Export Dynamics with Product Proximity *

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Abstract

Exporters make strategic decisions about which products to export together. Chinese customs data reveal that multiproduct exporters maintain persistent export status while strategically adding products that are close to their existing portfolios. We develop a dynamic general equilibrium model with firm and product heterogeneity in which firms benefit from reduced export costs when adding products in close proximity to their current export portfolio. This firm-level margin of adjustment magnifies the effects of tariff changes by reshaping product scope. As a result, trade policies that target only a narrow set of goods can have larger welfare consequences through spillovers across products.
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1 Introduction

While multiproduct firms play a dominant role in trade and regularly adjust their export portfolios, the impact of product proximity – the empirical tendency for certain products to be exported together – on these decisions and their broader trade implications remains largely unexplored. In this paper, we investigate the role of product proximity in shaping firms' export decisions through its effect on export costs. Specifically, we ask: how does proximity between products influence firms' export portfolio choices, and what are the implications for aggregate trade patterns and welfare?

Empirical evidence from Chinese customs data reveals two key patterns in firms' export behavior. First, a transition matrix of export status and survival rate analysis show that multiproduct firms exhibit strong export persistence, consistent with the literature on sunk costs (Roberts and Tybout (1997), Das et al. (2007)). Second, firms strategically expand their export portfolios by introducing products that are proximate to their existing offerings.[1] To quantify this, we develop a *Product Export Proximity Index* (PEPI) based on firm-product transaction data, measuring how often two products are exported together. A 0.1 point increase in PEPI for a potential export product raises the likelihood of its introduction by 20–30%, highlighting the role of product proximity in shaping firms' export decisions.

Motivated by these empirical findings, we develop a dynamic general equilibrium model with product and firm heterogeneity to capture the role of product proximity in shaping export dynamics and assess its welfare implications under trade policy changes. In our model, product proximity influences export decisions by reducing export costs for firms introducing related products. Simulations reveal that incorporating product proximity amplifies welfare gains from trade, as firms respond by introducing more products into export markets.

A key feature of our model is the role of product portfolio-dependent fixed and sunk

[1] Here, *proximity* does not refer to substitutability or complementarity in a demand system. Rather, it refers to the empirical tendency of products to be exported together. As we will show, proximity is not fully explained by product similarity based on HS codes.

export costs.[2] When a firm exports a new product, proximity to its existing export portfolio lowers the overall fixed export costs compared to introducing a distant product, making it more cost-effective to expand the product mix. In reality, such proximity effects may arise from shared distribution networks, marketing channels, or customer relationships across products. For tractability, we model product proximity in an abstract fashion, using the distance between products based on their relative preferences, where higher proximity lowers the marginal cost of introducing a new product. In our calibrated model, we find that, in some cases, firms can reduce their total export costs by up to 41% (measured as a share of profits) when introducing proximate products rather than distant ones.

Next, we examine how product proximity interacts with aggregate variables and welfare changes from tariff changes. We study various versions of tariff reductions and increases. First, due to product heterogeneity, we compare two trade liberalization scenarios in our quantitative analysis: a unilateral tariff reduction across all products and a more limited tariff reduction that maintains higher protection on highly preferred products. While both scenarios lead to welfare gains, the increase in welfare under the more limited tariff reduction is only 62% of that achieved with full liberalization. This result is notable because, despite constituting only 20% of total goods in our simulations, highly preferred products have a disproportionate impact on aggregate welfare.[3] As a result, maintaining higher protection on these products significantly dampens the overall benefits of trade liberalization, highlighting their outsized role in shaping trade policy outcomes. Furthermore, when we modify our fixed cost structure to eliminate cost reductions from product proximity, welfare gains decrease by up to 15%. This finding indicates that product proximity amplifies the aggregate effects of trade liberalization through lowered export costs and greater product expansion.

We also study an alternative policy where both countries raise tariffs. Our analysis

[2]We estimate key model parameters, particularly those related to export costs, by matching seven moments from transaction-level and manufacturing data: the productivity gap between incumbents and entrants, industry survival rates, product turnover rates, exporter share, long-run exporter survival, and the prevalence of single-product firms.

[3]In our model, product characteristics follow a Pareto distribution, where a small fraction of highly preferred goods accounts for a large share of consumption.

shows that the structure of trade barriers affects welfare outcomes. Specifically, targeted trade barriers (high barriers on select products with minimal barriers on others) produce larger welfare declines than a flat tariff structure (moderate barriers applied uniformly across products). This difference occurs because targeted barriers trigger product-level interactions that amplify aggregate economic effects. Our findings suggest that policymakers could mitigate economic damages by implementing moderate barriers across all products rather than imposing severe barriers on specific targeted products.

Our paper relates to several strands of the literature. First, it builds on research examining the role of sunk and fixed costs in shaping export dynamics. A well-established body of work finds that firms face significant sunk costs when entering export markets, leading to persistence in export participation (Roberts and Tybout (1997), Das et al. (2007)). Beyond entry costs, firms also incur fixed export costs that influence their product scope. Several studies suggest that these fixed costs may be linked to product relationships within the firm's portfolio. Baldwin and Harrigan (2011) and Freund and Pierola (2015) provide empirical evidence that firms bundle related products to minimize export costs, while Nocke and Yeaple (2014) develop a theoretical framework demonstrating that such relationships reduce the marginal cost of adding new products. Eslava et al. (2004) further show that firms restructure by shifting into product spaces with shared operational efficiencies. Arkolakis et al. (2021) develop a general equilibrium model in which economies of scope in market access costs reduce firms' export entry costs as they expand their product range. Their findings suggest that firms face increasing costs when exporting products further from their core competencies. Alessandria et al. (2021) study export dynamics in a dynamic general equilibrium setting. Our paper contributes to this literature by introducing a general equilibrium model that explicitly incorporates product proximity into firms' export decisions. While prior studies highlight the importance of relatedness in shaping export behavior, they do not examine how product proximity interacts with trade policy. We show that product proximity not only lowers export costs but also shapes firms' strategic responses to trade liberalization, influencing whether firms expand or contract their product range in response to tariff changes.

Second, our paper contributes to the literature on entry decisions and firm expansion strategies. A growing body of work highlights how firms expand sequentially across markets and products. Albornoz et al. (2012, 2023) show that firms enter export markets and expand their product scope sequentially, testing destinations and products gradually rather than entering all at once. Ruhl and Willis (2017) similarly find that new exporters exhibit high volatility, experiencing elevated exit rates but also rapid growth if they survive. Morales et al. (2019) and Alfaro-Urena et al. (2024) further demonstrate that exporting to one destination facilitates entry into others, particularly when markets share institutional or geographical similarities. Hoang (2022) highlights the role of global sourcing in firm expansion strategies. Our paper differs by focusing on firm expansion along the product dimension within a given market. We show that firms strategically expand their product range based on the proximity of new products to their existing portfolio, rather than introducing new products randomly.

Finally, our study contributes to research on how firms adjust their product portfolios in response to trade shocks. Bernard et al. (2011), Qiu and Zhou (2013), and Lopresti (2016) show that trade liberalization leads to significant adjustments in firms' product scope. In their frameworks, more productive or export-oriented firms tend to expand their product portfolios, while others reduce their product range. Goldberg et al. (2010) show that trade liberalization increases product switching among multiproduct firms, while theoretical work by Eckel and Neary (2009) explains these patterns through a flexible manufacturing framework. Our paper extends this literature by demonstrating that firms' responses to trade liberalization depend on how trade policy is structured. Specifically, in a general equilibrium setting, we show that under unilateral tariff reductions, firms tend to expand their product range, whereas when tariff reductions are not uniform across products, aggregate product portfolios tend to contract as firms drop products with higher trade costs and lower proximity to their existing exports.

The remainder of the paper is organized as follows. In Section 2, we provide a detailed description of the data and present some stylized facts derived from the analysis. Section 3 develops an extended sunk cost model accounting for multiproduct firms, which serves as the theoretical foundation for our analysis. Section 4 outlines the calibration of our model, and Section 5 presents results related to firm-level decisions and dynamics. In Section 6, we examine the aggregate impacts of trade liberalization with product proximity. Finally, Section 7 concludes the paper.

2 Data

In Section 2.1, we outline the data sources and provide summary statistics. In Section 2.2, we present the empirical motivations behind firm export choices, which serve as the foundation for our theoretical model.

2.1 Sources and Summary Statistics

We utilize Chinese Customs data to analyze firm-level export behavior between 2000 and 2006, with a focus on the exporting dynamics of multiproduct firms. This dataset provides detailed transaction-level information, including destination markets, corresponding HS codes, quantities, values, and firm characteristics such as names, ownership types, addresses, and cities, all at the monthly level.

In this paper, we investigate product proximity in exporters' behavior within specific markets. To achieve this, we distinguish between multiproduct producing firms (MPPF) and multiproduct exporting firms (MPEF) to analyze exporting dynamics at the market level. A multiproduct exporting firm is defined as a firm that exports more than one product to a given importing market. In contrast, a firm may produce multiple products but not export more than one of them to a particular market, thereby being classified as an MPPF but not an MPEF for that market. Furthermore, a firm can be an MPEF in one market while not qualifying as an MPEF in another. This market-level distinction is essential for understanding the role of product proximity in shaping firms' export behavior across destination markets.

The prevalence and significance of multiproduct firms in international trade have been extensively documented in the literature. Table 1 presents the share of multiproduct exporting firms across major destination markets, based on Chinese customs data. The data confirm the dominant role of multiproduct exporters in Chinese trade, consistent with previous findings. In all top five markets, multiproduct firms account for about 90% of total export value in the data. The large shares of multiproduct firms are consistent across other criteria. For example, in the US market, which is the focus of our paper, multiproduct firms represented 61% of the total number of exporting firms, accounted for 89% of export value, and 78% of export quantities.

Building on this, our empirical analysis examines two key dimensions of export behavior at the market level: (1) the persistence of firms' export status over time and (2) the role of product proximity in shaping export decisions. These findings provide the empirical foundation for our theoretical model, which captures the dynamic and interdependent nature of firms' export portfolio decisions within a given destination market.

Table 1: Shares of Multiproduct Exporting Firms

Market	Firms	Transactions	Value	Quantity
USA	61.0	93.9	89.4	78.3
HKG	60.5	95.9	86.4	72.2
JPN	61.6	93.7	90.2	83.7
KOR	53.1	88.4	77.9	71.7
DEU	52.9	89.3	83.6	81.2

Note: This table shows yearly average of the percentage share of multiproduct exporting firms in terms of the number of firms, transactions, trade value, and quantity for the top five importing markets from 2000 to 2006 using Chinese customs data.

To focus our analysis, we examine Chinese exporters to specific markets, such as the U.S. market. The resulting dataset includes 117,446 firms, representing approximately half of the total Chinese exporters recorded in the dataset and accounting for about 21% of the total export value. Among these exporters, more than 61% exported more than one HS6 product to the U.S. market, accounting for roughly 89% of the export value.[4] The top

[4]The top 10 exporting destination average for multiproduct exporting firms is approximately 54.2%, and they account for 71.1% of total trade value. If we extend the market to global market, then the multiproduct firm shares are 73.7% and they account for 93.5% of the trade value.

exported products were concentrated in Chapters 84 and 85 of the Harmonized System, which cover machinery and electro-mechanical appliances.

In addition, we utilize Chinese manufacturing data collected by the National Bureau of Statistics (NBS) of China from 2000 to 2007 to inform the calibration of key model moments. Specifically, we extract firm-level productivity and industry dynamics from the manufacturing data and incorporate them as externally calibrated parameters. A detailed explanation of the manufacturing dataset and the estimation of the production function is provided in the Appendix.

