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Tariffs on Input Trade Margins under Vertical Oligopoly: Theory and Evidence*

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Abstract

What is the effect of tariffs on the input trade margins when vertically related markets are oligopolistic? To address the question, this paper develops a vertical oligopoly model in which one country specializes in producing a final good while another country specializes in producing an intermediate good by taking into account strategic interactions among firms. We find that, for constant-elasticity demand, a tariff reduction increases the number of trading firms (extensive margin) and average trade value per firm (intensive margin) in the vertically related sectors, raising the intensive margin relative to the extensive margin. To assess the empirical relevance of our theoretical results, we focus on China's WTO accession which was a large policy change to Chinese firms. We find that a tariff reduction significantly increases both margins in the post-WTO period, though the effect on the extensive margin is much smaller than that on the intensive margin.

Keywords: Import tariffs, input trade, vertical oligopoly, extensive and intensive margins
JEL Classification Numbers: F12, F13, F14

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1 Introduction

Recent years have witnessed faster growth of intermediate inputs in world trade volume. It is often said that increased input trade has been triggered by *vertical specialization* where each country engages in a particular stage of production sequences spread across the globe. Such specialization on a global scale is also occasionally referred to as *global value chains* (GVCs) where each country completely specializes in production at each stage.[1] Furthermore, not only does foreign direct investment but also foreign outsourcing plays an important role in fragmenting production processes. When analyzing firms' decision regarding how and where to purchase input from foreign independent suppliers, most work in the existing literature emphasizes relationship specificity and contract incompleteness in the input price negotiation among particular buyer-seller relationships.[2] In practice, however, a large fraction of intermediate inputs is simultaneously traded on the markets where the input price is determined at the market-clearing level, which equates the total demand of anonymous buyers to the total amount of intermediate input supplied by anonymous sellers.

There is established evidence documenting the difference between contractual agreements and spot markets. Dividing manufactured goods into three groups, Rauch (1999) finds that differentiated goods tend to be traded by preexisting close ties (such as contractual agreements), while homogeneous goods tend to be traded on spot markets. Applying the Rauch (1999) classification to intermediate inputs, Nunn (2007) finds that differentiated inputs tend to be exchanged by non-market mechanisms, while homogeneous inputs tend to be exchanged by market mechanisms. Moreover, other empirical studies find that less developed countries—especially China—tend to produce and trade homogeneous inputs in vertical specialization. For example, adapting the similarity index developed by Schott (2008) to vertical specialization, Dean et al. (2011) show that the similarity between Chinese and OECD exports of intermediate inputs is generally very low. Examining GVCs from China's point of view, Dai et al. (2016) show that Chinese exports are significantly less skill- and R&D-intensive than those of developed countries. The findings imply that a large portion of intermediate inputs would be homogeneous and thus internationally traded on the markets in vertical specialization. Such market-based transactions coincide with recent work documenting the increasing strategic interdependence among large firms that are unlikely to be of measure zero relative to the markets.[3]

This paper develops a vertical oligopoly model where firms strategically produce and sell their product via market-based interactions between vertically related sectors. Following the literature on vertical specialization, we assume that one country (say Home) specializes in producing a final good and another country (say Foreign) specializes in producing an intermediate good. Further, following the evidence that homogeneous goods tend to be exchanged on the markets, we assume that these countries produce homogeneous goods and the price of the intermediate good is determined at the market-clearing level. A Home government imposes tariffs on imported input to affect the terms of trade, recognizing that Home final production requires Foreign intermediate input. In this simple setting, we derive the long-run effect of import tariffs in a free-entry equilibrium, distinguishing the number of trading firms (extensive margin) and average trade value per firm (intensive margin). In so doing, we consider the production side peculiar to oligopoly (i.e., strategic interactions among firms) and the demand side (i.e., elasticity and convexity of demand) in a unified framework, which is shown to be useful for examining how trade liberalization affects the input trade margins under vertical oligopoly.

[1] See Yi (2003, 2010) for the importance of vertical specialization. Antràs and Gortari (2020) and Johnson and Moxnes (2023) examine this kind of specialization in a framework of GVCs.

[2] For papers in this literature, see, in alphabetical order, Acemoglu et al. (2007); Antràs (2003); Antràs and Helpman (2004); Costinot (2009); Grossman et al. (2023); Ornelas and Turner (2008, 2012).

[3] For example, Head and Spencer (2017) find that only a few large firms participate in international trade and the markets are becoming more concentrated toward these firms over time, suggesting that market structure is more characterized by oligopoly.

We show that, when the market structure is endogenous via free entry, a reduction in tariffs always increases the *extensive* margin in the downstream and upstream sectors. However, a tariff reduction increases the *intensive* margin in each sector only for strictly convex demand. This contrasting effect on the trade margins is explained as follows. Regarding the extensive margin, a reduction in tariffs decreases production cost of all firms involved in vertical specialization and increases the profitability of Home and Foreign firms, which induces them to enter more into the respective sectors. This effect of tariffs is unique to our *vertical* oligopoly model where Home's final good and Foreign's intermediate good are *complements*: a reduction in tariffs leads to *co-movement* of firm entry in the vertically related sectors. This stands in sharp contrast to *horizontal* oligopoly models where traded goods are *substitutes*: a reduction in tariffs leads to *de-location* of firms by making it easier for Foreign firms to sell their final good to the Home market, which encourages the entry of Foreign firms but discourages the entry of Home firms (e.g., Bagwell and Staiger, 2012). Hence, our analysis reveals that this long-run impact of tariffs on firm entry and exit might not necessarily hold true in the world of vertical disintegration via complementarity of production.

In contrast, a reduction in tariffs can increase or decrease the intensive margin, as an increase in aggregate trade (by a tariff reduction) can be more or less than proportionate with an increase in the extensive margin. Consider Home firms' intensive margin. A reduction in tariffs directly increases Foreign input imports from the upstream sector which raises each Home firm's output in the downstream sector by reducing production cost. When the market structure is endogenous, a tariff reduction also induces the entry of Home and Foreign firms. As Foreign firms enter more, the input price determined at the market-clearing level is lower, which prompts each Home firm to increase their output further. As Home firms enter more, however, surviving Home firms face increased competition, which decreases each Home firm's output. Due to these effects related to co-movement of firm entry, the effect of tariffs on the average output per Home firm is generally ambiguous. We find that whether a tariff reduction raises Home firms' intensive margin depends on the demand structure. In particular, Home firms' intensive margin falls with tariffs if and only if demand is strictly convex. For linear demand, the positive and negative effects of tariffs exactly offset each other, so as to leave the intensive margin independent of tariffs. The finding also applies to Foreign firms' intensive margin in the upstream sector, in the sense that it critically depends on the demand structure.[4]

If a tariff reduction increases both extensive and intensive margins, which margin increases relatively more? As argued by Buono and Lalanne (2012), it is important to address whether a tariff reduction increases trade flows by permitting the entry of new firms into a foreign market (extensive margin) or raising the average trade value of incumbent firms (intensive margin), because it is directly related to who gains from trade liberalization. By assuming constant-elasticity demand that is quite common in the trade literature, our model predicts that while a tariff reduction increases both extensive and intensive margins, the intensive margin rises relatively more than the extensive margin, which holds in the upstream and downstream sectors. The reason is closely related to a pro-competitive effect: for this specific demand, a reduction in tariffs always leads to a proportional decline in firms' profit margin in the vertically related sectors. Consequently, the decreased profit margin generates a limited entry effect of new firms (via an increase in the extensive margin) relative to a scale effect of incumbent firms (via an increase in the intensive margin).

To assess the empirical relevance of our predictions, we use the Chinese transaction-level import data and focus on China's WTO-accession related reductions in import tariffs in the post-2001 period. During 2000–2007,

[4]These results on the extensive and intensive margins bear some resemblance to those in a recent literature of firm heterogeneity. One of the differences is that a response of the intensive margin to variable trade costs depends on the demand side (i.e., demand curvature) in our vertical oligopoly model; while it depends on the supply side (i.e., firm distribution) in monopolistic competition models, as reviewed by Melitz and Redding (2014). We will elaborate on this point in the literature review below.

Table 1: Ten most concentrated industries in China, 1998

Most concentrated			
CIC	Industry description	HHI	Upstreamness
4039	Applied TV equipment and other audio-video equipment	0.681	2.584
4127	Nucleon and nuclear radiation measuring apparatus manuf.	0.609	3.060
3313	Nickel cobalt smelting	0.573	4.877
4159	Other stationary and office machine manufacturing	0.527	3.060
3759	Navigation mark and other floating equipment manuf.	0.517	2.617
4124	Meter apparatus for forming, forestry and fishing manuf.	0.516	3.666
2433	Electronic musical instrument	0.479	2.781
3723	Trolley manufacturing	0.457	2.953
2413	Teaching specimen and mode	0.441	2.781
4152	Slide projector and overhead projector manuf.	0.396	3.060
		0.519	3.144

Source: China's annual survey of industrial firms and authors' calculations.
Note: The data cover industrial firms with sales above 5 million RMB and all state-owned enterprises, including both importers and non-importers in manufacturing industries.

