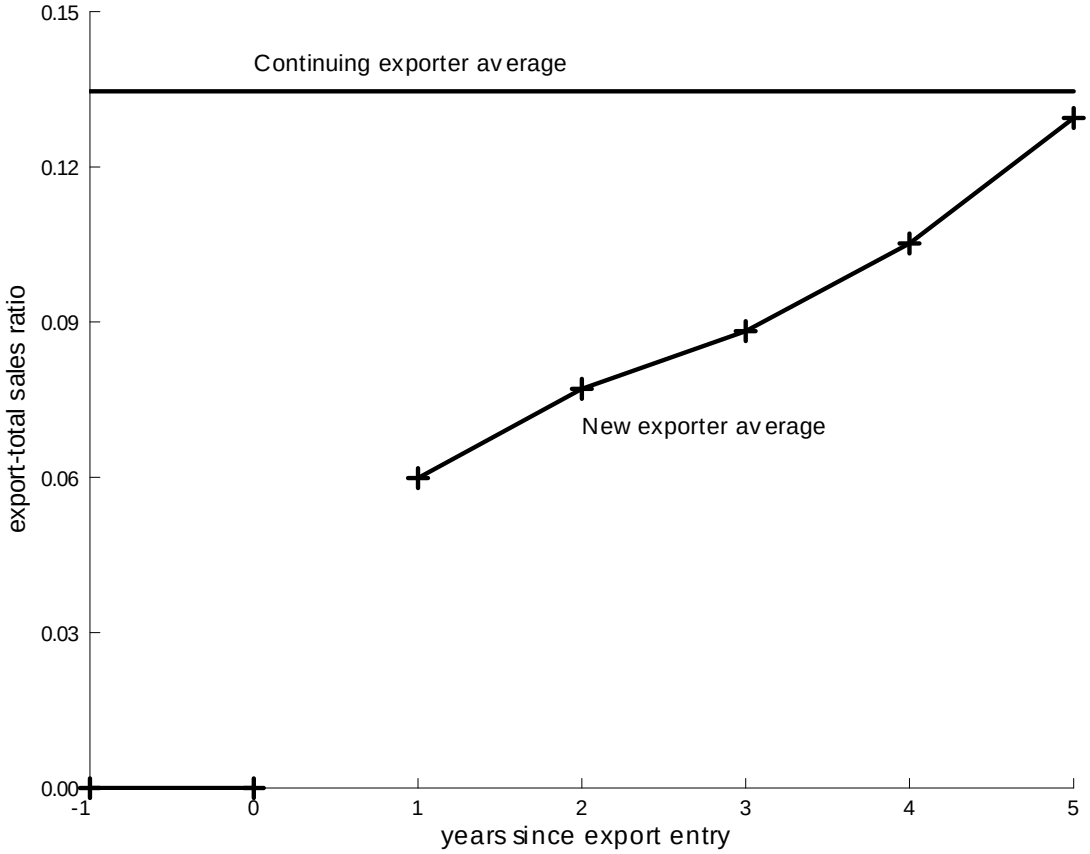


Figure 2a: Export Intensity and Duration

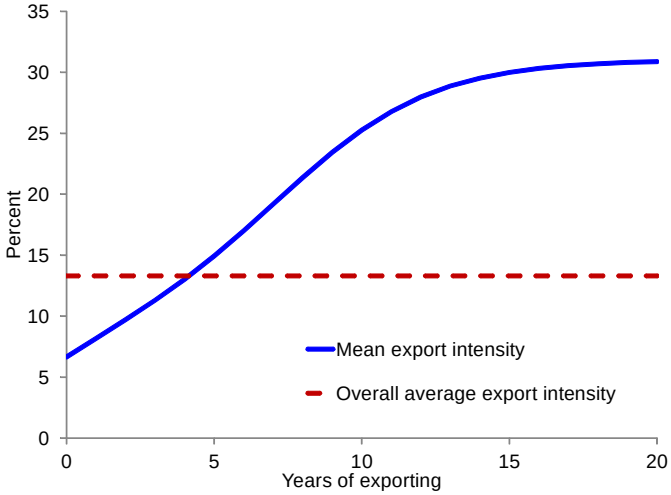


Figure 2b: Survival rate (1 year) and Duration