2.2 Empirical Motivations

We begin by analyzing the persistence of firms' export status, tracking transitions between non-exporters, single-product exporters, and multiproduct exporters. Additionally, we estimate conditional survival probabilities using probit and logit models, providing evidence of the stability of firms' exporting behavior over time. We then shift our focus to firms' product-level export decisions, examining how the proximity between a potential new product and a firm's existing export portfolio affects the likelihood of introducing that product in a given market.

2.2.1 Persistence of Exporting Behavior

The export status of firms within a specific market exhibits significant persistence, consistent with the findings in the export sunk cost literature (e.g., Roberts and Tybout (1997); Das et al. (2007)). This persistence reflects the substantial costs firms incur when entering international markets, such as setting up distribution networks, complying with foreign regulations, and adapting products to meet local demand. Once these entry costs are incurred, they create a high barrier to exit, leading to sustained export activity over time.

To document this persistence, we analyze the probabilities of firms remaining in each export status — non-exporter, single-product exporter, or multiproduct exporter —

between 2000 and 2001. Figure 1 illustrates the transition matrix for Chinese exporters to the US market during this period. The left panel presents a simplified transition matrix, depicting transitions between non-exporters and exporters, while the right panel provides a more detailed breakdown, including transitions between non-exporters, single-product exporters, and multiproduct exporters. These matrices reveal a clear pattern of stability, with non-exporters exhibiting the highest probability of remaining in the same status, followed by multiproduct exporters. Single-product exporters also demonstrate notable persistence, though some transition to multiproduct exporters or revert to non-exporter status.

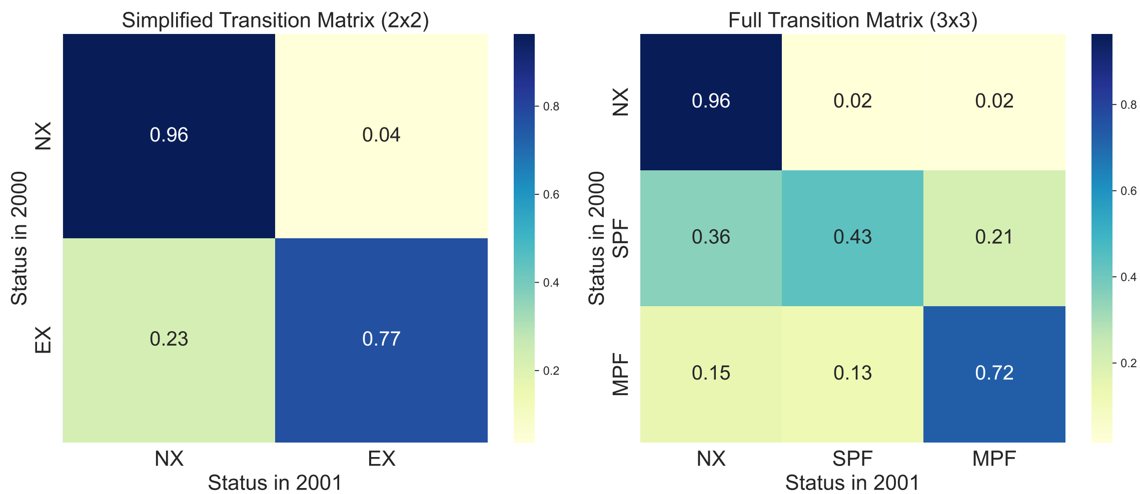


Figure 1: Transition matrix for Chinese exporters to the U.S. market from 2000 to 2001

To further validate the persistence of export status, a conditional survival probability analysis was performed using logit and probit regression models. These models examine how a firm's prior export status and other export-related characteristics influence the likelihood of maintaining or changing its export status. Specifically, we focus on firms known to be active in international markets and analyze their exporting behavior to the United States. The results reveal consistently high coefficients, documenting the strong persistence in firms' export status over time.[5] Specifically, on

[5]The regression equation for the logit and probit models is specified as follows:

$$\Pr(\text{ExportStatus}_{it} = 1) = F\big(\alpha_0 + \alpha_1 \text{ExportStatus}_{i,t-1} + \mathbf{X}_{it}\boldsymbol{\beta} + \varepsilon_{it}\big), \tag{1}$$

where $F(\cdot)$ is the cumulative distribution function corresponding to either the logit or probit model, average, the conditional survival probability, which measures the likelihood of a firm maintaining its export status, is approximately 87.47% for the logit model and 87.95% for the probit model. Export behavior remains stable across years, reinforcing the transition matrix analysis. The findings highlight how past investments in market entry influence firms' long-term export decisions and contribute to our theoretical model on dynamic export portfolio choices.

2.2.2 Product Proximity in Firms' Export Portfolios

In this section, we examine how firms expand their export product portfolios by leveraging the proximity between potential new products and their existing export mix. To do so, we develop a firm-level Product Export Proximity Index ($PEPI$) for each product and analyze its role in shaping firms' decisions to introduce new products into their export portfolios. This framework allows us to quantitatively assess the extent to which a firm's current export activities influence its product expansion strategies.

Our focus on product proximity within firms' export portfolios at the product level aligns conceptually with the findings of Alfaro-Urena et al. (2024), who study export complementarities across destination markets. While Alfaro-Urena et al. (2024) document how firms enjoy cost reductions when exporting to geographically or linguistically similar markets, or to those sharing deep trade agreements, we shift the lens to examine another dimension of exporting firms' decisions: the proximity between products within a single market.

To measure product proximity, we adopt an outcome-based approach originally developed by Hidalgo et al. (2007), but compute it at the firm level. This methodology identifies proximity between products based on observed patterns in firms' export behavior rather than relying on predetermined industrial or technological classifications. The measurement strategy involves three key steps.[6]

ExportStatus_{it} is a binary indicator of whether firm i is exporting to the U.S. in year t, and $\text{ExportStatus}_{i,t-1}$ captures the firm's export status in the previous year. The vector $\mathbf{X}_{it}$ includes standardized covariates: the number of markets served, the number of products exported, the export value and quantity to the global market, and the export value and quantity to the US market.

[6] In the empirical analysis, the calculations are conducted at the destination market level. However, for

First, we calculate the *revealed comparative advantage* (RCA_{fpt}) for each firm-product pair in each year. Following Balassa and Noland (1989), RCA_{fpt} for firm f and product p at year t is defined as the ratio of two proportions: the share of product p in firm f's exports relative to the product's share in total exports. This is formally expressed as:

$$RCA_{fpt} = \frac{X_{fpt}/X_{ft}}{X_{pt}/X_t} = \frac{\text{Firm's share of product } p \text{ exports}}{\text{Overall share of product } p \text{ exports}}, \tag{2}$$

where X_{fpt} represents firm f's export value of product p in year t, X_{ft} is firm f's total exports in year t, X_{pt} is the aggregate export value of product p across all firms in year t, and X_t denotes total exports across all products in year t. This measure quantifies a firm's relative specialization in exporting a product by comparing the firm's export intensity for the product to the product's overall export intensity in the market. A higher RCA_{fpt} indicates that the firm demonstrates a comparative advantage in exporting the product p relative to the broader market.

Second, we construct a product proximity matrix that captures the similarities between products based on co-export patterns across all firms. For each pair of products i and j, we calculate the conditional probability of having a revealed comparative advantage in one product given a revealed comparative advantage in the other. The proximity measure ϕ_{ijt} is defined as the minimum of these conditional probabilities:

$$\phi_{ijt} = \min\{\mathbb{P}(RCA_{it} > 1 | RCA_{jt} > 1), \mathbb{P}(RCA_{jt} > 1 | RCA_{it} > 1)\}. \tag{3}$$

The probabilities in the proximity matrix are calculated empirically. Specifically, $\mathbb{P}(RCA_{it} > 1)$ is computed as the fraction of firms that have a revealed comparative advantage in product i in year t relative to the total number of firms. Similarly, the joint probability $\mathbb{P}(RCA_{it} > 1 \text{ and } RCA_{jt} > 1)$ is calculated as the fraction of firms that have a revealed comparative advantage in both products i and j simultaneously. From these probabilities, we compute the conditional probabilities in the proximity measure. Taking the minimum ensures that the measure is symmetric and robust to differences in the overall prevalence of comparative advantage across products.

simplicity, we omit the destination market subscript d throughout the paper.

The resulting Φ matrix is universal, not firm-specific, and represents the proximity of products in a given year based on their co-export patterns across all firms. This matrix is a $J \times J$ matrix, where J is the number of unique products in the dataset for year t. Due to the nature of the data, the Φ matrix is very sparse, as most product pairs are unlikely to have significant co-export relationships. The intuition behind the proximity measure is that products frequently co-exported by the same firms are likely to share similar production requirements, supply chain linkages, or demand characteristics. By focusing on firms with revealed comparative advantages in these products, the measure captures the underlying proximity driving these co-export patterns.

Finally, we develop a firm-specific Product Export Proximity Index ($PEPI_{fpt}$) to measure how well a potential new product p aligns with a firm's existing export portfolio S_{ft}. The index is computed as a weighted average of proximities between the candidate product and the firm's current products:

$$PEPI_{fpt} = \frac{\sum_i s_{fit}\phi_{ipt}}{\sum_i \phi_{ipt}} = \frac{\text{Weighted sum of proximities between } p \text{ and } S_{ft}}{\text{Total proximities of } p \text{ to all current products}}, \tag{4}$$

where s_{fit} is an indicator equal to 1 if firm f currently exports product i ($s_{fit} = 1$ if $i \in S_{ft}$), and 0 otherwise. The proximity ϕ_{ipt} represents the similarity between the potential product p and the existing product i, as captured by the co-export patterns in the global proximity matrix. This normalized measure ranges from 0 to 1, with higher values indicating greater proximity between the candidate product and the firm's existing portfolio. We normalize by the total proximities to ensure that the index remains comparable across products, accounting for differences in overall connectivity within the global product space and reducing potential biases toward products that are frequently co-exported.

To illustrate how the PEPI is constructed in practice, consider a hypothetical example involving a firm f and four products. Suppose firm f currently exports two products—electric motors (product i) and water pumps (product j)—to the United States. The same firm also exports two additional products—air compressors (product p) and electric fans (product q)—to other countries, but not yet to the U.S., making them potential candidates for market entry. Now let's also assume based on co-export patterns across all firms, air compressors exhibit relatively high proximity to the firm's current U.S. exports (for example, $\phi_{ipt} = 0.65$ and $\phi_{jpt} = 0.52$), whereas electric fans show lower proximity values (for example, $\phi_{iqt} = 0.22$ and $\phi_{jqt} = 0.30$).[7]

The PEPI values for these two candidate products are then calculated as:

$$PEPI_{fpt} = \frac{s_{fit} \cdot \phi_{ipt} + s_{fjt} \cdot \phi_{jpt}}{\phi_{ipt} + \phi_{jpt}} = \frac{1 \cdot 0.65 + 1 \cdot 0.52}{0.65 + 0.52} \approx 0.56,$$

$$PEPI_{fqt} = \frac{s_{fit} \cdot \phi_{iqt} + s_{fjt} \cdot \phi_{jqt}}{\phi_{iqt} + \phi_{jqt}} = \frac{1 \cdot 0.22 + 1 \cdot 0.30}{0.22 + 0.30} \approx 0.26.$$

Although both products are already part of the firm's global export portfolio, the higher PEPI value for air compressors indicates that this product is more proximate to the firm's current U.S. exports. As we show in the following empirical analysis, products with higher PEPI values are significantly more likely to be introduced into a new market.