Chinese aggregate imports, extensive, and intensive margins of input trade respectively grew at an annual rate of 23.5%, 8%, and 15.5% on average at the country-product level. Incorporating a rich set of fixed effects in a linear regression model, reductions in average tariffs by 1.2% per year accounts for approximately 16% of the import growth, 6% of the extensive margin growth, and 20% of the intensive margin growth. Our difference-in-difference specification attributes a larger role to the extensive margin accounting for approximately a quarter of the overall response in intermediate goods in the post-WTO period. This supports our theoretical results that tariff reductions significantly increase both margins, though the effect of tariff reductions on the extensive margin is much smaller than that on the intensive margin. Our finding is different from that in previous papers in this literature (e.g., Debaere and Mostasharic, 2010; Buono and Lalanne, 2012) which show that tariff reductions do not necessarily allow new firms to start exporting or importing; instead, the effect of such liberalization mainly operates through the intensive margin, whereby incumbent firms mostly increase their shipments in response to lower tariffs. Our analysis implies that the difference primarily stems from whether the papers consider trade liberalization in a developed versus developing country, rather than whether the papers analyze different types of trade, such as export versus import side of trade and intermediate versus final goods trade.

The key premise of the paper is that the vertically related sectors are oligopolistic. As an illustration of the potential empirical relevance of our setting, Table 1 provides a list of the ten most concentrated industries in terms of the Herfindahl-Hirschman Index (HHI) along with the upstreamness of industry production by using China's annual survey of industrial firms in 1998. While the HHI is computed in a usual way, the upstreamness is computed by applying the measure of Antràs et al. (2012). Table 1 shows that some industries are featured with high concentration in 1998 (the median HHI is 0.03 in this year). Further, industries whose HHI is above the median played a pivotal role in the Chinese economy: they accounted for 38.9% of sales, 30.1% of exports, and 26.6% of employment. We also find a negative relationship between the HHI and upstreamness: the average upstreamness is 3.144 for the ten most concentrated industries (3.395 for the ten least concentrated industries). These figures imply that some industries are indeed characterized by oligopoly, albeit more upstream industries are associated with a weaker degree of concentration.

Our paper contributes to the literature of vertical specialization and GVCs. Most papers in this literature consider perfectly competitive firms in a multistage production process where production stages are completed sequentially. For example, Antràs and Gortari (2020) explore the specialization pattern of participant countries within GVCs that is endogenously determined with trade barriers, while Johnson and Moxnes (2023) find that input trade is more sensitive to changes in trade costs than final goods trade due to the endogenous reorganization of GVCs.[5] Our model setting is simpler than that of previous work in that we consider two production sectors (i.e., upstream and downstream sectors) but try to shed new light on the key aspect ignored by existing studies: imperfect competition and strategic interdependence among firms in vertically related sectors. As the number of firms in each sector is endogenously determined by free entry in the model, this consideration also allows us to make interesting predictions on the extensive and intensive margins in vertical specialization.

A handful of papers have analyzed vertical relationships in oligopoly. Ishikawa and Spencer (1999) examine the effect of export subsidies for an imported intermediate good on social welfare in vertically related markets with a fixed number of firms. Ghosh and Morita (2007) study social efficiency in terms of the number of firms in a vertical oligopoly model with free entry. These papers, however, do not consider the effect of policy changes on the input trade margins. On the other hand, using single-stage oligopoly models, Horstmann and Markusen (1986), Venables (1985) and, more recently, Etro (2011), Bagwell and Staiger (2012) all show that the effect of tariffs may be substantially altered when invoking the free entry condition in oligopolistic markets. We extend this valuable insight to a vertical oligopoly model to examine the long-run effect of tariffs on firm entry and exit in the presence of international disintegration of production.

Demand-side conditions, like the elasticity and convexity of demand, play an important role in determining the impact of tariffs on input trade margins in the vertical oligopoly framework. This finding is reminiscent of Mrázová and Neary (2017) who highlight how the demand structure critically shapes the degree of pass-through under monopoly and monopolistic competition. Our vertical oligopoly model is able to offer a richer context, thereby incorporating strategic interactions among firms and vertical linkages across countries. However, unlike Mrázová and Neary (2017), we do not consider general demand functions; instead we focus on restrictive demand functions to keep our analysis tractable and use a specific demand function to provide precise characterizations of the impact of tariffs.

Our empirical framework is most closely related to that in Buono and Lalanne (2012). They find that tariff reductions by the Uruguay Round do not lead more firms to start exporting (extensive margin) but only induce incumbent firms to increase their shipments (intensive margin) for French firms.[6] In contrast, we find that tariff reductions by China's WTO accession significantly increases the two trade margins, though the impact is larger on the intensive margin than on the extensive margin for Chinese firms. Like theirs, our result differs from that highlighting the larger role of the extensive margin relative to the intensive margin in the gravity equation (e.g., Bernard et al., 2007), as we mainly consider tariffs, not distance, as variable trade costs. On the other hand, our finding that tariff reductions raise the extensive margin has a similar flavor to that in previous work using the China Customs data. For example, Feng et al. (2017) find that the acceleration of China's export growth after its WTO accession is explained by reductions in trade policy uncertainty, allowing Chinese firms to enter export markets. However, they focus mainly on the effect of China's WTO accession on the extensive margin. We instead show that although tariff reductions by the WTO accession raise the extensive margin, this effect is quantitatively much smaller than that on the intensive margin.

[5] See Antràs and Chor (2022) for a comprehensive literature review on GVCs. We use the terms "stage," "sector," and "industry" synonymously in this paper.

[6] Using cross-sectional data, Egger et al. (2011) find the limited effect of preferential trade agreements on the extensive margin of exporting firms. Following Buono and Lalanne (2012), we mainly use panel data to obtain our results.

2 Theory

This section develops a model of vertical specialization with input-output linkages across countries. There are two countries, say Home and Foreign, that produce final and intermediate goods in downstream and upstream sectors, respectively. Oligopolistic Foreign firms produce an intermediate good in the upstream sector, whereas oligopolistic Home firms produce a final good using imported input subject to tariffs in the downstream sector. We first describe our model setup and solve for equilibrium keeping the number of firms in each sector fixed. Then, we impose the free entry condition and study the long-run effect of tariffs on the number of trading firms (extensive margin) and the average trade value per firm (intensive margin) in each sector. Finally, we specify the demand function and address which trade margin increases relatively more by a tariff reduction.

2.1 Basics

Consider first the structure of consumer preferences and demand. Home has a unit mass of identical consumers with a quasi-linear utility function, $U = U(Q) + y$, where Q is aggregate output produced under oligopoly and y is a numeraire good produced under perfect competition. Foreign has no consumers. Assuming income to be sufficiently high, utility maximization subject to budget constraint gives an inverse demand function $P = P(Q)$. We assume that the function is continuous, twice differentiable, and strictly decreasing in aggregate output with $P'(Q) < 0$ for all $Q \geq 0$. Following Mrázová and Neary (2017), we measure the slope and curvature of demand in terms of the elasticity and convexity of the inverse demand function, respectively, defined as

$$\varepsilon(Q) \equiv -\frac{P(Q)}{QP'(Q)}, \qquad \rho(Q) \equiv \frac{QP''(Q)}{P'(Q)}.$$

Note that the demand is convex if and only if $\rho < 0$. We impose the following two restrictions on these measures. First, while the elasticity of demand is naturally greater than zero, the convexity is greater than minus two.[7] Loosely speaking, the latter condition rules out inverse demand functions that are too convex, requiring that final-good industry marginal revenue $(QP(Q))'$ falls with Q. Thus, for all $Q \geq 0$, we impose

$$\varepsilon(Q) > 0, \qquad \rho(Q) > -2. \tag{1}$$

Second, the elasticity of demand is weakly decreasing in aggregate output. This assumption is quite standard in monopoly and oligopoly, and is also sometimes made in monopolistic competition (e.g., Krugman, 1979), with the elasticity being defined in terms of firm-level output instead of aggregate output. For simplicity, we assume that the convexity of demand measured by ρ is constant. Thus, for all $Q \geq 0$, we impose

$$\varepsilon'(Q) \leq 0, \qquad \rho'(Q) = 0, \tag{2}$$

To understand our restrictions, consider constant-elasticity demand that is widely used in the trade literature: $P(Q) = AQ^{-1/\sigma}$ where $\sigma > 1$. The elasticity of demand is $\varepsilon = \sigma > 1$ and the convexity of demand is $\rho = -(\frac{\sigma+1}{\sigma})$, taking $-2 < \rho < -1$ under (1). Further, both elasticity and convexity are constant, satisfying (2). This feature of demand structure is very special in that the two measures of demand are determined by a single parameter σ where an admissible combination of (ε, ρ) is narrower than that of (1) and (2). We will use this specific demand later, but let us consider the general demand satisfying (1) and (2) for now.

[7] Mrázová and Neary (2017) define ρ with a minus sign so that the convexity is smaller than two. Like theirs, the restriction is closely related to the second-order condition of firms' profit-maximization problem (see Appendix A.1).