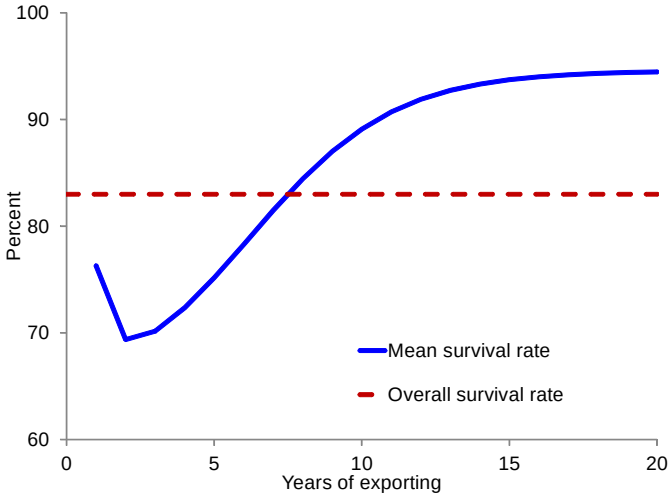


Figure 2c: Profits (net/gross) of Marginal Starters

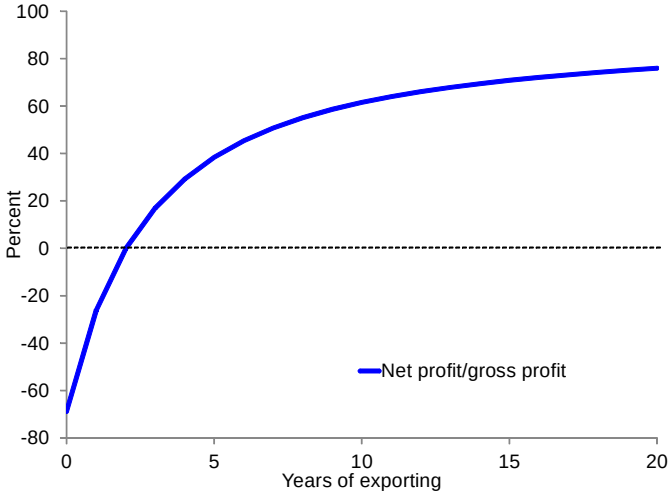
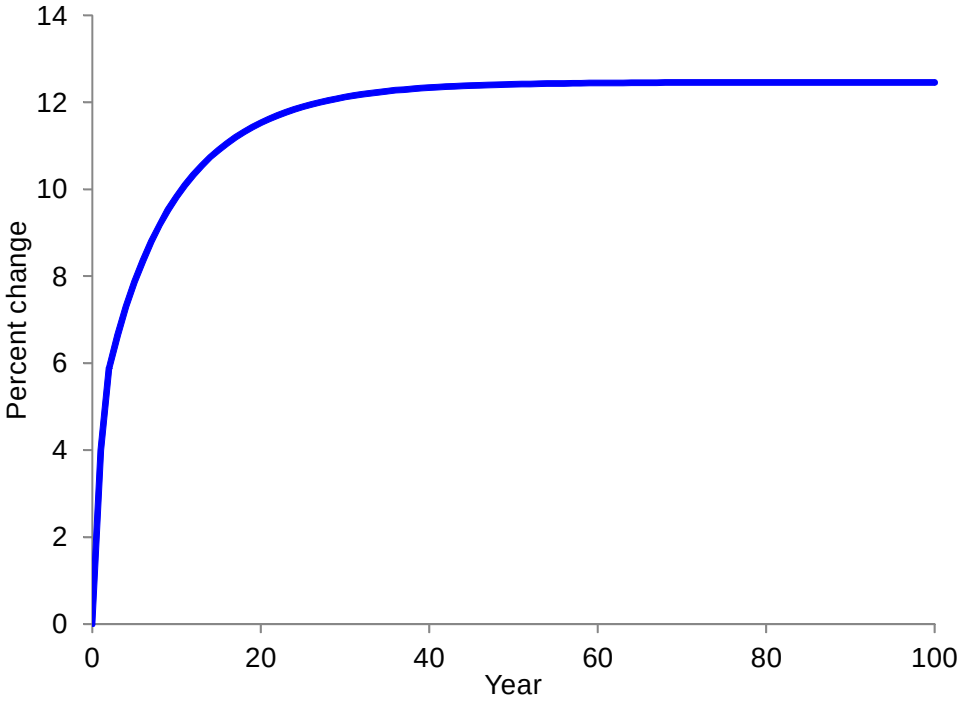