In short, the $PEPI_{fpt}$ combines global and firm-specific elements to assess the proximity between a candidate product and a firm's existing export portfolio. Product proximities ϕ_{ijt} are derived from global co-export patterns across all firms, capturing universal relationships between products based on observed exporting behavior. These global proximities are then weighted by firm-specific information (s_{fit}), which reflects the firm's current export portfolio, allowing $PEPI_{fpt}$ to tailor global relationships to the firm's unique specialization and production capabilities. This integrated framework provides a quantitative tool to evaluate product proximity, capturing both direct and indirect linkages arising from shared capabilities, technologies, or market relationships—without relying on strong ex-ante assumptions about the nature of these connections.

Figure 2 illustrates the product proximity matrix (ϕ_{ip2000}) for selected products in the year 2000, capturing similarities between products based on co-export patterns across all firms. The proximity matrix is constructed as a $J \times J$ matrix, where J is the number of unique products, and each cell represents the proximity value (ϕ_{ip}) between product i

[7] All values in this example are hypothetical and are used solely to illustrate the mechanics of the index.

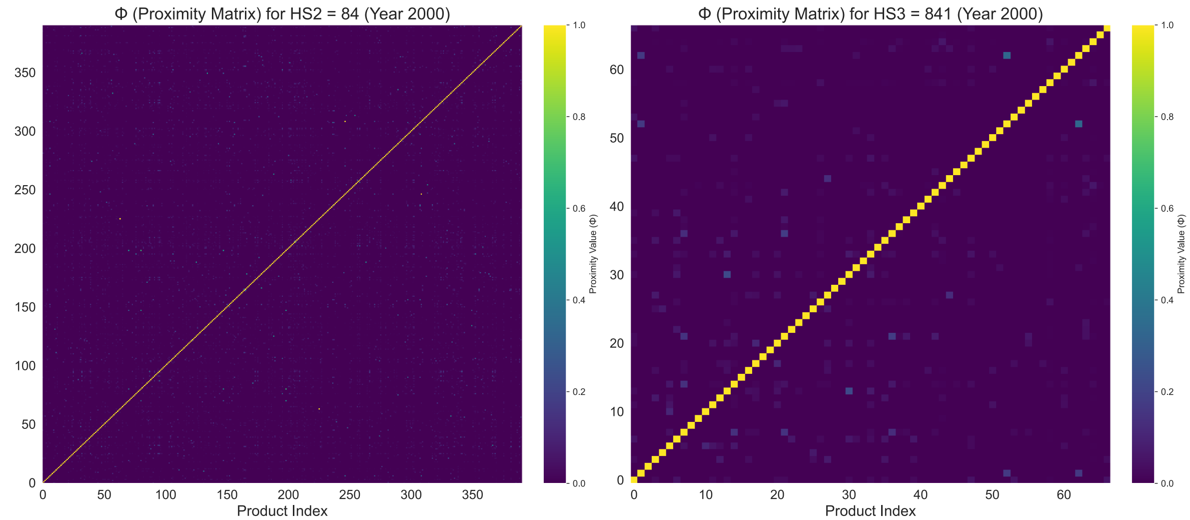


Figure 2: Proximity Matrix for Selected Products in 2000

and product p. Higher proximity values, indicated by brighter cells, suggest stronger co-export relationships between products. The left panel of the figure depicts the ϕ matrix for products under HS2 = 84, while the right panel focuses on products under HS3 = 841.

The figure reveals several important patterns. First, the Φ matrix is highly sparse, reflecting the reality that most product pairs exhibit limited co-export relationships. This sparsity is particularly evident away from the diagonal, where proximity values drop off sharply. While bright diagonal elements dominate the matrix—as products are most closely related to themselves—only a few spots near the diagonal exhibit higher proximity values, rather than forming contiguous clusters. Unlike broader expectations of clustering patterns along product IDs, these results suggest that strong proximities are localized rather than widely distributed, even within closely related product groups. For instance, the proximity values for HS3 = 841 show isolated pockets of high proximity rather than a continuous pattern near the diagonal. These observations highlight the selective nature of co-export relationships and suggest that product proximity is driven by nuanced and specific linkages, rather than broad industrial or technological categories.

Building on this definition, we examine the relationship between the Product Export Proximity Index ($PEPI_{fpdt}$) and firms' decisions to introduce new products into destination markets. Specifically, we analyze whether the new products introduced by exporters exhibit higher $PEPI$ values compared to products not exported to the given market. To do so, we define the "product set" for each firm in a given year as the set of products the firm exports to the world. For a specific destination market, such as the United States, we classify this product set into three categories: (1) products already exported to the market (existing products), (2) products newly introduced to the market (newly introduced products), and (3) products not exported to the market (non-exported products). For non-existing products, whether a product is introduced into the market is modeled as a function of $PEPI_{fpt}$, which measures how proximate the product p is to the firm's existing export portfolio. This relationship is specified by the following equation:

$$\Pr(\text{Introduction}_{fpt} = 1) = F\big(\alpha_0 + \alpha_1 \text{PEPI}_{fpt} + \text{FE.} + \varepsilon_{fpt}\big), \tag{5}$$

where $F(\cdot)$ is the cumulative distribution function corresponding to either the probit or logit model, and $\text{Introduction}_{fpt}$ is a binary indicator that equals 1 if firm f introduces product p to the U.S. in year t, and 0 otherwise. The key independent variable, PEPI_{fpt}, captures the proximity of the new product p to the firm's existing export portfolio. Fixed effects, denoted as $FE.$, control for firm-, year-, and product-specific characteristics.

Table 2: Probit and Logit Regression Results for Product Introduction Decisions

	No FE		Firm-Year FE		Product-Year FE	
	Probit	Logit	Probit	Logit	Probit	Logit
α_1	20.99***	44.65***	16.29***	34.29***	17.99***	39.60***
	(0.019)	(0.050)	(0.017)	(0.42)	(0.018)	(0.047)
Probability (%)	22.93	23.27	27.83	30.59	29.66	31.73
R^2	0.52	0.53	0.30	0.32	0.33	0.37
Observation	7,069,989					

Note: Regression results for probit and logit models evaluating the relationship between $PEPI$ and the probability of introducing a product into the market. The reported probabilities represent the change in the likelihood of introducing a product into the market when $PEPI$ increases by 0.1. Fixed effects (FE) include firm, year, and product characteristics.

Table 2 presents the probabilities of introducing a product into the market when $PEPI$ increases by 0.1. By comparing the $PEPI$ values of newly introduced products to those of non-exported products, we find that a 0.1 increase in $PEPI$ corresponds to an approximately 20% to 30% increase in the probability of a product being introduced to the market. This result holds consistently across both logit and probit specifications, highlighting the role of product proximity in driving firms' export expansion strategies for a given market. Just as Alfaro-Urena et al. (2024) highlight the importance of inter-market complementarities in shaping firms' export decisions across destinations, our analysis demonstrates that product proximity is a similarly critical driver of export decisions within a market.

3 Baseline Model with Product Heterogeneity

In this section, we develop a dynamic general equilibrium model with product and firm heterogeneity. In particular, we build on our empirical findings that firms do not randomly expand products, but instead tend to expand into products closely related to their current export portfolio. We show that these expansion patterns are driven by reduced export entry costs for related products.

Consider discrete time with infinite horizon. There are two symmetric countries: Home (H) and Foreign (F). In each country, there is a representative consumer, a representative final-goods producer, and heterogeneous intermediate-goods producers. The overall set-up of this model is similar to previous literature, such as Alessandria and Choi (2007) and Alessandria et al. (2021), but we extend their framework to include product heterogeneity through consumer preferences as in Bernard et al. (2010).

The representative household in each country derives utility from a final non-traded consumption good. They also decide how much to invest in capital and bonds. Households purchase a one-period nominal bond, denominated in units of the home-country final good, that pays one unit of the final good in the next period. A representative final-goods producer purchases different products from intermediate goods producers in both countries, and each product is made up of differentiated intermediate inputs. The nontraded final good is used for household consumption, investment, and as materials.

Intermediate-goods firms, indexed by subscript i, produce products that are differentiated by characteristics. These characteristics are represented through relative preferences of final-goods producers over different varieties and are denoted by ω, where ω lies in a firm-specific range $[\underline{\omega}_i, \overline{\omega}_i]$ and follows a standard Pareto distribution with shape parameter γ.[8] The product range of intermediate-goods firms may depend on their productivity, resulting in heterogeneous product spaces across firms within a given period or across different periods for a specific firm. In our baseline calibration, we assume that firms' productivity and product spaces are independent, though we later drop this assumption and find that our main results still hold.

While the range of product space is exogenous, firms' export decisions are endogenous. Intermediate-goods producers' export decision is determined by a threshold, which we denote by $\tilde{\omega}$, that lies within $[\underline{\omega}_i, \overline{\omega}_i]$. In practice, the product space is discretized evenly from $\underline{\omega}$ to $\overline{\omega}$, and firms' export choices are constrained to lie on this grid if they choose to export. Thus, a firm's full potential export choices for $\tilde{\omega}$ are $[0, \underline{\omega}, \omega_2, ..., \overline{\omega}]$. If a firm's export choice is $\tilde{\omega}^*$, then the firm exports all products whose attributes are lower than this threshold, i.e., $\omega \leq \tilde{\omega}^*$. Depending on the export decision, they become non-exporter ($\tilde{\omega} = 0$), single product exporter ($\tilde{\omega} = \underline{\omega}$), or multiproduct exporter ($\tilde{\omega} > \underline{\omega}$). Therefore, intermediate-goods producers in each country are characterized by their productivity (z) and export history ($\tilde{\omega}$). Exporting requires paying fixed and variable costs that depends on product portfolio, which will be formally introduced later.

Our choice to model export decisions this way was deliberate. A key challenge in modeling heterogeneous firms with multiple export products is the dimensionality of export choices: with N potential products, firms would face 2^N possible export portfolio combinations, making the problem computationally intractable. By imposing a structure where products are ordered according to their relative preferences and firms choose an optimal threshold to determine their export range, we reduce the export choice space from 2^N to $N + 1$. This approach makes the model computationally feasible while

[8] Representing product heterogeneity through preferences is equivalent to modeling products through intermediate-goods firm-specific relative productivity differences.

preserving the essential features of firms' export decisions.

For consistency, we index firms with subscript i and products with subscript k. In this section, we only present the equations related to the home country, but foreign country's problems are analogous.[9] Finally, firms face an exogenous industry exit rate which is dependent on their productivity, denoted by $E(z)$.

3.1 Representative Household

The representative household in each country derives utility from the consumption of a final good, denoted by C_t. Households maximize the expected utility of the form

$$U = \mathbb{E}_t \left[\sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\sigma}}{1-\sigma} \right], \tag{6}$$

where β is the discount factor between 0 and 1, and σ denotes the parameter that relates to the household's risk aversion. The budget constraint for the household can be written as

$$P_t[C_t + K_{t+1}] + Q_t B_{t+1} = W_t \bar{L} + R_t K_t + (1-\delta) P_t K_t + B_t + \Pi_t + T_t, \tag{7}$$

where K_t and B_t denote the capital stock and bond holdings at time t. δ is the depreciation rate of capital. P_t, W_t, R_t, and Q_t are the price of the final good, wage rates, rental rates, and the price of one-period bond, respectively. $\bar{L}$ is the total amount of labor supplied by households, which we normalize to 1. Finally, Π_t and T_t are the profits from home producers and the lump-sum transfer of tariff revenue, respectively.