The production side is characterized by vertical oligopoly. Each Home and Foreign firm first decide whether or not to incur the entry costs K_H, K_F, respectively. After entry, M Home firms and N Foreign firms compete in quantities in the respective sectors. Home firms require one unit of the intermediate good to produce one unit of the final good. The intermediate good is imported subject to ad valorem tariffs τ imposed on the input price r and transform it into the final good without any additional cost. Hence Home firms' per unit cost is $r\tau$. On the other hand, Foreign firms incur constant marginal cost c as well as iceberg transport cost t to ship the intermediate good to Home firms. Hence Foreign firms' per unit cost is ct.

As explained in the Introduction, we are interested in market-based interactions between vertically related sectors. We thus assume that the input price r is determined at the market-clearing level of the intermediate good, which equates the total demand of Home firms to the total amount of intermediate input supplied by Foreign firms. Taking the input price and the tariff rate as given, Home firms produce the final good as Cournot competitors. This price-taking behavior of Home firms implies that each Home firm has no oligopsony power over the upstream sector, which is a standard modeling choice in the literature on successive vertical oligopoly (e.g., Ishikawa and Spencer, 1999; Ghosh and Morita, 2007).

The timing of the game is as follows. First, a large number of identical entrants exist in both countries, each of whom must decide whether to enter each sector. Should a Home firm decide to enter the downstream sector, it must incur the entry cost K_H. Similarly, a Foreign firm must incur the entry cost K_F if it decides to enter the upstream sector. Upon entry, Cournot competition occurs among M Home firms in the downstream sector and N Foreign firms in the upstream sector. As usual, we solve the model backwards.

2.2 Short-Run Analysis

Home firms engage in Cournot competition in the downstream sector where profits of Home firm $i(= 1, 2, ..., M)$ are $\pi_{Hi} \equiv \big(P\big(q_i + \sum_{j\neq i}^{M} q_j\big) - r\tau\big)q_i$. Home firm i chooses q_i to maximize its profits, taking other Home firms' quantities q_j (for $j \neq i$) as given. Solving the first-order conditions of Home firms' profit-maximization problem, there exists a symmetric Nash equilibrium $q_1 = q_2 = ... = q_M \equiv q(> 0)$ such that

$$q = -\frac{P(Q) - r\tau}{P'(Q)},$$

where aggregate output in the downstream sector Q is obtained by aggregating q over all M Home firms, i.e., $Q = Mq$. From q above, this is implicitly given by

$$MP(Q) + QP'(Q) = Mr\tau. \tag{3}$$

Next we consider the demand for intermediate input. (3) shows that, for a given input price, the smaller are import tariffs that Home firms pay, the greater is aggregate output that Home firms produce in the downstream sector. This affects the input demand of Home firms, which in turn affects aggregate output that Foreign firms produce in the upstream sector. To analyze this kind of interactions between downstream and upstream sectors, let X denote aggregate output produced by Foreign firms at any input price. As production of one unit of the final good requires one unit of the intermediate input, it must equal aggregate output produced by Home firms so that $X = Q$. Substituting Q with X in (3) and rearranging, the input price is given by

$$r = \frac{P(X) + \frac{XP'(X)}{M}}{\tau} \equiv g(X, M, \tau). \tag{4}$$

If the input price is determined at the market-clearing level, the inverse demand function faced by Foreign firms is given by (4). In addition, treating the number of firms as a continuous variable, (4) implies that the demand for intermediate input satisfies the following inequalities:

$$g_X(X, M, \tau) < 0, \quad g_M(X, M, \tau) > 0, \quad g_\tau(X, M, \tau) < 0.$$

From the signs of partials, it follows immediately that (i) the input demand is downward-sloping; (ii) an increase in the number of Home firms raises the input demand; and (iii) a reduction in import tariffs works as a reduction in production cost of Home firms, which helps boost the input demand. As formally shown in Appendix A.2.1, all features of the input demand hold for any inverse demand functions $P(Q)$ that satisfy the elasticity and convexity of demand given in (1).

In addition to these, the inverse demand function whose curvature is constant, as stated in (2), has one more interesting feature of the input demand. Differentiating (4) with respect to X twice, we find that changes in the input price necessarily require the third derivative of the inverse demand function $P'''(X)$. However, this class of inverse demand functions enables us to bypass that complication keeping constant the curvature of demand measured by ρ. Exploiting that fact, the convexity of demand for intermediate input is given by

$$\frac{Xg_{XX}(X, M, \tau)}{g_X(X, M, \tau)} = \frac{QP''(Q)}{P'(Q)} = \rho. \tag{5}$$

(5) shows that the convexity of demand is exactly the same between the final good and the intermediate good.[8] While admittedly special to constant convexity in (2), the feature of demand structure is remarkably useful in characterizing an equilibrium of vertical oligopoly. As a result, the convexity of demand in (1) and (2) applies to the demand for intermediate good. In particular, intermediate-good industry marginal revenue $\left(Xg(X, M, \tau)\right)'$ decreases with X as well.

Perceiving Home firms' demand of intermediate inputs above, Foreign firms engage in Cournot competition in the upstream sector where profits of Foreign firm $i(= 1, 2, ..., N)$ are $\pi_{Fi} \equiv \left(g\left(x_i + \sum_{j\neq i}^{N} x_j, M, \tau\right) - ct\right)x_i$. Foreign firm i chooses x_i to maximize its profits, taking other Foreign firms' quantity x_j (for $j \neq i$) as given. Solving the first-order conditions of Foreign firms' profit-maximization problem, there exists a symmetric Nash equilibrium $x_1 = x_2 = ... = x_N \equiv x(> 0)$ such that

$$x = -\frac{g(X, M, \tau) - ct}{g_X(X, M, \tau)},$$

where aggregate output in the upstream sector X is obtained by aggregating x over all N Foreign firms, i.e., $X = Nx$. From x above, this is implicitly given by

$$Ng(X, M, \tau) + Xg_X(X, M, \tau) = Nct. \tag{6}$$

The short-run equilibrium is characterized by either (3) or (6) for a given market structure (i.e., fixed M, N). The following lemma reports the comparative statics results with respect to import tariffs τ and the number of firms M, N (see Appendix A.2.1 for proof).[9]

[8] We will show that just as the convexity of demand ρ is the same between intermediate and final goods with constant convexity, the elasticity of demand ε is also the same between the two types of goods with constant elasticity (see Section 2.4).

[9] Although transport cost t can be similarly examined, we only report comparative statics results with respect to import tariffs, as we will mainly focus on the effect of import tariffs in the empirical analysis.

Lemma 1. *When the market structure is fixed, we have the following effects on equilibrium variables:*

(*i*) *A reduction in import tariffs increases aggregate output and firm-level output.*

(*ii*) *An increase in the number of firms in one sector increases aggregate output but decreases firm-level output in that sector; however, it increases firm-level output in another sector.*

(*iii*) *Import tariffs always improve the terms-of-trade for Home.*

Naturally, aggregate output increases (the price of the final good decreases) with a reduction in tariffs and an increase in the number of firms in each sector. A tariff reduction acts as declined production cost of firms while an increase in the number of firms acts as increased competition. A tariff reduction increases firm-level output (intensive margin) as well, because the number of firms is fixed. In contrast, the effect of increased competition on the intensive margin is nuanced. Entry in one sector steals business from existing firms in that sector but creates business in another sector due to input-output linkages. For example, when the number of Home firms rises, this leads to increased competition in the downstream sector and reduces Home firms' intensive margin; however, this leads to increased demand for intermediate input in the upstream sector and raises Foreign firms' intensive margin. The opposite is true for the number of Foreign firms.

As import tariffs decrease aggregate output, the increased elasticity of demand leads to the lower input price. A reduction in the input price by tariffs acts as the terms-of-trade improvement for Home, though this is more like firms' terms-of-trade. As in horizontal specialization, the Home government imposes tariffs on Foreign input to affect the terms-of-trade, recognizing that Home final production rests on such input in vertical specialization. Notwithstanding a reduction in the input price, Home firms must face the higher tariff-inclusive input price $r\tau$, as the input price declines proportionately less than tariffs.

2.3 Long-Run Analysis

Now consider an environment where the number of firms is endogenously determined via free entry and is variant to changes in import tariffs. Each Home firm pays K_H to enter the downstream sector, whereas each Foreign firm pays K_F to enter the upstream sector. For simplicity, we assume that these entry costs are small enough so that at least one Home firm and one Foreign firm enter the respective sectors. Observe that the equilibrium conditions in Section 2.2 continue to hold in the long-run analysis, in that aggregate output in each sector Q, X is implicitly determined by (3) or (6). The only key difference is that the number of firms in each sector M, N (extensive margin) is an endogenous variable under free entry. Together with Q, X, this in turn pins down the average output per firm (intensive margin) in each sector q, x.