Figure 3: Dynamics following Elimination of 10 percent Tariff

(a) Trade Elasticity



(b) Aggregate Dynamcis

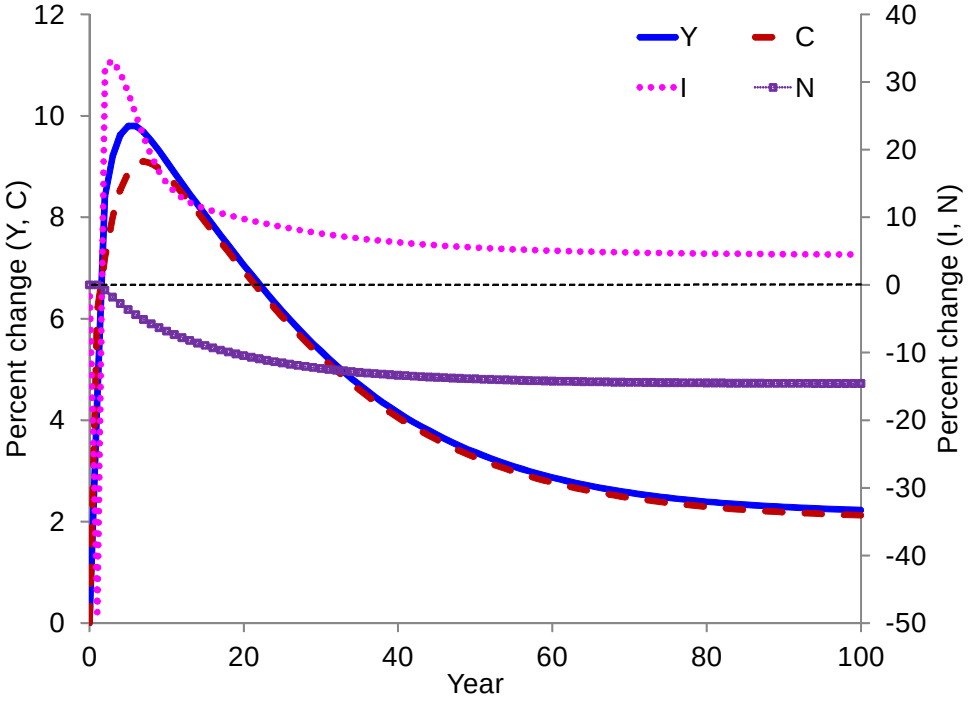


Figure 4: Consumption Dynamics following Elimination of 10 percent Tariff