[9] Variables chosen in the foreign country are denoted with an asterisk.

3.2 Representative Final-Goods Producers

The nontraded final good, D_t, is a combination of different products, each with its own varieties from both countries. This can be expressed as follows:

$$D_t = \left(\int \int (\omega_{ki} y_{Hkit})^{\frac{\epsilon-1}{\epsilon}} dkdi + \int \int (\omega_{ki} y_{Fkit})^{\frac{\epsilon-1}{\epsilon}} dk^* di^* \right), \tag{8}$$

where, with a slight abuse of notations, $di(di^*)$ represents the distribution of Home(Foreign) producers, and ϵ is the elasticity among intermediate goods of product k. ω_{ki} is the demand parameter that determines the household's relative demand for the varieties of different firms within each product. y_{Hkit} and y_{Fkit} are the amounts of intermediate goods from firm i/i^* to produce final good k/k^* in the Home/Foreign countries.[10]

The final-goods market is perfectly competitive. Given the price of home and foreign intermediate goods, P_{Hkit} and P_{Fkit}, the profit maximization problem for the final goods producers can be written as

$$\max_{y_{Hkit}, y_{Fkit}} \left\{ P_t D_t - \int \int P_{Hkit} y_{HKit} dkdi - \int \int (1+\tau_k) P_{Fkit} y_{FKit} dk^* di^* \right\}, \tag{9}$$

where $\tau_k \geq 0$ is the tariff rate imposed by the government for product k. Solving for the demand equation yields

$$y_{Hikt} = \left(\frac{1}{\omega_{ki}} \right)^{1-\epsilon} \left(\frac{P_{Hkit}}{P_t} \right)^{-\epsilon} D_t, \qquad y_{Fikt} = \left(\frac{1}{\omega_{ki}} \right)^{1-\epsilon} \left(\frac{(1+\tau_k) P_{Fkit}}{P_t} \right)^{-\epsilon} D_t. \tag{10}$$

The natural CES price index that follows from the optimization problem is

$$P_t^{1-\epsilon} = \left(\int \int \left(\frac{P_{Hkit}}{\omega_{ki}} \right)^{1-\epsilon} didk \right) + \left(\int \int \left(\frac{(1+\tau_k) P_{Fkit}}{\omega_{ki}} \right)^{1-\epsilon} di^* dk^* \right). \tag{11}$$

We set the final goods price as numeraire, which implies that $P_t = P_t^* = 1$.

[10]Without loss of generality, we have set the elasticity of substitution between products, firms, and countries to equal values to keep the model computationally tractable.

3.3 Intermediate-Goods Producers

Intermediate-goods firms produce all products using capital, k, labor, n, and materials, m, according to a Cobb-Douglas production function at the firm-level.

$$y_{it} = z_{it}(k_{it}^{\alpha} n_{it}^{1-\alpha})^{(1-\alpha_m)} m_{it}^{\alpha_m}, \tag{12}$$

where $\alpha(1-\alpha_m)$ is the capital share, α_m is the materials share, and z_{it} is the firm-specific productivity that follows AR(1) process in logs. Intermediate-goods producers are differentiated by their productivity, z_{it}, which is persistent and stochastic, and their past export history. All intermediate-goods producers manufacture the full range of products and their decision to export is selective.

Firms' export participation varies depending on their productivity level, which not only determines export or not but also determines the subset of products they choose to export. In other words, a firm's productivity dictates the proportion of the product space, ω_i, that it will export. More productive firms will export a larger share of their product range, while less productive firms will export a smaller share or may not export at all. Therefore, a firm's export history is given by some value within the support of product attributes, $\tilde{\omega}_i \in [\underline{\omega}_i, \overline{\omega}_i]$[11], if it was an exporter previously. If a firm was a non-exporter in the last period, then $\tilde{\omega}_i = 0$.

The firm is subject to the feasibility constraint, which says that the total amount of output produced by the firm i equals the total amount of output produced for both home and foreign markets across the product space.

$$y_{it} = \int_{\underline{\omega}_i}^{\overline{\omega}_i} (y_{Hikt} + y_{Hikt}^{*}) dk, \tag{13}$$

We further assume that CES demands from final-goods producers are fully satisfied at the product level. Thus, given a firm's export choice, $\tilde{\omega}_i$, and the level of productivity, z_i,

[11] i subscript on the support of product attributes is not necessary if the product range is not correlated with firm's productivity. However, we keep this for clarity and generality.

the profit maximization problem of intermediate-goods producers can be written as

$$\pi_{it} = \max_{P_{Hikt}, P^*_{Hikt}, k_{it}, n_{it}, m_{it}} \left\{ \int_{\underline{\omega}_i}^{\overline{\omega}_i} P_{Hikt} y_{Hikt} dk + \int_{\underline{\omega}_i}^{\tilde{\omega}_i} P^*_{Hikt} y^*_{Hikt} dk - W_t n_{it} - (R_t + \delta) k_{it} - P_t m_{it}, \right\}, \tag{14}$$

$$\text{subject to} \quad y_{Hikt} = \left(\frac{1}{\omega_{ki}}\right)^{1-\epsilon} \left(\frac{P_{Hkit}}{P_t}\right)^{-\epsilon} D_t, \quad y^*_{Hikt} = \left(\frac{1}{\omega_{ki}}\right)^{1-\epsilon} \left(\frac{P^*_{Hkit}}{P^*_t}\right)^{-\epsilon} D^*_t, \tag{15}$$

$$z_{it}(k_{it}^{\alpha} n_{it}^{1-\alpha})^{(1-\alpha_m)} m_{it}^{\alpha_m} = \int_{\underline{\omega}_i}^{\overline{\omega}_i} (y_{Hikt} + y^*_{Hikt}) dk. \tag{16}$$

Plugging in the first two constraints for y_{Hkit}, y_{Fkit} to the objective functions and assigning MC_{it} as the Lagrange multiplier to the third constraint above, we can find that the firm's pricing decisions are equal across products and charge a constant markup over the marginal cost for each product.

$$P_{Hikt} = P^*_{Hikt} = \frac{\epsilon}{\epsilon - 1} MC_{it}. \tag{17}$$

Next, we discuss the costs associated with exporting. For a firm's export decision in the next period to take effect, they must pay the relevant fixed costs of exporting in the current period. The total cost of exporting is the sum of two components: the cost related to the firm's export choice in the previous period and the additional export costs incurred if the firm decides to add products to their export portfolio. Given the past export history, $\tilde{\omega}$, and the export choice in the next period, $\tilde{\omega}'$, the cost of exporting can be written as

$$f(\tilde{\omega}, \tilde{\omega}') = \gamma_0 (\tilde{\omega}')^{\gamma_1} + \gamma_2 \max\left\{0, (\tilde{\omega}' - \tilde{\omega})\right\}^{\gamma_3}, \tag{18}$$

where $\gamma_0, \gamma_1, \gamma_2$, and γ_3 are non-negative parameters related to the cost of exporting. The first term in the equation represents the continuation cost of exporting for the firm, which depends on the firm's export portfolio. The second term captures the cost associated with the introduction of a set of new products. In our model, product proximity between the current export set and a potential new set is defined by the difference between $\tilde{\omega}'$ and $\tilde{\omega}$. A smaller difference between these sets implies higher product proximity, which results in lower export costs. This theoretical formulation differs slightly from our empirical approach. In our empirical analysis, we examined how firms introduce specific new products given their existing export portfolio, whereas in our model, we compare complete current and potential product sets. Nevertheless, this difference is minimal and our model effectively captures the key mechanisms observed in the data.

Our export cost function is a generalization of the approach used in several single-product models in the literature, such as the one formulated in Ruhl and Willis (2017). If we suppose that ω can only take a single value to collapse the case into one without multiproduct exporting firms, $\underline{\omega} = \overline{\omega} = 1$, then the possible export history can be reduced to $\tilde{\omega} \in \{0, 1\}$. In this case, the sunk cost formulation collapses to

$$f(\tilde{\omega}, \tilde{\omega}') = \gamma_0 I(\tilde{\omega}' = 1) + \gamma_2 \max\{0, (\tilde{\omega}' - \tilde{\omega})\}, \tag{19}$$

where $I(.)$ is an indicator function. In this case, $\gamma_0 + \gamma_2$ is the cost of newly entering the export market, and γ_0 is the continuation cost of exporting. Then, γ_2 is the one-time sunk cost of exporting.

Going back to the general case, the dynamic programming problem for an intermediate-goods producer with a state variable $s = (z, \tilde{\omega})$ can be written as

$$V(s) = \max_{\tilde{\omega}'} \left\{ \Pi(s) - Wf(\tilde{\omega}, \tilde{\omega}') + (1 - E(z))Q\mathbb{E}\left[V(s'|s)\right] \right\}. \tag{20}$$

As denoted before, in practice, we discretize the product space, $\omega(s) = [\underline{\omega}(s), \ldots, \overline{\omega}(s)]$. Furthermore, we constrain the export choice to lie on the discretized product grid if a firm chooses to export. Firms that choose not to export any products implies that $\tilde{\omega} = 0$. Consider a current non-exporter of a firm with some productivity level, $\bar{z}$. This firm decides to export one or more products if the following inequality holds:

$$f(0, \tilde{\omega}') < (1 - E(z))Q(\mathbb{E}\left[V((\tilde{\omega}', z')|(0, \bar{z}))\right] - \mathbb{E}\left[V((0, z')|(0, \bar{z}))\right]), \tag{21}$$

for any $\tilde{\omega}' > 0$. The left-hand side of the inequality is the cost of exporting next period that is paid the current period. The right-hand side of the inequality is the discounted expected gains from exporting compared to continuing not to export. Thus, the firm becomes a new exporter if the discounted expected benefit is greater than the export cost.

3.4 Government, Free Entry and Market Clearing Conditions

The government collects tariffs and redistributes it back to households in lump sum fashion. The government budget constraint is

$$T_t = \int \int \tau_k P_{Fkit} y_{Fkit} di^* dk^*. \tag{22}$$

New establishments enter by paying an entry cost of γ_E units of labor in the period prior to production. They enter as non-exporters, and their productivity is drawn from an entrant-specific distribution, $G(z)$. The free-entry condition is

$$V_t^E = -W_t \gamma_E + Q_t \int_{z'} V_{t+1}(0, z') dG(z') \leq 0. \tag{23}$$

We denote the mass of entrants at time t as $N_{E,t}$ and the mass of incumbents as $N_t = \int di$. In equilibrium, labor, capital, and bond markets clear.

$$\int n_{it} di + F_t + N_{E,t} \gamma_E = \bar{L}, \qquad \int k_{it} di = K_t, \qquad B_{t+1} + B_{t+1}^* = 0, \tag{24}$$

where $F_t = \int \int f(\tilde{\omega}, \tilde{\omega}') dk di$ is the aggregate value of fixed export cost paid by intermediate-goods producers in terms of labor. Finally, combining the household budget constraint, final-goods producer profit, and intermediate-goods producer profit equations, we arrive at the final-goods market clearing condition.

$$C_t + I_t + M_t = D_t, \tag{25}$$

where $I_t = K_{t+1} - (1 - \delta) K_t$ is the aggregate investment and $M_t = \int m_{it} di$ is the aggregate materials demand.