To analyze the entry decision of firms in the vertically related sectors, let $\pi_H \equiv (P - r\tau)q$ and $\pi_F \equiv (r - ct)x$ denote the post-entry profits of a Home firm and a Foreign firm, where P and r are the equilibrium price of the respective goods. In the long run, firm entry occurs until the post-entry profits of firms equal the entry costs so that the net profits become zero: $\pi_H = K_H$, $\pi_F = K_F$. In this setting, M and N are the equilibrium number of Home and Foreign firms that is consistent with zero profits in the respective sectors. From $q = \frac{Q}{M}$ and $x = \frac{X}{N}$, the free entry conditions for the downstream and upstream sectors can be respectively expressed as

$$\frac{(P - r\tau)Q}{M} = K_H, \tag{7}$$

$$\frac{(r - ct)X}{N} = K_F. \tag{8}$$

These conditions show that the free entry number of Home firms M and Foreign firms N is implicitly given as a solution to (7) in the downstream sector and (8) in the upstream sector, respectively.

We already show that aggregate output Q, X is implicitly determined by the aggregate first-order condition in each production sector. Further, from Lemma 1, aggregate output increases with the number of firms M, N. The results mean that the long-run equilibrium is jointly characterized as a solution to the first-order condition, (3) or (6), and the free-entry conditions, (7) and (8). Solving all of these equilibrium conditions simultaneously, we can address how a reduction in import tariffs τ endogenously affects aggregate output Q, X, extensive margin M, N, and intensive margin q, x in the presence of vertical linkages (see Appendix A.2.2 for proof).

Proposition 1. *When the market structure is endogenous, we have the following effects on equilibrium variables.*

(*i*) *A reduction in import tariffs always increases aggregate output and the number of firms in the vertically related sectors, while it increases firm-level output in each sector only for strictly convex demand.*

(*ii*) *Import tariffs do not always improve the terms-of-trade for Home.*

A reduction in import tariffs increases aggregate output (and lowers the price of the final good) even when market structure is exogenously fixed. Here, a reduction in import tariffs increases the number of firms M, N, which in turn increases aggregate output even further. This effect of tariffs is unique to our *vertical* oligopoly model where Home's final good and Foreign's intermediate good are *complements*: a reduction in tariffs leads to *co-movement* of firm entry in the vertically related sectors ($\frac{dM}{d\tau} < 0, \frac{dN}{d\tau} < 0$). This stands in sharp contrast to *horizontal* oligopoly models where traded goods are *substitutes*: a reduction in tariffs leads to *de-location* of firms by making it easier for Foreign firms to sell their final good to the Home market, which encourages the entry of Foreign firms but discourages the entry of Home firms (see, e.g., Bagwell and Staiger, 2012). Hence, our analysis reveals that this long-run impact of tariffs on firm entry and exit might not necessarily hold true in the world of vertical disintegration via complementarity of production.

On the other hand, firm-level output q, x can increase or decrease by a reduction in tariffs. This is because an increase in aggregate output Q, X can be more or less than proportionate with an increase in the number of firms M, N, which ultimately depends on the demand structure in our vertical oligopoly model. To show this, consider the effect on the Home firms' intensive margin q, which can be decomposed as

$$\frac{dq}{d\tau} = \frac{\partial q}{\partial \tau} + \frac{\partial q}{\partial M}\frac{dM}{d\tau} + \frac{\partial q}{\partial N}\frac{dN}{d\tau}.$$

Lemma 1 shows that a reduction in tariffs increases Home firms' output for a given market structure ($\frac{\partial q}{\partial \tau} < 0$). Here, it additionally induces entry of Home and Foreign firms. As Foreign firms enter more, the input price is lower, which prompts each Home firm to increase their output further ($\frac{\partial q}{\partial N}\frac{dN}{d\tau} < 0$). As Home firms enter more, however, surviving Home firms fail to exploit their scale of production, which decreases Home firms' output ($\frac{\partial q}{\partial M}\frac{dM}{d\tau} > 0$). Due to the additional effects, the effect of tariffs on the intensive margin is generally ambiguous. However, the sign of that margin depends only on the demand curvature in the downstream sector. Indeed, Home firms' intensive margin decreases with tariffs if and only if demand is strictly convex:

$$\frac{dq}{d\tau} < 0 \quad \Longleftrightarrow \quad \rho < 0.$$

For linear demand ($\rho = 0$), the positive and negative effects exactly offset each other, so as to leave Home firms' intensive margin independent of import tariffs.

Concerning the effect of import tariffs on Foreign firms' intensive margin x,

$$\frac{dx}{d\tau} = \frac{\partial x}{\partial \tau} + \frac{\partial x}{\partial M}\frac{dM}{d\tau} + \frac{\partial x}{\partial N}\frac{dN}{d\tau}.$$

Lemma 1 shows that a reduction in tariffs increases Foreign firms' output for a given market structure ($\frac{\partial x}{\partial \tau} < 0$). Here, there is a further increase in x, because a reduction in tariffs induces Home firms to enter more, which in turn increases the demand for intermediate input ($\frac{\partial x}{\partial M}\frac{dM}{d\tau} < 0$). Counteracting these positive effects on x is a negative effect arising from tougher competition among Foreign firms: a reduction in tariffs induces Foreign firms to enter more, which in turn decreases the scale of production for surviving Foreign firms ($\frac{\partial x}{\partial N}\frac{dN}{d\tau} > 0$). Which effect dominates depends not only on the demand curvature just as in the downstream sector, but also on the market-clearing input price in the upstream sector. Specifically, Foreign firms' intensive margin decreases with tariffs if and only if the input price satisfies the following condition:

$$\frac{dx}{d\tau} < 0 \quad \Longleftrightarrow \quad r < \frac{ct}{1 + \frac{\rho}{N} - \frac{2+\rho}{N(2M+\rho)}}. \tag{9}$$

As $r > ct$ when intermediate input is produced under conditions of imperfect competition, the denominator in the right-hand side of (9) must be smaller than unity for the inequality to be satisfied. We can see however that this inequality never holds for any weakly concave demand ($\rho \geq 0$). In other words, the necessary (though not sufficient) condition for (9) is that the inverse demand function is strictly convex ($\rho < 0$). On top of the demand structure, the market structure also matters. For example, (9) does not hold when the number of Foreign firms N is arbitrary large (i.e., the entry cost K_F is arbitrary small) so that the upstream sector is close to a perfectly competitive environment.

Finally, we turn to the effect of tariffs on terms-of-trade. Similarly to above, this is decomposed as

$$\frac{dr}{d\tau} = \frac{\partial r}{\partial \tau} + g_X(X, M, \tau)\frac{\partial X}{\partial N}\frac{dN}{d\tau}. \tag{10}$$

As seen in Lemma 1, tariffs put downward pressure on the input price in the absence of entry-exit considerations. This effect is reflected in the first term of (10) which is a negative sign. Under free entry, tariffs also put upward pressure on the input price, since tariffs prompt the exit of Foreign firms via co-movement with vertical linkages. This new force is reflected in the second term of (10) which is a positive sign. The increased input price acts towards worsening of the terms-of-trade for Home. Like the effect on Home and Foreign firms' intensive margin, therefore, entry-exit considerations make the effect on the terms-of-trade ambiguous. Upon some rearrangement, we find that these two opposing forces can be summarized only by changes in Foreign firms' intensive margin. In particular, tariffs *worsen* the terms-of-trade if and only if the intensive margin decreases with tariffs:

$$\frac{dr}{d\tau} > 0 \quad \Longleftrightarrow \quad \frac{dx}{d\tau} < 0.$$

We know that tariffs do not necessarily decrease Foreign firms' intensive margin in endogenous market structure. (9) shows that tariffs can decrease that margin only for strictly convex demand, in which case tariffs deteriorate the terms-of-trade for Home. (10) shows that the counter-intuitive result occurs because the tariff-induced exit of Foreign firms is sufficiently large relative to the direct terms-of trade improvement by tariffs. The key takeaway from the analysis is that the terms-of-trade improvement is less likely to occur with entry-exit considerations, due to co-movement of firm entry and exit pertaining to vertical specialization.

2.4 Constant-Elasticity Demand

So far, we have shown that a tariff reduction always increases the extensive margin while it increases the intensive margin only for strictly convex demand in the vertically related sectors. As argued by Buono and Lalanne (2012), it is important to address whether a tariff reduction increases trade flows by permitting the entry of new firms into a foreign market (extensive margin) or raising the average trade value per firm (intensive margin), because it is directly related to who gains from trade liberalization. On the one hand, if a tariff reduction mainly increases the extensive margin, such liberalization mostly benefits new entrants by allowing for additional foreign access. On the other hand, if such a reduction mainly increases the intensive margin, it mostly benefits incumbent firms by reaping the scale of production. Specifying the inverse demand function, we analyze a more precise response of the input trade margins to a tariff reduction and its mechanism.

Below we focus on constant-elasticity demand that is quite common in the trade literature: $P(Q) = AQ^{-1/\sigma}$. As noted in Section 2.1, both elasticity and convexity of demand are determined by a single parameter σ with the elasticity $\varepsilon = \sigma$ and the convexity $\rho = -\left(\frac{\sigma+1}{\sigma}\right)$. As the elasticity satisfies $\varepsilon = \sigma > 1$, the convexity satisfies $-2 < \rho < -1$ implying demand is strictly convex. Compared to (1) and (2), we thus impose stronger restrictions on the demand structure. In addition to these features, the elasticity of demand satisfies (see Appendix A.2.3):

$$\varepsilon = -\frac{P(Q)}{QP'(Q)} = -\frac{g(X, M, \tau)}{Xg_X(X, M, \tau)}. \tag{11}$$

(11) shows that the elasticity of demand is the same as ε between the final good and the intermediate good, so long as the elasticity is constant. Recall from (5) that the convexity of demand is also the same as ρ between the two types of goods, so long as the curvature is constant. This special property of constant-elasticity demand allows us to generate sharp comparative statics results.