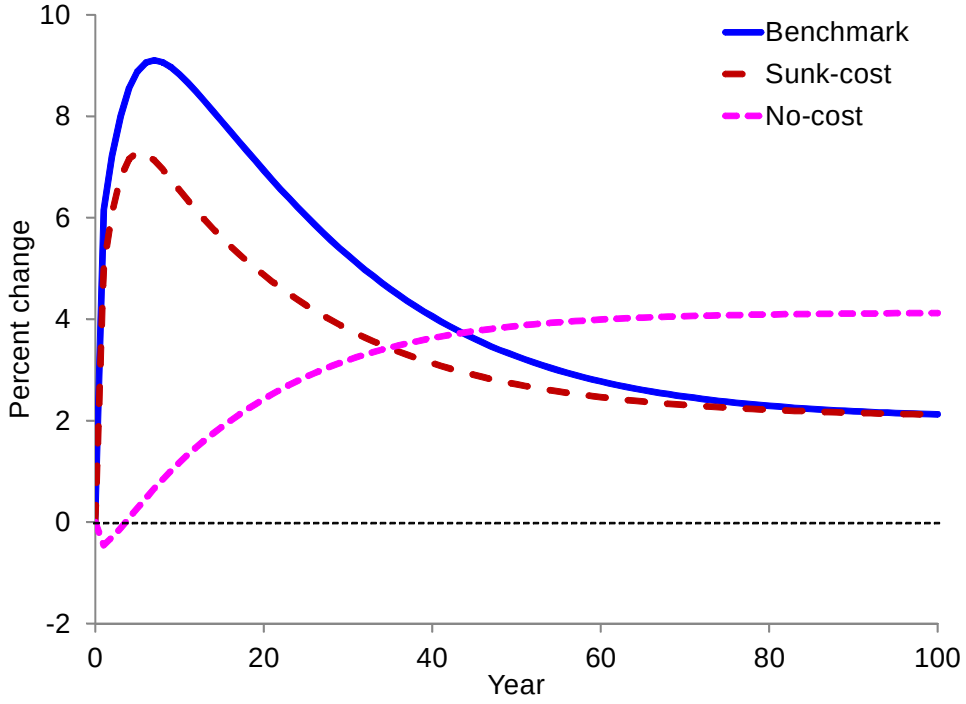


Figure 5: Trade Elasticity Dynamics following Elimination of 10 percent Tariff

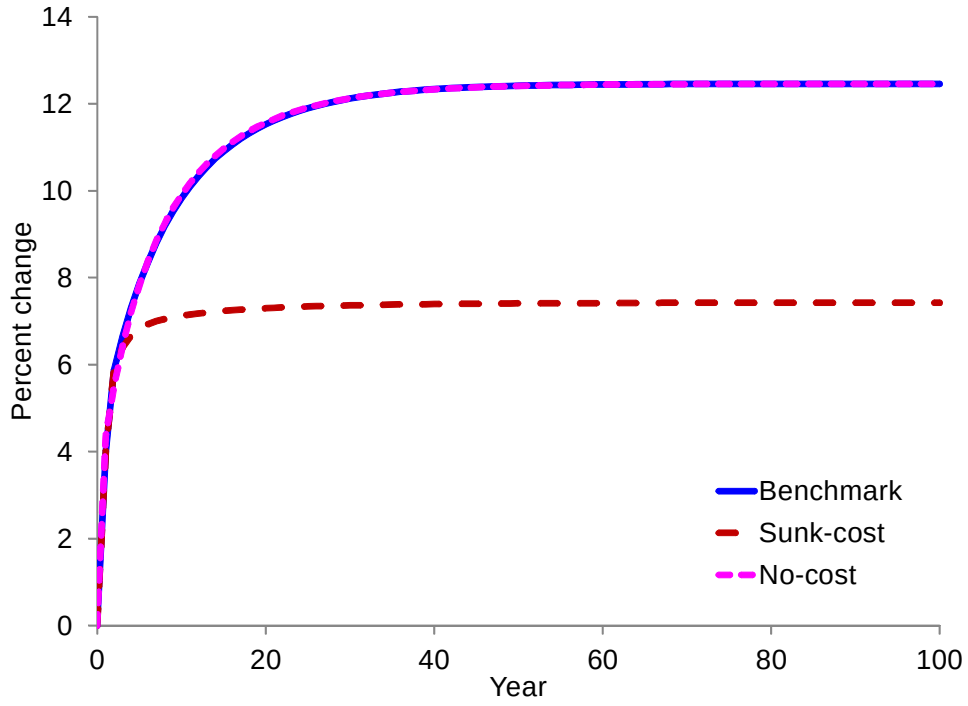


Figure 6: Mass of Establishments Dynamics following Elimination of 10 percent Tariff