Let Λ_t be the distribution of firms over its idiosyncratic state variables at time t in the home country. We now formally define the equilibrium of our model economy. Given initial conditions $\{K_0, B_0, K_0^*, B_0^*, \Lambda_0, \Lambda_0^*\}$, and a deterministic path of tariffs, $\{\tau_{kt}, \tau_{kt}^*\}$, an equilibrium for this economy is given by sequences from $t = 0, 1, ..., \infty$ of: household choices, $\{C_t, B_{t+1}, \quad K_{t+1}, L_t, C_t^*, B_{t+1}^*, K_{t+1}^*, L_t^*\}$, final-goods producers' decisions, $\{D_t, y_{Hkit}, y_{Fkit}, D_t^*, y_{Hkit}^*, y_{Fkit}^*\}$, decisions by intermediate-goods producers, $\{P_{Hkit}, P_{Fkit}, k_{it}, n_{it}, m_{it}\}$, mass of entrants, $\{N_{E,t}, N_{E,t}^*\}$, government transfers, $\{T_t, T_t^*\}$, real wages and rental rates, $\{W_t, R_t, W_t^*, R_t^*\}$, bond prices, $\{Q_t, Q_t^*\}$, and the distributions of firms, $\{\Lambda_t, \Lambda_t^*\}$, such that the following conditions hold:

1. Households maximize their lifetime utility by choosing consumption, bond, capital, and labor choices given prices;
2. Final-goods producers' allocations solve their profit-maximization problems;
3. Intermediate-goods producers' input choices, prices, and export decisions maximize their value functions given final goods demands and factor prices;
4. Government budget constraint is satisfied;
5. Labor market, capital market, bond market, and goods market clear;
6. The free-entry condition holds;
7. Aggregate law of motion is generated by export decisions of intermediate-goods producers.

As is standard in models with heterogeneous firms that study trade liberalizations, when $\tau_{kt} = \tau_k$ for all k, the model converges to a stationary equilibrium in which the aggregate quantities, the distribution of firms, and prices are constant. We first study the firm-level dynamics in the stationary equilibrium. Next, we study the aggregate impact from varying tariff rates. Details on methods used to solve both the stationary equilibrium and transition dynamics are provided in the Appendix.

4 Calibration

We categorize the model parameters into three groups. The first group consists of parameters drawn from the literature or set as baseline values. The second group

Table 3: **Externally Calibrated Parameters**

Parameter	Description	Value
Group 1 - Standard/Baseline Values		
σ	Risk aversion	2
ϵ	Elasticity of substitution	5
β	Discount factor	0.95
δ	Capital depreciation rate	0.08
γ_E	Entry cost	0.26
$\tau = \tau_k$	Tariff rate	0.10
Group 2 - Externally Estimated from Data		
ρ_z	Persistence of firm productivity	0.77
σ_e	Std. dev. of firm innovation	0.21
$\alpha(1-\alpha_m)$	Capital share	0.05
α_m	Materials share	0.60

includes parameters estimated externally using Chinese manufacturing data from 2000-2007. The final group comprises of parameters that we estimate internally using the Method of Simulated Moments, matching key moments of product churning and exporter dynamics. Table 3 presents parameters from the first two groups. For standard parameters from the literature, we set the risk aversion parameter σ to 2 and the elasticity of substitution ϵ to 5. We choose a discount factor β of 0.95, implying a 5 percent annual interest rate in steady state. The annual capital depreciation rate δ is set to 8 percent. The entry cost parameter γ_E is normalized to set the mass of entrants equal to 1 in the initial stationary equilibrium. Finally, we set a uniform baseline tariff rate of 10 percent across all products.

The second half of Table 3 presents parameters estimated using the Chinese Manufacturing Survey from 2000 to 2007. We model firm productivity as an AR(1) process in logs:

$$\ln z_{t+1} = \rho_z \ln z_t + \sigma_e \varepsilon_{z,t+1}, \tag{26}$$

where ρ_z is the persistence parameter, σ_e is the standard deviation of innovations, and ε_z follows a standard Normal distribution. We estimate factor shares and firm-level productivity following the production function estimation literature. The capital coefficient, α, and materials share, α_m, are estimated to be 0.13 and 0.60, respectively. This implies that the capital share, $\alpha(1-\alpha_m)$, is 0.05. We also estimate the persistence of firm-level productivity and the standard deviation of its innovation terms. We estimate ρ_z to be 0.77 and σ_e to be 0.21. Details on parameter estimations can be found in the Appendix.

The remaining parameters are internally calibrated to match key firm statistics with multi-product decisions and industry/exporter dynamics at the micro-level. Unless stated otherwise, we calibrate our model using time-averaged moments from the Chinese customs data and the Chinese Manufacturing Survey. There are seven parameters to estimate: the entrant distribution parameter (μ_E), the exogenous industry exit rate parameter (ξ), the tail parameter of product attributes (γ), and four parameters governing export costs (γ_0, γ_1, γ_2, γ_3).[12] These parameters are jointly calibrated to match seven key moments: 1.) productivity gap between incumbents and entrants, 2.) long-run industry survival rates, 3.) the product addition rate (probability of MP firms adding new export products), 4.) the product drop rate (probability of MP firms discontinuing export products), 5.) exporter share in the economy, 6.) The long-run exporter survival rate, and 7.) the proportion of single-product firms among exporters. Let θ be a vector of parameters $[\mu_E, \xi, \gamma, \gamma_0, \gamma_1, \gamma_2, \gamma_3]$ and $M(\theta)$ be the vector of moments. We minimize the following objective function:

$$F(\theta) = (M^{data} - M^{model}(\theta))^T (M^{data} - M^{model}(\theta)). \tag{27}$$

The third column of Table 4 lists the estimated parameters. Entrants draw their initial productivity (ε_E) from the unconditional productivity distribution of incumbents ($\ln z$), but shifted to the left by μ_E, i.e., $\varepsilon_E = \ln z - \mu_E$, where ε_E follows the distribution $G(z)$. The productivity gap between incumbents and entrants are estimated to be around 10% in the data and μ_E is estimated to be 0.16. For the exogenous industry exit rate, we assume that the exit rate is declining in productivity following a logit functional form. That is,

$$E(z) = \frac{1}{1 + \exp(\xi z)}, \tag{28}$$

[12]The entrant distribution parameter and the exogenous exit parameter can be matched independently since neither depend on other parameters. Therefore, we calibrate these parameters separately from the main estimation procedure.

where ξ governs the relationship between productivity and exit probability, which is around 11% in the data. We estimate ξ to be 2.30. The tail parameter of product characteristics, γ, is estimated slightly over 5.78. For the export cost function, we find the scale parameters (γ_0, γ_2) are similar in magnitude, both around 0.01, while the power parameters (γ_1, γ_3) are estimated at 1.11 and 5.42, respectively. This parameterization of the export cost function generates a key feature of our model: multiproduct exporters face lower costs when introducing new products that share proximity with their existing export portfolio. This result is consistent with Qiu and Zhou (2013), which showed, using a theoretical framework, that a necessary and sufficient condition for scope expansion is that the fixed cost of introducing a new product increases rapidly with the firm's product scope.

In our model, optimal product expansions operate through export costs. To quantify the gains from accounting for product proximity, we examine a no-proximity gains (NPG) case by changing the export cost function. The alternative can be written as:

$$f(\tilde{\omega}, \tilde{\omega}') = \gamma_0(\tilde{\omega}')^{\gamma_1} + \gamma_2 \mathbb{1}(\tilde{\omega}' > \tilde{\omega}). \tag{29}$$

Here, we see that the firm pays a constant fixed cost, γ_2, to expand its portfolio regardless of its previous export status. We re-estimate γ_0, γ_1, and γ_2 to match the share of exporters, exporter survival rate, and the share of single-product exporters. Estimated parameters are shown in the fourth column of Table 4. In the NPG case, removing gains from product proximity implies a higher coefficient for the export entry cost term. Quantitatively, γ_2 is 0.008 in the standard calibration while the parameter is 0.012 in the alternative calibration without accounting for proximity gains. Without the exponent (γ_3) in the entry cost, γ_2 requires a larger coefficient to match the observed empirical moments. Furthermore, the exponent of the continuation cost term, γ_1, is larger (1.85 in the NPG case vs. 1.11 in the Standard case), while its coefficient, γ_0, is smaller (0.008 vs. 0.006). Finally, we only re-estimate parameters related to the fixed cost without influencing other aspects of the model, as these are the only parameters affecting product proximity gains. As μ_E and ξ depend only on the firm-level productivity, these parameters are set to the same value as in the standard case. We also fix the value of γ

Table 4: **Group 3 - Internally Calibrated Parameters**

Parameter	Description	Standard	NPG
μ_E	Entrant distribution parameter	0.16	0.16*
ξ	Industry exit parameter	2.30	2.30*
γ	Pareto shape parameter	5.78	5.78*
γ_0	Fixed cost parameter 1	0.008	0.006
γ_1	Fixed cost parameter 2	1.11	1.85
γ_2	Fixed cost parameter 3	0.008	0.012
γ_3	Fixed cost parameter 4	5.42	-

Note: This table lists parameter values that are chosen to match the moments in Table 5. Standard refers to the model with proximity gains. NPG refers to an alternative model without proximity gains. Asterisks denote parameters that are not re-estimated in the alternative model.

because changing it would alter the product space, which would affect our comparative analysis. By maintaining a consistent product space, we ensure a methodologically sound comparison that isolates the aggregate effects of accounting for gains from product proximity.

Table 5 compares model-generated moments with their empirical counterparts. The model matches all targeted moments precisely. In the data, product portfolio dynamics show distinct patterns: 31% of surviving multiproduct firms maintain stable export portfolios (stasis rate), whereas 38% of firms add products and the other 31% remove products (drop rate). The extensive margin of trade is characterized by a 32% export participation rate, with 61% of the firms exporting multiple products and 39% exporting a single product. The model also matches the high persistence in export status, with an 87% long-run survival rate in the export market. Similarly, the model exactly matches the targeted moments in the NPG case.

To externally validate the model, we also compare the transition probabilities of multi-product exporters as they are the main focus of this paper. The model matches the data pretty well along the untargeted dimension. In the data, 72% of multiproduct exporters maintain their multiproduct status in the following year whereas 13% of multiproduct exporters switch to single-product exporters and 15% of multiproduct exporters exit the exporting market altogether. In the standard calibration of the model, 74% of firms maintain their multiproduct exporter status while 18% and 8% of firms

Table 5: **Calibration Results**

Targeted moments	Data	Standard	NPG
Entrant/incumbent prod. difference	0.10	0.10	0.10
Industry exit rate	0.89	0.89	0.89
Product drop rate	0.31	0.31	–
Product stasis rate	0.31	0.31	–
Product add rate	0.38	0.38	–
Share of exporters	0.32	0.32	0.32
Exporter survival rate	0.87	0.87	0.87
Share of single-product exporters	0.39	0.39	0.39
Share of multi-product exporters	0.61	0.61	0.61
Untargeted Moment			
MPEF to MPEF	0.72	0.74	0.74
MPEF to SPEF	0.13	0.18	0.21
MPEF to NX	0.15	0.08	0.05

switch to single-product exporters and exit the export market, respectively. In the NPG case, the share of multi-product exporting firms (MPEF) that switch to single-product exporting firms (SPEF) is higher than both the standard calibration and the data. It also understates the share of firms that switch from MPEF to non-exporters (NX) to a greater degree relative to the standard calibration.

Next, we examine additional model implications, focusing on new exporter dynamics and the model-implied productivity distribution of firms. Figure 3 illustrates two key patterns: the evolution of survival probability and export intensity for new exporters. Since Ruhl and Willis (2017), new exporter dynamics have been an important feature to examine, as these firms behave distinctly differently from continuing exporters. A key empirical pattern is that both survival probability and export intensity start low but gradually increase the longer firms remain in the export market.