The following lemma records the relative pass-through of tariffs that arises with this specification.

Lemma 2. *For constant-elasticity demand, a reduction in import tariffs always leads to a proportional decline in firms' profit margin in the vertically related sectors.*

Consider first the effect on Foreign firms' profit margin in the upstream sector $r - ct$. Obviously, tariffs alter only the input price r without affecting Foreign firms' unit cost ct. We have shown two opposing forces of tariffs on the input price in (10): the downward pressure that exists even in the absence of entry-exit considerations; and the upward pressure associated with the tariff-induced exit of Foreign firms that exists only in the presence of such considerations. Hence, tariffs can increase or decrease the equilibrium price of the intermediate good. The ambiguous effect of tariffs on the input price is summarized by the effect on Foreign firms' intensive margin as shown by (9). For constant-elasticity demand with strong convexity, however, the upward pressure outweighs the downward pressure so that tariffs always increase the input price satisfying the inequality of (9) irrespective of market structure. This equilibrium outcome implies that, for this specific demand structure, a tariff reduction always decreases the profit margin of Foreign firms.

Consider next the effect on Home firms' profit margin in the downstream sector $P - r\tau$. In this case, tariffs alter not only the final-good price P but also Home firms' unit cost $r\tau$. First, tariffs increase production cost of Home firms, decreasing aggregate output produced in the downstream sector Q and increasing the equilibrium price of the final good P. Second, tariffs also increase the equilibrium price of the intermediate good r, as seen above, and hence increase Home firms' unit cost $r\tau$. This means that a tariff reduction can increase or decrease

the profit margin of Home firms; however, for constant-elasticity demand, the equilibrium price of the final good always declines proportionally more than a fall in Home firms' unit cost so that

$$\frac{d\ln P}{d\ln \tau} - \frac{d\ln(r\tau)}{d\ln \tau} > 0.^{10}$$

Thus a tariff reduction decreases the profit margin of Home firms as well.

The results of the relative pass-through have direct implications for the effect of tariffs on the extensive and intensive margins of intermediate input trade (see Appendix A.2.4 for proof):

Proposition 2. *For constant-elasticity demand, the elasticity of input trade flows with respect to import tariffs is always greater for the intensive margin than for the extensive margin in the vertically related sectors.*

Proposition 2 says that the elasticity of the two margins with respect to tariffs satisfies

$$\begin{aligned} \frac{d\ln M}{d\ln \tau} - \frac{d\ln q}{d\ln \tau} > 0, \\ \frac{d\ln N}{d\ln \tau} - \frac{d\ln x}{d\ln \tau} > 0. \end{aligned} \tag{12}$$

For constant-elasticity demand with $-2 < \rho < -1$, Proposition 1 means that the extensive and intensive margins are strictly decreasing in tariffs in the downstream sector ($\frac{d\ln M}{d\ln \tau} < 0, \frac{d\ln q}{d\ln \tau} < 0$). Given that both trade margins have negative signs, the first equality in (12) suggests that the elasticity of the extensive margin is smaller than that of the intensive margin (in absolute terms) on the import side of input trade from the downstream sector ($\left|\frac{d\ln M}{d\ln \tau}\right| < \left|\frac{d\ln q}{d\ln \tau}\right|$). The second inequality in (12) suggests that the same relationship holds even when we look at the export side of input trade from the upstream sector ($\left|\frac{d\ln N}{d\ln \tau}\right| < \left|\frac{d\ln x}{d\ln \tau}\right|$).

Intuition behind the results is explained as follows. Generally, a reduction in tariffs can increase or decrease firms' profit margin. When a tariff reduction increases that margin, the increased profitability induces firms to enter more, whereby an increase in the extensive margin is relatively larger than that in the intensive margin. The opposite is true when the profit margin decreases by such reduction. However, constant-elasticity demand shuts down the former and allows for only the latter, as shown in Lemma 2. The declined profitability implies the entry effect (via an increase in the extensive margin) limited relative to the scale effect (via an increase in the intensive margin). The results hold for the vertically related sectors, since both elasticity and convexity of demand are the same between the two types of goods, as stated in (5) and (11).

In summary, a tariff reduction increases aggregate output and the extensive margin, but the intensive margin can increase or decrease in vertically related sectors. Further, an increase in the extensive margin can be greater or smaller than the intensive margin in these sectors. Guided by theory, we next explore an empirical framework for testing our predictions. Proposition 1 shows that the effect of tariffs on the intensive margin depends on the demand curvature; however, relatively little is known about the actual curvature of demand in the literature (McCalman, 2023). To circumvent this challenge, we posit constant-elasticity demand in the empirical analysis, just like Proposition 2. Under the assumption, our model predicts that: (i) a reduction in tariffs increases both extensive and intensive margins; and (ii) it has a larger effect on the intensive margin than the extensive margin in the vertically related sectors.

[10] While the *relative* pass-through of tariffs occurs if and only if demand is strictly log-convex ($\rho < -1$), the *absolute* pass-through occurs ($\frac{dP}{d\tau} - \frac{d(r\tau)}{d\tau} > 0$) if and only if demand is strictly convex ($\rho < 0$). We will focus on the relative pass-through in this section, as our empirical analysis is mainly concerned with the elasticity of the extensive and intensive margins.

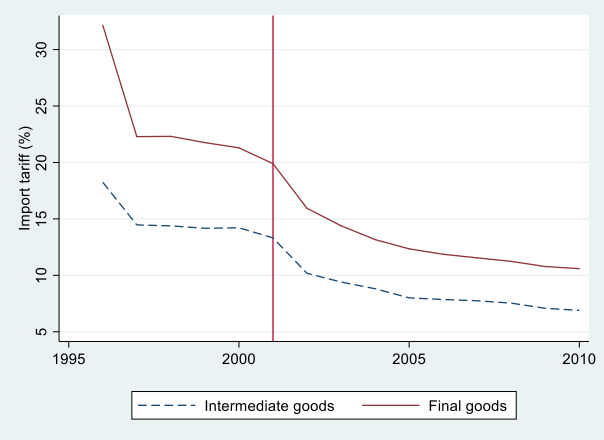


Figure 1: China's import tariffs, 1996–2010

3 Evidence

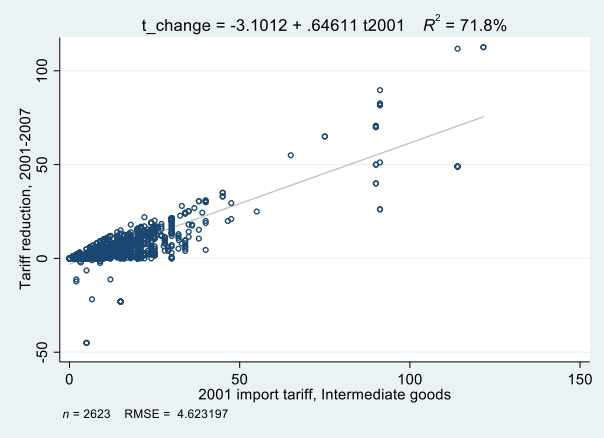
This section reports empirical evidence on the effects of tariff reductions on input trade margins of Chinese firms. We first describe tariff and trade data used in our analysis and stress that China's accession to WTO was indeed a large policy change to Chinese firms. Subsequently, we conduct a set of robust empirical exercises and show that both the number of importing firms (extensive margin) and average imports per firm (intensive margin) significantly increase in the post-WTO period, though the effect of tariff reductions on the former margin is much smaller than that on the latter. Finally, we discuss potential reasons why our results are different from those in previous work in this literature. For the expositional purpose, we focus attention on Chinese imports; however, as our theory predicts, the results would be similar even when we look at Chinese exports.

3.1 Data

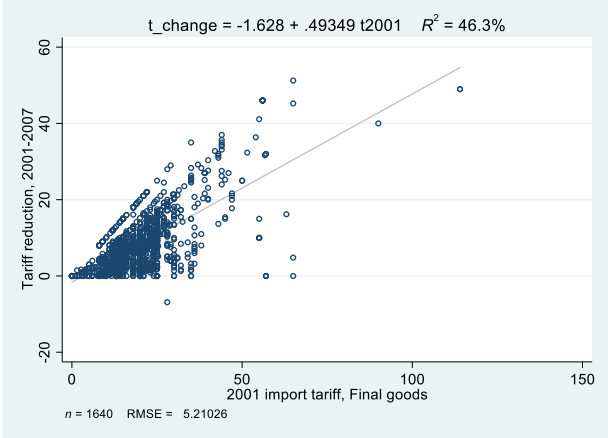
China joined WTO in 2001. Tariff reductions in 2002, right after China's WTO accession, were very drastic. We measure these tariff reductions endorsed by the WTO accession using China's effectively applied ad-valorem tariffs at the HS 6-digit product-year level by partner countries.[11] Our tariff data are obtained from the Trade Analysis Information System (TRAINS) database available at the World Integrated Trade Solution (WITS) website. It covers more than 5,000 products, and for each product at the HS 6-digit level, the tariff database provides detailed information on tariff lines, average, minimum and maximum ad-valorem tariff duties, which contains 159 countries of both WTO and non-WTO members.