Our model successfully captures both patterns. Survival probability starts below 55% when new exporters enter and gradually increases to to above 85% after 5 or 6 years, eventually converging to the long-run mean. Similarly, export intensity, measured by the export-sales ratio, rises from slightly above 27% when firms enter the exporter market to over 32% after eight years.

The model's ability to generate rising export intensity without additional shocks is quite interesting. In a single-product framework, the export-sales ratio is given by:

$$\frac{exp_{it}}{sales_{it}} = \frac{P^*_{Hit}y^*_{Hit}}{P^*_{Hit}y^*_{Hit} + P_{Hit}y_{Hit}} = \frac{(1+\tau)^{-\epsilon}}{(1+(1+\tau)^{-\epsilon})}, \tag{30}$$

which yields a constant ratio across firms and time. With our baseline 10 percent tariff rate, this ratio would be fixed at 38%. In single-product models, additional heterogeneity is introduced through firm-level cost shocks, as in Alessandria et al. (2021).

In contrast, our multi-product framework generates variable export intensity through the following relationship:

$$\frac{exp_{it}}{sales_{it}} = \frac{\int_{\underline{\omega}_i}^{\tilde{\omega}_i} P^*_{Hikt}y^*_{Hikt}dk}{\int_{\underline{\omega}_i}^{\tilde{\omega}_i} P^*_{Hikt}y^*_{Hikt}dk + \int_{\underline{\omega}_i}^{\overline{\omega}_i} P_{Hikt}y_{Hikt}dk}. \tag{31}$$

This ratio varies across firms and time as it depends on both the export history, $\tilde{\omega}_i$, and the product scope, $[\underline{\omega}_i, \overline{\omega}_i]$. As firms' productivity changes, they adjust their export scope, leading to changes in export intensity. This endogenous mechanism provides a novel explanation for new exporter dynamics, distinct from previous models that rely on dynamic sunk costs and exogenous shocks.

In our baseline calibration, export intensity grows exclusively through the extensive margin—firms expand their export activity by introducing new products rather than increasing export sales of existing products. This outcome is a direct consequence of our model's structure, in which the demand for each product is independent and follows a standard CES formulation. As a result, the introduction of an additional exported product does not affect the demand for previously exported goods, eliminating the intensive margin as a channel for export intensity growth. However, if productivity and product space are correlated, then export intensity grows through both intensive and extensive margins, as changes in firms' productivity lead to firms producing different products.

Regardless, our modeling of export costs reinforces the extensive-margin-driven mechanism. Since export costs are fixed rather than per-unit, firms optimize by adjusting the number of exported products rather than increasing the export volume of

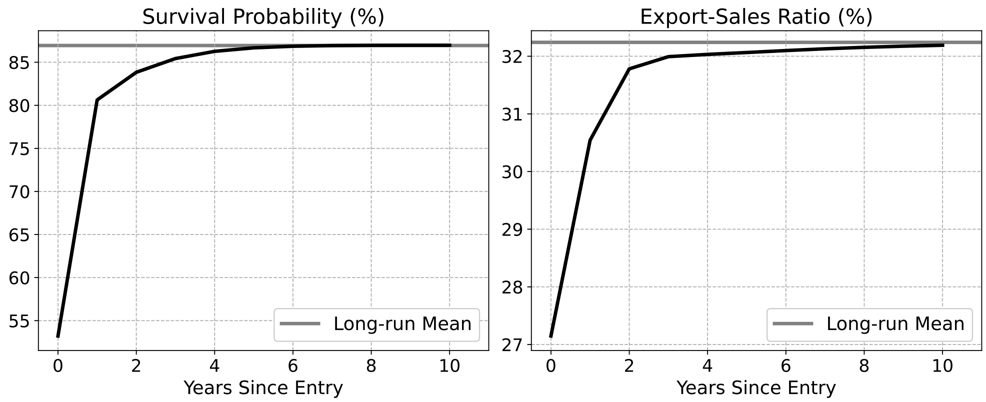


Figure 3: New Exporter Dynamics

existing products. This is not a limitation but rather a distinguishing characteristic of our model. Traditional trade models, such as Melitz (2003), often assume firms adjust their export volumes at the intensive margin. By contrast, our framework provides a complementary mechanism where product proximity and export cost structures drive extensive-margin-based expansion. While models such as Fitzgerald et al. (2024) decompose export growth into intensive and extensive margins, our results highlight a distinct pathway through which firms expand their export activity.

Figure 4 shows the model-implied stationary distribution of firm productivity across three types of firms: non-exporters, single-product exporters, and multi-product exporters. The productivity distribution of non-exporters is centered below zero, while single-product exporters are concentrated slightly above zero. Multi-product exporters exhibit both the highest mean productivity and the largest variance. This pattern emerges because more productive firms are better able to overcome export costs and sustain larger export portfolios, consistent with findings from Bernard et al. (2010) and Mayer et al. (2014).

5 Firm-level Decisions and Dynamics

Having calibrated the model to match exporter and industry dynamics, we now characterize firm-level decisions and examine the gains from product proximity. Unlike

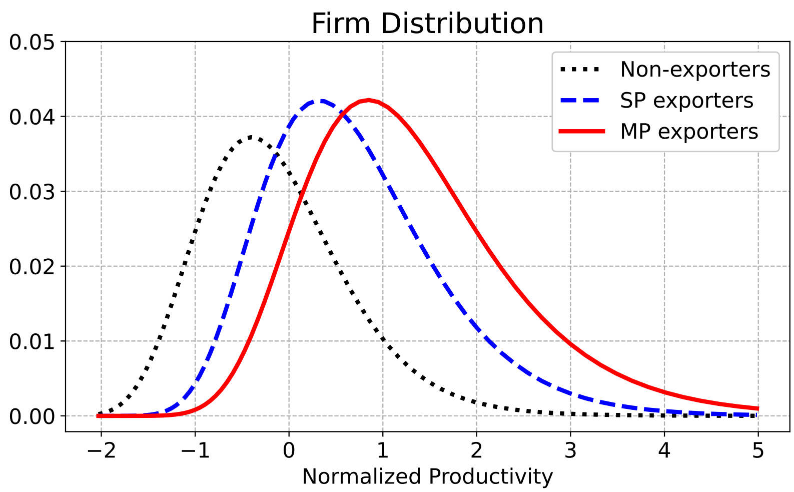


Figure 4: Stationary Distribution of Firms: Model

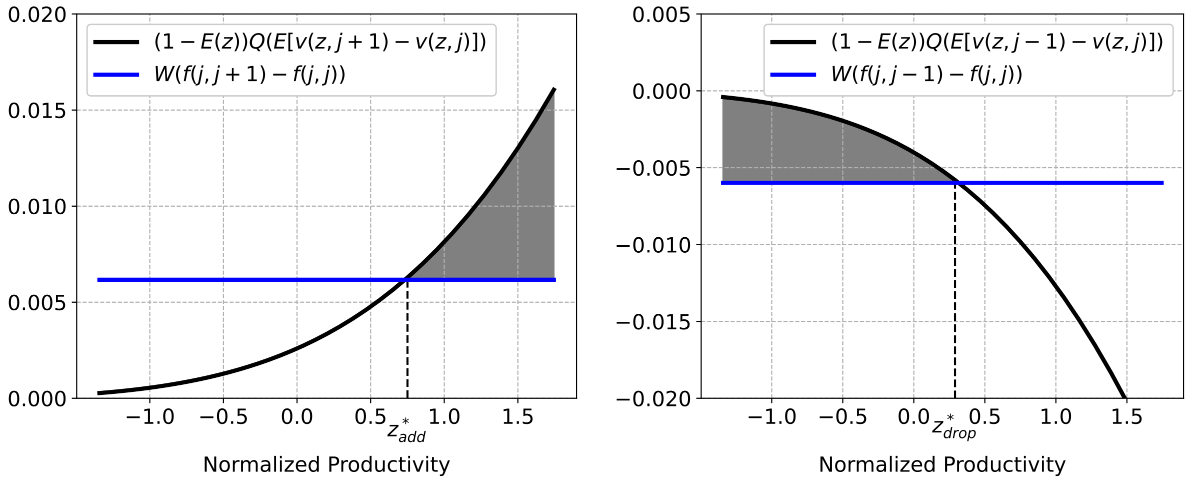
standard binary export models, firms in our framework choose between expanding, shrinking, or maintaining their current export portfolio. Suppose that an exporter is deciding whether to keep its current export portfolio or choose a new portfolio, $\tilde{\omega}'$. We can identify the productivity threshold at which firms optimally chooses the new export portfolio. This threshold is determined by the productivity level z that satisfies:

$$W[f(\tilde{\omega},\tilde{\omega}') - f(\tilde{\omega},\tilde{\omega})] = (1 - E(z))Q\mathbb{E}[v(z',\tilde{\omega}') - v(z',\tilde{\omega})|(z,\tilde{\omega})] \tag{32}$$

At this threshold, the change in the export cost from expanding/dropping products (left-hand side) equals the discounted expected changes in profits from export expansion/reduction (right-hand side). Figure 5 illustrates these decision rules for a particular multiproduct exporter, showing how productivity levels determine optimal export choices.

In both panels of Figure 5, the blue line represents the difference in fixed costs between maintaining the current portfolio and either adding a product (left panel) or dropping a product (right panel). The black line shows the corresponding difference in discounted expected value - the potential gains from adding a product (left panel) or losses from dropping a product (right panel). The intersection of these lines defines productivity thresholds that characterize optimal firm behavior.

Firms expand their export portfolio when their productivity z exceeds z^*_{add}, and



(a) Identifying Add Region (b) Identifying Drop Region

Figure 5: Firm-level Decisions

contract their portfolio when productivity falls below z^*_{drop}. Between these thresholds ($z \in [z^*_{drop}, z^*_{add}]$), firms maintain their current portfolio, creating a region of inaction. Quantitatively, we find that the threshold for adding products (z^*_{add}) lies slightly above 0.5 standard deviation from the mean of the normalized productivity, while the threshold for dropping products (z^*_{drop}) lies below 0.5 standard deviation from the mean of the normalized productivity.

Having characterized firms' decision rules and export costs, we now examine how close product proximities benefit exporters through export cost reductions. Suppose an exporter is deciding whether to expand to a new product set with either high proximity, $\tilde{\omega}^{HP}$, or low proximity $\tilde{\omega}^{LP}$ to its current export portfolio, $\tilde{\omega}$. This would imply that $\tilde{\omega}^{HP} < \tilde{\omega}^{LP}$. Figure 6a illustrates the changes in export costs (blue lines) and discounted expected benefits (black lines) for two different potential portfolios while holding the current portfolio fixed. From eq. 32, we can identify two different productivity thresholds, denoted by z^{HP} and z^{LP} respectively, that correspond to these two potential choices. Similar to the last figure, these thresholds occur at the points where the black and blue lines intersect. The dashed line represents the case of low product proximity between the current and the potential portfolios, where the difference, $\tilde{\omega}^{LP} - \tilde{\omega}$ is high. In this scenario, firms need a relatively high productivity threshold

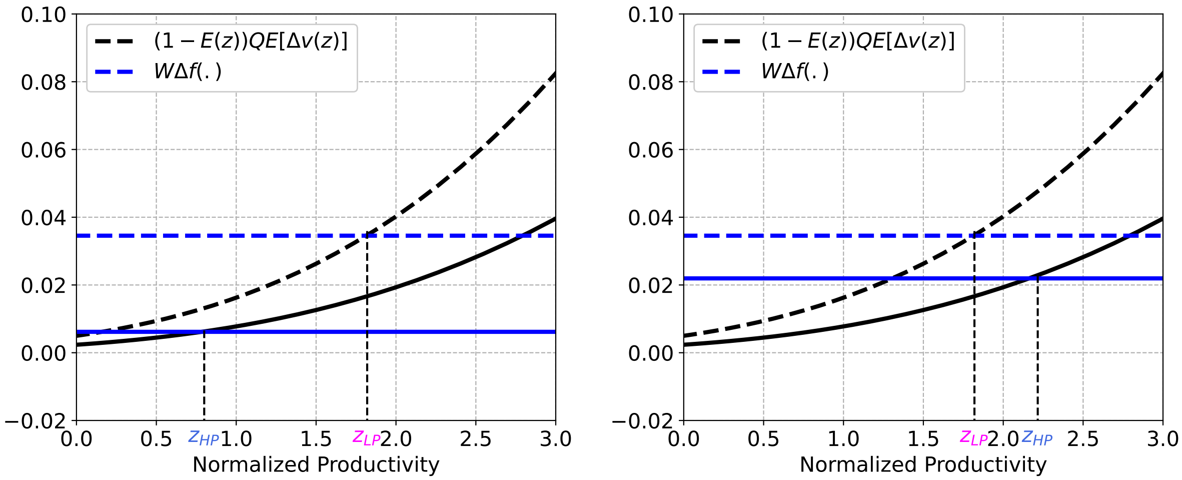
(z_{LP})—approximately 1.8 standard deviations above the mean-to justify expanding their export portfolio to the desired level.

In contrast, the solid lines show the case where the desired export portfolio exhibits high proximity between the current and the desired product portfolios, which implies a lower value of $\tilde{\omega}^{HP} - \tilde{\omega}$. The intersection of expected benefits (black line) and costs (blue line) occurs at a lower productivity threshold (z_{HP}). This lower threshold emerges from two effects: while the potential profit gains are somewhat reduced due to the smaller scope of expansion, the significantly lower export costs associated with introducing exporting similar products more than compensate, making portfolio expansion optimal at lower productivity levels. Quantitatively, we find that z_{HP} is around 1 standard deviation lower than z_{LP}, demonstrating that close product proximity substantially reduces the productivity threshold required for export expansion.

Figure 6b shows that the productivity threshold, z_{HP}, is higher in the case without accouting for gains from close product proximity. This implies that firms actually require a higher productivity threshold to newly export similar products. This result stems from the change to the sunk cost of the export cost function where firms pay uniform costs for each additional product regardless of previous export history. While there is some export cost reduction due to lower continuation costs (as $\tilde{\omega}^{HP} < \tilde{\omega}^{LP}$), there is no cost advantage for introducing products that are close to the firm's current export portfolio. Consequently, the change in export costs does not justify the decline in potential profit, which lead to a higher productivity threshold. These firm-product level decisions significantly influence aggregate dynamics. As demonstrated in subsequent analysis, we find that aggregate welfare gains are reduced in the absence of product proximity gains.

6 Trade Policy Experiments

Having characterized the partial equilibrium decision rules, we now examine how these decisions impact aggregate variables following trade policy changes. We analyze both trade liberalizations and trade wars. While we consider liberalization scenarios to



(a) Standard

(b) No Gains from Proximity

Figure 6: Productivity Thresholds

align more closely with our empirical data, trade war scenarios remain an interest. Therefore, we present results for both types of trade policy changes.

6.1 Trade Liberalizations

In practice, trade liberalization rarely leads to uniform tariff reductions across all products. We explore the quantitative implications of product heterogeneity in our multi-product framework. We model post-liberalization tariffs as a function of product characteristics according to:

$$\tau^{post}(\omega_{ki}) = \max\{\tau^{pre}(1 - \exp(-\psi(\omega_{ki} - \underline{\omega}_i))), 0\}, \tag{33}$$

where ψ controls how product characteristics influence tariff reductions. Figure 7 illustrates the resulting tariff schedules for different values of ψ, with all scenarios allowing for up to a 10 percent reduction in tariffs.

When $\psi = 0$, all products face a uniform 10% tariff cut. With positive ψ values, tariff cuts become product-specific, with smaller reductions applied to more preferred products. At $\psi = 1$, the post-liberalization tariff rates range from 0% for less preferred products to 8% for most preferred products. At $\psi = 5$, several products in the model

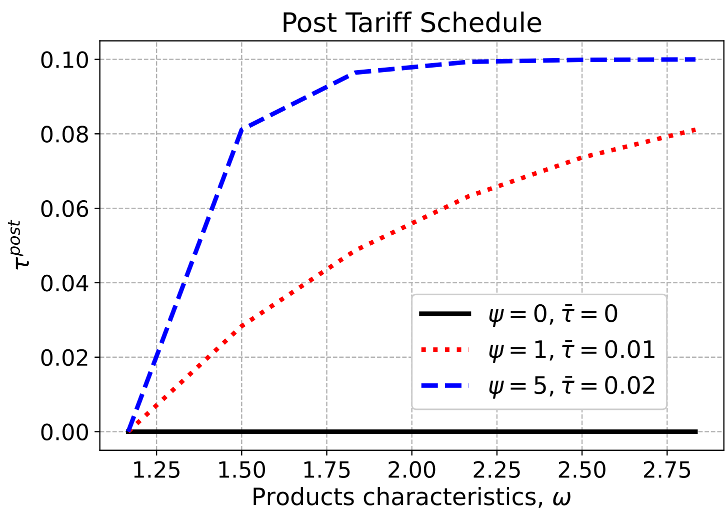


Figure 7: Tariff Schedules

sees no tariff reductions.

Before presenting our simulation results, we note two important features of the model. First, high-valued ω's are products that are highly preferred but exported by only a few very productive firms. This is because the export cost, even the continuation cost, rises as products' relative preferences grow. Second, due to the Pareto distribution of product attributes, only about 19% of the products' tariff rates are impacted by ψ greater than 0. That is, even though it appears that a large proportion of products are not liberalized, when examining the average tariff rates, defined by $\bar{\tau} = \int \tau_k dk$, there is still a substantial degree of trade liberalization in our economy. For example, For example, with $\psi = 1$, the resulting average tariff rate is only about 1%. When $\psi = 5$, the average tariff rate is about 2%.

Figure 8 illustrates the dynamic responses of key aggregate variables to trade liberalization, showing percent deviations from pre-liberalization steady state values. We consider three scenarios: uniform tariff reduction (solid black line) and two cases of heterogeneous tariff reduction (dotted red and dashed blue lines) following our previously described schedules. In all these cases, we assume that tariff reductions are unexpected and decline simultaneously. Let us first examine the uniform case where all tariffs decline by 10 percent.

The long-run effects show substantial gains: consumption increases by 3.5%, output by 6%, and capital stock by 10%. Wages rise by 10% as firms engage in more trade. The transition paths exhibit interesting dynamics. The initial surge in consumption leads to a sharp increase in real interest rates which are determined by the household's Euler equations. This temporarily depresses capital investment, though firms quickly resume capital accumulation as interest rates normalize.

The industry dynamics experience significant changes during the transition. Increased competition causes lower productivity firms to exit and the number of establishments declines by almost 6%. This triggers labor market adjustments as workers reallocate towards remaining productive firms. These adjustments cause slight overshooting in several variables: consumption peaks at 4% above the steady state, while output, capital, and wages each exceed 10%, and labor used in production rises by 5%.

As previously noted, higher values of ψ correspond to steeper tariff schedules, resulting in higher average tariff rates and greater protectionism across products. This, in turn, leads to largely different transition dynamics, even though tariffs directly affect only a relatively small share of high-ω products. These scenarios are depicted by dotted red lines ($\psi = 1$) and dashed blue lines ($\psi = 5$). While most of the aggregate variables still exhibit relatively mild hump-shaped transitions following partial trade liberalization, their quantitative values differ significantly despite the relatively low average tariff rate. This reflects the interconnection between products and their potential to generate substantial spillover effects.

The impact of spillovers on key economic variables is significant. For consumption, the peak gains are halved, dropping from 4% in the uniformly liberalized case to 2% when $\psi = 5$ as well as eliminating the overshooting of consumption. Peak gains in output are reduced to 8% when $\psi = 1$ and 6% when $\psi = 5$, respectively. The long-run effects are also considerably diminished: consumption gains fall to 2.3% compared to 3.4% in the uniform case, while output gains settle at 5.6% (when $\psi = 1$) and 4.1% (when $\psi = 5$).

We now examine the welfare gains from trade in our economy and analyze the

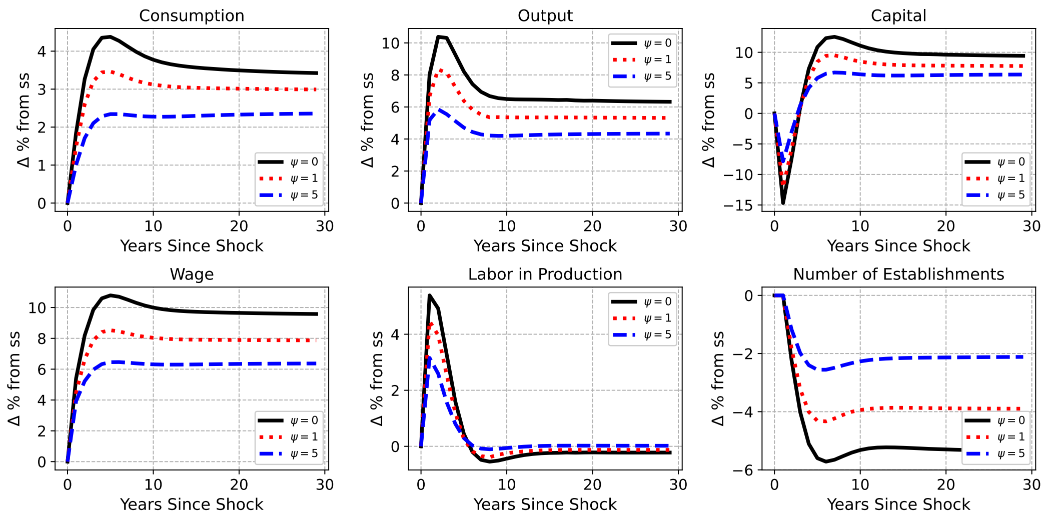
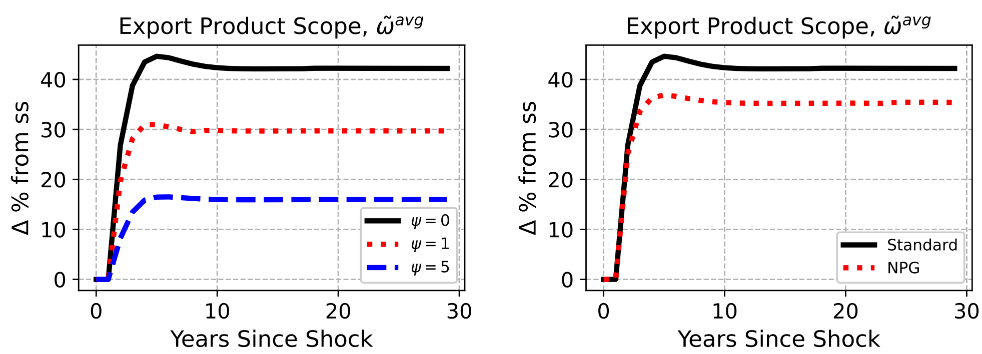


Figure 8: Trade Liberalization Dynamics - Aggregates

quantitative implications of gains from product proximity. Table 6 presents welfare gains from trade liberalization across various scenarios. In our standard calibrated model, which is shown in the first row (standard), welfare gains that account for transition dynamics slightly exceed those from steady-state comparisons alone, driven by industry dynamics. A uniform decline in tariffs generates welfare gains of approximately 3.41%, while heterogeneous tariff reductions yield gains are substantially less at 2.85% when $\psi = 1$ and 2.12% when $\psi = 5$. Steady-state welfare is also higher than the welfare that accounts for the transition, which is driven by the lack of overshooting in the aggregate consumption.