Figure 1 plots the time trend of China's simple average applied tariffs during 1996–2010, where the vertical line indicates the year where China joined WTO. Tariffs are further dividid into those imposed on intermediate goods and final goods. The figure clearly shows that China's import tariff rates dropped substantially in 1997 but remained largely unchanged during 1997–2001, especially for intermediate goods. However, it started to decrease in 2002 until it stabilized in the late 2000s. Specifically, China's import tariffs on intermediate goods decreased from 14.2% in 2000 to 6.0% in 2010. The trend is quite similar to import tariffs on final goods which decreased from 21.3% to 10.8% during 2000–2010.

[11] Throughout the empirical analysis, we focus on *applied* tariffs induced by China's WTO accession, rather than *bounded* tariffs. Bounded tariffs refer to the maximum level of tariffs allowed by WTO, whereas applied tariffs refer to the actual level of tariffs. Applied tariffs are typically much lower than bounded tariffs, as reported by Buono and Lalanne (2012).



(a) Intermediate goods



(b) Final goods

Figure 2: China's tariff reductions by initial tariff levels across HS 6-digit products

While Figure 1 shows a general pattern of changes in import tariffs by two types of goods (i.e., intermediate goods and final goods), there are large variations across products. Figure 2(a) shows that the relation between tariffs in 2001 and the tariff reductions for intermediate goods between pre-WTO (2000–2001) and post-WTO (2002–2007) periods across 6-digit level products. Obviously, there is a strong positive correlation between the initial level of tariffs and the afterward change of tariffs because of the WTO accession. That is, intermediate goods with higher initial levels experienced larger reductions in tariffs. As a result, import tariff levels in the post-WTO period are more uniform across products than the levels in the pre-WTO period. Figure 2(b) shows that the pattern is quite similar for final goods. Thus, a product's relative protection in 2007 is well explained by its initial protection in 2001, rather than other possible economic factors such as domestic political economy, pointing towards exogeneity of the tariff changes.

Regarding the data on Chinese imports, we use the census of annual firm-level import transactions of Chinese firms during 2000–2007, collected by the China Customs. The data contain the trade value, quantity, origin and destination countries at the HS 8-digit product classification. The original data are at the firm-product-country level and we aggregate them at the product-country level to obtain our key variables, i.e., aggregate imports, the number of importers (extensive margin) and the average import value per firm (intensive margin). Then, we use the publicly available 6-digit level concordance tables to adjust the product codes consistent over time. The number of countries is 159 and the number of products is about 5,000, which covers more than 95% of Chinese imports. The import value is measured in thousand U.S. dollars and we convert it to thousand Chinese RMB using the annual exchange rate published by China's National Statistics Bureau.

As our theory concerns a model of vertical specialization, it is necessary to divide our data of traded goods into intermediate goods and final goods. We do this by using the classification of the Broad Economic Categories (BEC) due to the United Nations.[12] According to this, intermediate goods include: (i) industrial supplies not elsewhere specified; (ii) fuels and lubricants other than motor spirit; (iii) parts and accessories of capital goods; (iv) parts and accessories of transport equipment; and (v) food and beverages mainly supplied for the industry. Capital goods and consumption goods are classified as final goods.

[12]For details of the BEC classification, please visit the following link: https://unstats.un.org/unsd/tradekb/Knowledgebase/50090/Intermediate-Goods-in-Trade-Statistics.

Table 2: Effect of tariffs on extensive and intensive margins of intermediate input imports

	(1)	(2)	(3)	(3) − (2)	(4)
Intermediate goods	All	Pre-WTO	Post-WTO	Difference	Std Error
Total imports	3.765	3.492	3.833	0.342***	0.012
	(2.754)	(2.587)	(2.790)		
Extensive margin	1.636	1.523	1.663	0.140***	0.005
	(1.111)	(0.991)	(1.137)		
Intensive margin	2.130	1.968	2.170	0.202***	0.010
	(2.155)	(2.078)	(2.171)		
Tariff rate	9.177	13.113	8.203	−3.909***	0.028
	(6.540)	(8.541)	(5.525)		
Final goods					
Total imports	3.227	3.006	3.280	0.274***	0.016
	(2.642)	(2.523)	(2.667)		
Extensive margin	1.518	1.415	1.543	0.128***	0.006
	(1.033)	(0.912)	(1.058)		
Intensive margin	1.709	1.591	1.737	0.146***	0.013
	(2.094)	(2.078)	(2.096)		
Tariff rate	13.059	19.191	11.594	−7.597***	0.046
	(8.222)	(9.000)	(7.300)		

Note: Total imports, extensive and intensive margins are in logarithm. Standard deviations in parentheses. The sample size is 175,598 in pre-WTO (2000–2001) period and 309,052 in post-WTO (2002–2007) period, respectively.

In this study, we exclude imports entering China as processing imports and focus only on ordinary imports. As pointed out by Dai et al. (2016) or Liu and Qiu (2016), processing trade is exempt from import duties on imported inputs and materials, and the effective tariff rate is zero for processing firms in both pre-WTO and post-WTO periods. As we are interested in the effect of tariff reductions of the trade margins, processing trade is inappropriate for our purpose. In addition, since processing firms are provided with technologies, designs and intermediate goods by their foreign partners, processing firms are likely to have different production functions and importing behaviors from those of non-processing firms.

Table 2 reports the summary statistics of the key variables in our regressions. Total imports, extensive and intensive margins are mean values across HS 6-digit product-country over the entire sample period (2000–2007). Overall, China tends to import more intermediate goods than final goods. Imports in both intermediate goods and final goods increased significantly from the pre-WTO (2000–2001) period to the post-WTO (2002–2007) accession period. It is important to emphasize that both extensive and intensive margins of intermediate goods are larger than those of final goods during the entire sample period. Moreover, the growth of the two margins in intermediate goods are larger than those of final goods from the pre-WTO period to the post-WTO accession period. Finally, observe that both mean tariff rates and standard deviations decreased significantly because of China's WTO accession.

3.2 Empirical Analysis

To examine the effect of import tariffs on the extensive and intensive margins of intermediate goods imports, we conduct a battery of estimations and robustness checks: (i) a standard fixed effects regression with a lagged independent variable (tariffs), (ii) a difference-in-differences (DID) specification and (iii) a Poisson estimation.

We show that tariff reductions induced by China's WTO accession significantly affect intermediate goods imports via the extensive and intensive margins, though the effect on the extensive margin is much smaller than that on the intensive margin. For the expositional purpose, we report the estimation results for intermediate goods trade below, but the results for final goods trade will be discussed later.

We start with the standard fixed effects model. For each product imported from each trading partner in each year, the total imports are decomposed into the number of importers (extensive margin) and the average import value (intensive margin). Let Q_{pct}, M_{pct} and q_{pct} respectively denote the total imports, the extensive margin, and the intensive margin for product p imported from country c in year t, which must satisfy $Q_{pct} = M_{pct} * q_{pct}$. We first estimate the following regression:

$$\ln y_{pct} = \beta_0 + \beta \ln \tau_{pct-1} + \theta_{pt} + \gamma_{ct} + \alpha_{cp} + \epsilon_{pct}, \tag{13}$$

where y_{pct} is either Q_{pct}, M_{pct} or q_{pct}, respectively, and τ_{pct-1} is the ad-valorem tariff rate applied on product p imported from country c in year $t-1$. Note that (13) is *not* a usual gravity equation, in the sense that variable trade costs are measured only by tariffs without including distance as an independent variable. We also include a full set of product-year, country-year, and country-product fixed effects. We cluster the standard errors at the product level to deal with the potential heteroskedasticity and serial autocorrelation. This regression equation is equivalent to the "within" regression by Buono and Lalanne (2012) where the variation in tariffs comes from tariff changes applied to each foreign country-product pair. As stressed by them, this specification is useful for exploiting a three-dimensional panel, and it is thought of as a comprehensive fixed effects specification so that we can control for various patterns of comparative advantage, product and country dynamics.

Columns (1)–(3) of Panel A of Table 3 reports the estimation results. We find that tariff reductions (induced by the implementation of China's WTO accession) leads to a significant response in terms of the extensive margin as well as the intensive margin of Chinese imports. The coefficients imply that reductions in average tariffs by 1.2% per year accounts for approximately 16% of the import growth, 6% of the extensive margin growth, and 20% of the intensive margin growth, as reviewed in the Introduction.[13]

Our results of the "within" regressions are qualitatively different from Buono and Lalanne (2012) who report that tariff reductions (induced by the implementation of the Uruguay Round) do not significantly increase the extensive margin, while it only increases the intensive margin of French exports. In a slightly different context, using a probit model with a full vector of goods dummies, Debaere and Mostasharic (2010) demonstrate that tariff reductions tend to have a statistically significant but small impact on the extensive margin of U.S. imports. These existing results suggest that the extensive margin has not amplified the impact of tariffs on trade flows to such an extent that recent theoretical work armed with new trade models has claimed. The potential reasons for this difference between previous work and ours will be discussed in detail in Section 3.3.