We then compare the welfare gains from trade between the Standard economy and the one that does not account for gains from product proximity. This comparison is shown in the second and third rows of Table 6. Product proximity generates higher welfare gains in most scenarios through two key mechanisms: larger export cost reductions and enhanced gains from product laddering. Quantitatively, under flat tariff schedules ($\psi = 0$), the baseline model with product proximity produces welfare gains approximately 8% larger than the no proximity gains (NPG) case. This difference increases to 15% under steeper tariff schedules ($\psi = 5$), as detailed in the third row of Table 6.

The welfare gap reveals an important interaction: even when products with high relative preferences face smaller tariff reductions, firms that experience gains from



(a) Standard with Different ψ's (b) Standard vs. NPG ($\psi = 0$)

Figure 9: Trade Liberalization and the Dynamics of Export Product Scope

product proximities are more likely to introduce new products. In contrast, firms in the NPG economy face constant per-product costs, making portfolio expansion less attractive when tariff reductions are heterogeneous. In summary, these results imply that not accounting for product-level interactions can underestimate welfare gains from trade by as much as 15%.[13]

To illustrate this point more clearly, we define the economy-wide average export product scope, which we denote with $\tilde{\omega}^{avg}$, as $\frac{\int \tilde{\omega} d\Lambda(z,\tilde{\omega})}{\int d\Lambda(z,\tilde{\omega})}$. A larger value of $\tilde{\omega}^{avg}$ indicates that firms are exporting a broader range of products. In Figure 9, we plot the dynamics of these variables as percentage deviations from the initial steady state for the trade liberalization experiments considered so far. The left panel, Figure 9a, presents these changes for various values of ψ. As shown in the figure, under unilateral trade liberalization—where all tariffs decline—the export product scope increases by approximately 42% in the long-run and peak at 45%, which is substantial. In contrast, when there is significant heterogeneity in tariff reductions, with only minimal declines for highly preferred products, firms do not expand their product portfolios as much and these responses reduce welfare gains from trade.

Similarly, Figure 9b compares the degree of export expansions at the product-level with and without proximity. As in the left panel, when we modify the fixed cost

[13] In the Appendix, we discuss additional simulation results where we dropped the assumption that firm-level productivity and product space were uncorrelated. We continue to find that proximity gains amplify welfare changes to trade liberalizations.

structure to exclude gains from product proximity, firms expand their product portfolios less than in the standard case. The peak increase in the export product scope is around 37%, which remains substantial but is lower than in the scenario with product proximity. In the long-run, firms expand their export scope by 35%. Thus, product proximity results in approximately 7% more products being added in the long-run. Nevertheless, it is important to note that welfare gains persist even without product proximity or unilateral tariff declines, as the overall decline in average tariff rates leads to efficiency improvements. However, these efficiency gains are smaller because firms do not expand their export portfolios as much.

Table 6: Welfare Gains from Trade for Different Tariff Schedules

	$\psi = 0, \bar{\tau} = 0$		$\psi = 1, \bar{\tau} = 0.1$		$\psi = 5, \bar{\tau} = 0.2$	
CEV(%)	SS	Trans	SS	Trans	SS	Trans
Baseline						
(1) Standard	3.38	3.40	2.98	2.85	2.37	2.12
(2) NPG	3.18	3.15	2.88	2.68	2.03	1.84
(1)/(2)	1.06	1.08	1.03	1.06	1.17	1.15

Note: The welfare gains are calculated as the lifetime consumption that the household from the post-liberalized economy is willing to give up to stay. SS compares steady state welfare and Trans incorporates transition dynamics. NPG refers to the case where there are no gains from proximity. See text for details.

6.2 Trade Wars

In this section, we study alternative trade policies where both countries raise trade barriers rather than reducing them. To quantify how product-level interactions impact aggregates in the event of a trade war, we compare two types of trade barriers. In the first case, we examine a flat tariff schedule where we increase the tariff rates of all products from 10% to 20%. We call this the flat tariff policy. In the second case, we study a more targeted tariff policy where, while the average tariff rate remains 20%, we vary the tariff structure depending on product characteristic, ω, as in the previous section so that products with higher ω values face larger tariff rates. In this targeted scenario, the majority of products with relatively low characteristic values actually have

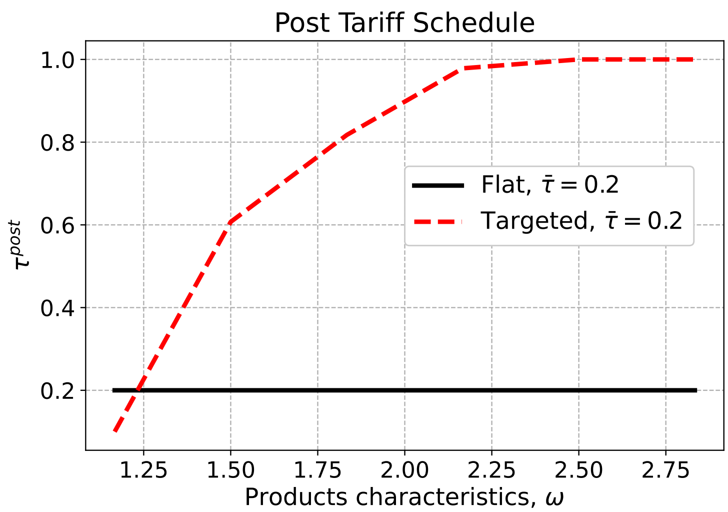


Figure 10: Tariff Schedule: Protectionism

post-scheduled tariff rates below 20%. Some tariff rates for products with very high ω values can reach as high as 100% in this tariff structure.[14] These two different tariff schedules are plotted in Figure 10. The solid black line represents the flat tariff scenario and the dotted red line shows the targeted tariff scenario.

Figure 11 plots how aggregate consumption, output, capital, wage, labor used in production, and mass of firms change in response to the two tariff policies cited above. We observe significant macroeconomic impacts in both scenarios. Capital stock rises initially following the implementation of trade barriers as interest rates decline. Despite this short-term increase, our simulations show that capital stock ultimately settles below its initial steady state value in the long run. The number of establishments also rise because firms face reduced competitive pressure, allowing less productive firms to remain in the market longer than they would under more intense competition.

When comparing targeted and flat tariff structures, we find meaningful differences in adjustment dynamics and welfare outcomes. Output, capital, and labor in production experience sharper initial declines under the targeted structure, as firms aggressively adjust their export portfolios in response to the higher tariff levels imposed on specific products. These more pronounced adjustments have substantial impacts on long-run

[14] We have found that our results are robust to different tariff schedules as long as the tariff rate increases with product characteristics.

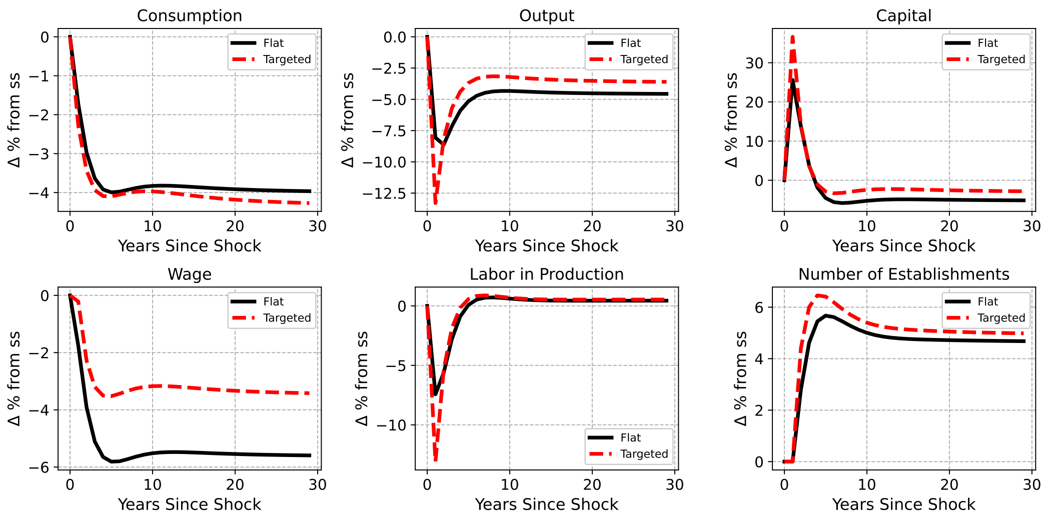


Figure 11: Aggregate Dynamics - Trade War

consumption levels and lead to larger welfare losses. Quantitatively, our simulations indicate that the flat tariff schedule results in a welfare loss of approximately 3.59%, while the targeted tariff schedule generates a welfare loss of about 3.84%—representing a roughly 7% larger welfare reduction under targeted trade policies.

These findings suggest that while economic damages from a trade war are sizable regardless of approach, the structure of tariffs plays an important role in determining the magnitude of these damages. Our simulations demonstrate that product-level interactions stemming from product proximities make flat tariff structures less economically damaging than policies specifically targeting products highly preferred by consumers. This result provides important insights for policymakers considering the design of trade barriers when trade restrictions become unavoidable.

7 Conclusion

Jerome Powell's observation that "higher inflation is a possible outcome which will depend very much on specific facts of what goods are taxed and by how much" highlights the critical importance of product-level analysis in trade policy.[15] This paper

[15] *https://www.reuters.com/markets/us/feds-powell-heads-congress-with-good-data-hand-rising-uncertainty-2025-02-11/.*

demonstrates that firms' product-level export decisions follow specific patterns of product proximity, with significant macroeconomic implications.

Our analysis of Chinese firm-level customs data reveals two key facts. First, multiproduct exporters show remarkable persistence in export status across time periods, suggesting substantial sunk costs and firm-specific export capabilities. Second, firms exhibit strong tendency to introduce new products that are proximate to their existing export portfolios, indicating a structured approach to export expansion.

Motivated by these empirical findings, we develop and estimate a dynamic general featuring multiproduct firms with heterogeneity at both firm and product levels. In the model, firms face product portfolio-dependent export costs, capturing the idea that expanding into products related to current exports is less costly than venturing into entirely new categories. This mechanism incentivizes firms to adjust exported products based on their proximity over time, enabling them to benefit from reduced export costs as their product portfolios change.

The estimated model successfully matches key industry and product churning moments from the data. Furthermore, although not directly targeted in the estimation, the model also captures the substantial persistence in exporter status of different types, the rising export intensity of new exporters, and their increasing survival probabilities over time.

Our policy simulations reveal that product proximity amplifies the effects of tariff changes—whether liberalization or protection—by influencing firms' product mix adjustments. Notably, policies targeting highly preferred products generate larger welfare effects due to firm-level reallocation across proximate products. These findings emphasize the importance of incorporating product proximity into trade policy models and underscore the necessity of product-level data for comprehensive evaluation of trade reform's distributional and efficiency impacts.

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