To further confirm the causal impact of tariff reductions on the margins of imports, we next exploit the fact that after China's accession to WTO, products that had previously been more protected (i.e., products with higher tariffs in 2001) experienced greater tariff reductions under the WTO agreement, whereas previously less protected products (i.e., products with lower tariffs in 2001) experienced small changes in tariffs, as shown in Figures 2(a) and 2(b). Such large variations and the timing of tariff reductions in 2002 allow us to conduct a DID estimation. We compare the changes in input trade margins in previously more protected products with larger tariff reductions (the treatment group) before and after 2001 and the corresponding changes in previously

[13]The average tariffs in 2000 and 2007 are 13.3% and 6%, respectively, which are used to calculate the average contribution of tariff reductions to the growth rate above. For example, the effect on aggregate imports are $[\ln(1+0.06) - \ln(1+0.133)] \times (-3.508) = 0.26$. Dividing this number by the time period and adjusting the average growth rate gives us the annual growth rate above.

Table 3: Effect of tariffs on intermediate goods imports

	(1)	(2)	(3)
	$\ln Q_{pct}$	$\ln M_{pct}$	$\ln q_{pct}$
Panel A. Linear Regression			
$\ln \tau_{pct-1}$	-3.508^{***}	-0.468^{**}	-3.040^{***}
	(1.056)	(0.208)	(0.936)
No. of obs	306,805	306,805	306,805
Adj. R^2	0.825	0.925	0.768
Panel B. DID Specification			
$\ln \tau_{pc2001} * Post_{2002}$	-1.105^{***}	-0.265^{***}	-0.841^{***}
	(0.305)	(0.089)	(0.233)
No. of obs	408,971	408,971	408,971
Adj. R^2	0.776	0.894	0.710

Note: Total imports, extensive margin, and intensive margin are in logs. Robust standard errors are clustered at the product level in parentheses. ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

less protected products with smaller tariff reductions (the control group) during the same period. Specifically, we use the following specification for our DID estimation:

$$\ln y_{pct} = \beta \ln \tau_{pc2001} * Post_{2002} + \theta_p + \gamma_{ct} + \alpha_{cp} + \epsilon_{pct}, \tag{14}$$

where τ_{pc2001} is the ad valorem tariff rate of product p imported from country c in 2001,[14] and $Post_{2002}$ is an indicator of the post-WTO accession period, taking a value of one if $t \geq 2002$, and zero otherwise. As before, we include a full set of product, country-year, and country-product fixed effects in (14). Note, however, that we do not control for product-year fixed effects here, as our main regressor is already specified at the product-year level.

The estimation results are reported in columns (1)–(3) of Panel B of Table 3. Once again the results confirm that reductions in tariffs increase both intensive and extensive margins of intermediate goods trade. Although the response of the extensive margin is less than one-fifth of that of the intensive margin in the baseline linear regression, the extensive margin now accounts for a quarter of the overall trade response in the DID specification. The finding points towards a quantitatively crucial role that the extensive margin plays in the overall response of intermediate goods trade to reductions in import tariffs.

In estimating (14), we employ the dummy variable $Post_{2002}$ to divide the pre-WTO and post-WTO periods. The interaction term $\tau_{pc2001} * Post_{2002}$ estimates the average treatment effect which compares the difference between the treatment group and control group in the average difference between the pre-WTO and post-WTO periods. Since the approach does not consider the year-to-year changes, we also use a more flexible estimation specification to replace the interaction term with a series of interaction terms as follows:

$$\ln y_{pct} = \beta \ln \tau_{pc2001} * d_t + \theta_p + \gamma_{ct} + \alpha_{cp} + \epsilon_{pct}, \tag{15}$$

where d_t is a year dummy, taking a value of one if $t = 2001, \cdots, 2007$, and zero otherwise.

[14] Using average tariffs over 2000–2001 or 2000 tariff rates (instead of 2001 tariff rates) yields similar results as import tariffs did not change much between 2000 and 2001.

Table 4: Alternative DID estimations

	(1)	(2)	(3)
	$\ln Q_{pct}$	$\ln M_{pct}$	$\ln q_{pct}$
$\ln \tau_{pc2001} * d_{2001}$	-0.576^{***}	-0.204^{***}	-0.372^{*}
	(0.240)	(0.047)	(0.203)
$\ln \tau_{pc2001} * d_{2002}$	-0.778^{***}	-0.220^{***}	-0.558^{***}
	(0.259)	(0.062)	(0.214)
$\ln \tau_{pc2001} * d_{2003}$	-1.335^{***}	-0.430^{***}	-0.905^{***}
	(0.318)	(0.084)	(0.256)
$\ln \tau_{pc2001} * d_{2004}$	-1.376^{***}	-0.394^{***}	-0.982^{***}
	(0.398)	(0.105)	(0.313)
$\ln \tau_{pc2001} * d_{2005}$	-1.517^{***}	-0.372^{***}	-1.145^{***}
	(0.467)	(0.126)	(0.362)
$\ln \tau_{pc2001} * d_{2006}$	-1.593^{***}	-0.370^{***}	-1.223^{***}
	(0.498)	(0.136)	(0.384)
$\ln \tau_{pc2001} * d_{2007}$	-1.849^{***}	-0.434^{***}	-1.415^{***}
	(0.431)	(0.127)	(0.335)
No. of obs	408,971	408,971	408,971
Adj. R^2	0.776	0.894	0.710

Note: Total imports (Q_{pct}), extensive margin (M_{pct}), and intensive margin (q_{pct}) are in logarithm. Robust standard errors are clustered at the product level in parentheses. ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

The regression results are reported in Table 4. The estimated coefficients are statistically significant in all years after 2001 and the magnitudes become larger from 2002 onwards. These results imply that the effect of tariff reductions is significantly different between the treatment and control groups. Because we only have two years of data in the pre-WTO (2000–2001) period, it is not possible for us to compare the time trends between our treatment and control groups. This is not a serious problem, however, since the high-tariff industries group and low-tariff industries group have quite similar trends in their pre-WTO (1998–2001) period, as reported by Lu and Yu (2015) and Liu and Qiu (2016) who analyze industry-level tariffs during 1998–2007. Nevertheless, the results of the flexible estimations in Table 4 are very similar with those of average treatment effect and yearly tariffs in Table 3.

Finally, we check the robustness of our estimation results using the fixed effect Poisson model as an alternative estimation method. Specifically, we use Poisson pseudo maximum likelihood (PPML) model with high-dimension fixed effects, including country-product, product-year and country-year fixed effects as in (13):

$$y_{pct} = \exp\Big(\beta_0 + \beta\tau_{pct-1} + \theta_{pt} + \gamma_{ct} + \alpha_{cp} + \epsilon_{pct}\Big), \tag{16}$$

where y_{pct} and τ_{pct-1} are measured in level. This approach has been frequently used in the literature to account for zero trade flows in the trade matrix. See, in particular, Santos Silva and Tenreyro (2006). For simplicity, we focus on the regressions with lagged one year tariff rates.

The results are reported in Table 5. We find estimation results that are very similar to those in Table 3. Several differences are worth mentioning below. First, the elasticities obtained from (16) are slightly higher than those obtained from the within regression (13). This may reflect that (16) takes into account zero trade

Table 5: Poisson estimations

	(1)	(2)	(3)
	Q_{pct}	M_{pct}	q_{pct}
$\ln \tau_{pct-1}$	-4.675^{***}	-1.107^{**}	-4.207
	(1.673)	(0.436)	(2.677)
No. of obs	283,763	283,763	283,763

Note: Total imports (Q_{pct}), extensive margin (M_{pct}), and intensive margin (q_{pct}) are in real numbers. Robust standard errors are clustered at the product level in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

flows which are completely ignored in (13). Second, just like the DID specification (14), the extensive margin is approximately a quarter of the overall response in intermediate goods in the Poisson specification (16) too. Nonetheless, we find that the coefficient of the intensive margin is greater than that of the extensive margin (in absolute terms) in the Poisson estimation. Third and interestingly, in contrast to the previous specifications, only the extensive margin registers a significant response to tariff reductions, while leaving the intensive margin statistically insignificant in the Poisson specification.

In summary, import tariff reductions after China's WTO accession significantly increased Chinese imports of intermediate goods through both extensive and intensive margins. A reduction in tariffs induced incumbent importers to source more intermediate goods from their trade partners. At the same time, a tariff reduction also induced new entrants to start importing intermediate goods from abroad. The effect on the extensive margin is statistically significant in all specifications. However, we also find that the elasticity of the extensive margin is smaller than that of the intensive margin (in absolute terms). This is along the lines with our theory, suggesting that the entry effect via an increase in the extensive margin is limited relative to the scale effect via an increase in the intensive margin. The DID and Poisson specifications attribute the larger role of the extensive margin response in the post-WTO period, but the basic results continue to hold in these specifications.

3.3 Discussions

We have shown that China's WTO-accession related tariff reductions significantly increase both extensive and intensive margin of input trade in the post-WTO period, though the effect of tariffs on the extensive margin is much smaller than that on the intensive margin. While the finding is consistent with our theory, it is different from that of previous papers in this literature: tariff reductions do not always allow new firms to start exporting or importing; instead, incumbent firms mostly increase their shipments in response to lower tariffs (e.g., Debaere and Mostasharic, 2010; Buono and Lalanne, 2012). Therefore, it is important to address the potential reasons why trade liberalization significantly increases the extensive margin in our study.

The first reason to come to mind is China's WTO-accession related tariff reductions are sufficiently large to induce new firms to enter foreign markets relative to previous studies. It is well-known that firms must incur large sunk cost to enter exporting or importing markets (Melitz and Redding, 2014). Our result can be realized when tariff reductions induced by China's WTO accession are large enough to cover such sunk costs. However, this channel is not operative in our analysis. As in Table 2, average import tariffs on intermediate goods and final goods decreased around 3.9% and 7.6%, respectively, before and after China's WTO accession, which is

Table 6: Effect of tariffs on final goods imports

	(1)	(2)	(3)
	$\ln Q_{pct}$	$\ln M_{pct}$	$\ln q_{pct}$
Panel A. Linear Regression			
$\ln \tau_{pct-1}$	-2.995^{***}	-0.601^{**}	-2.394^{***}
	(0.686)	(0.181)	(0.585)
No. of obs	172,985	172,985	172,985
Adj. R^2	0.800	0.908	0.742
Panel B. DID Specification			
$\ln \tau_{pc2001} * Post_{2002}$	-1.650^{***}	-0.996^{***}	-0.655^{***}
	(0.327)	(0.125)	(0.245)
No. of obs	247,099	247,099	247,099
Adj. R^2	0.752	0.870	0.686

Note: Total imports, extensive margin, and intensive margin are in logs. Robust standard errors are clustered at the product level in parentheses. ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

almost comparable magnitude to those in previous work: average tariffs decreased by 6.37% for WTO countries before and after the Uruguay Round in France (Buono and Lalanne, 2012). Given that, it is hard to state that our result of the extensive margin is driven by the big magnitude of tariff reductions.[15]

The second possible reason is the type of goods trade: the current paper analyzes the effect of tariff reductions by making clear distinction between intermediate goods trade and final goods trade; while previous work analyzes the effect without such distinction. To check this channel, we examine all specifications of estimations in Section 3.2 by replacing intermediate goods imports with final goods imports. Below we report the estimation results of (13) and (14) in Table 6, relegating those of (15) and (16) to Appendix A.3. The comparison between Tables 3 and 6 shows that, in either the linear regression or DID specification, reductions in tariffs increase both intensive and extensive margins of final goods trade, whereby the elasticities of the extensive margin are slightly higher in final goods trade than in intermediate goods trade. From this comparison, our focus on intermediate goods trade seems to be immaterial to the key finding that tariff reductions significantly increase the extensive margin. However, the Poisson estimations show contrasting results: (i) the elasticity of the extensive margin is smaller for final goods trade than intermediate goods trade; and (ii) the elasticity of the intensive margin is statistically significant for final goods trade (see Table A.2 in Appendix). Hence, when taking into account zero trade flows, our focus on intermediate goods imports is more relevant to our result.

The final reason we consider is the fact that China is a developing country. Most papers in this literature have studied the effect of tariff reductions on the trade margins from a point of view of developed countries; Debaere and Mostasharic (2010) examine the effect on U.S. imports, while Buono and Lalanne (2012) investigate the effect on French exports. As pointed out by Dean et al. (2011) and Dai et al. (2016), however, the patterns of vertical specialization and GVCs are quite different between developed and developing countries, which may in turn lead to different impacts of tariff reductions on the trade margins in developing countries. For example, if China has a comparative advantage in producing less R&D-intensive inputs whose sunk costs are low enough, tariff reductions would easily allow Chinese firms to cover sunk costs and increase the extensive margin.

[15]Tariff reductions may allow new Chinese firms to enter, as sunk costs are low in particular in processing trade (Dai et al., 2016). As noted in Section 3.1, however, we exclude imports entering China as processing trade and focus only on ordinary trade.

4 Conclusion

This paper has analyzed a vertical oligopoly model to investigate the effect of tariffs on the input trade margins when vertically related sectors are oligopolistic. Our central contribution is to provide a better understanding of the mechanism through which import tariffs can affect the input trade margins from the long-run perspectives. We showed that, for constant-elasticity demand, a reduction in tariffs increases the number of trading firms (extensive margin) as well as the average trade value per firm (intensive margin) in the vertically related sectors, raising the intensive margin relative to the extensive margin. To assess the empirical relevance of our theoretical results, we focused on China's WTO accession which was a large policy change to Chinese firms. We found the theory-consistent evidence such that a tariff reduction significantly raises both trade margins in the post-WTO period, though the effect of tariffs on the extensive margin is much smaller than that on the intensive margin. The results are robust to a battery of specifications but differ from those in previous work. We concluded that the key reason stems from whether the focus is placed on a developed versus developing country, rather than export versus import side of trade and intermediate versus final goods trade.

While many papers have demonstrated the importance of vertical specialization and GVCs in accounting for recent trade flows, most existing work assumes perfectly competitive firms in a multistage production process. In reality, however, globalization leads to the increasing strategic interdependence among large firms that are unlikely to be of measure zero relative to the markets: only a few large firms participate in international trade and the markets are becoming more concentrated toward these firms over time, suggesting that market structure is more characterized by oligopoly. The present paper tries to fill this significant gap in the literature by exploring market-based interactions between vertically related sectors. To avoid the complexity of vertical oligopoly where the strategic interdependence among firms inherently exists, we resort to restrictive demand-side conditions (e.g., constant elasticity and convexity of demand) as well as supply-side conditions (e.g., two-stage production with homogeneous firms). The extent to which our results can be generalized is crucial for understanding the role of strategically interdependent large firms in vertical specialization and GVCs and its related trade policy issues, which we leave to future research.

Appendix

A.1 Curvature of Demand

We show that the demand-side condition on curvature (i.e., the convexity of demand is greater than minus two) is closely related to the second-order condition of firms' profit-maximization problem. The discussion is simple application of that made by Mrázová and Neary (2017) to our vertical oligopoly model. For interested readers, please refer to Appendix B in their paper.

Recall that firm-level output and aggregate output are respectively denoted by q_i and Q in our paper, which needs to be distinguished for one another when defining the convexity of the inverse demand function $P(Q)$. Following Mrázová and Neary (2017), we have defined the convexity of demand in terms of aggregate output Q instead of firm-level output q_i in the case of oligopoly (albeit without a minus sign):

$$\rho(Q) \equiv \frac{QP''(Q)}{P'(Q)}.$$

To understand that the condition on convexity in (1) is related to the second-order condition in our setting, it is necessary to invoke the first-order condition of Home firms' profit-maximization problem. In Section 2.2, we have already shown that the first-order condition of Home firm i is expressed as

$$P(Q) + q_i P'(Q) = r\tau > 0. \tag{A.1}$$

In Section 2.1, we have also assumed that each Home firm has no oligopsony power over the upstream sector. Since Home firm i takes as given the input price r (as well as import tariffs τ chosen by the Home government) in (A.1), the second-order condition of Home firm i is expressed as

$$2P'(Q) + q_i P''(Q) < 0. \tag{A.2}$$

If the inequality in (A.2) holds for any Home firm, we must have

$$\rho(Q) > -\max_i \left(\frac{2}{s_i}\right),$$

where $s_i \equiv \frac{q_i}{Q}$ is the output share of Home firm i in the final-good market.

Together with (A.2), this imposes the following condition on convexity to satisfy the second-order condition. In the case of monopoly (where firm-level output equals aggregate output, $q_i = Q$) and monopolistic competition (where the convexity needs to be defined in terms of firm-level output, $\rho = \frac{q_i P''(q_i)}{P'(q_i)}$), the convexity of demand must be greater than minus two, as argued by Mrázová and Neary (2017). In the case of oligopoly where firms are identical like the present paper, the output share is symmetric, $s_1 = s_2 = ... = s_M \equiv s = \frac{1}{M}$, requiring that the convexity must be greater than $-2M$. In addition, as long as we consider a free-entry equilibrium where at least one Home firm exists, the lower bound approaches a maximum value when there is a dominant Home firm in the final-good market ($-2M \to -2$). Clearly the lower bound becomes smaller when there are more than two Home firms, but the condition on convexity in (1) is sustained even in such equilibrium. These considerations lead us to assume that the convexity of demand is greater than minus two in our vertical oligopoly model, as in the second inequality in (1).

A.2 Proofs

A.2.1 Proof of Lemma 1

To show the comparative statics results of the paper, it is useful to derive the effect on the demand of intermediate inputs first. Differentiating (4) with respect to its arguments,

$$\begin{aligned}
g_X(X,M,\tau) &= \frac{P'(X)(M+1+\rho)}{M\tau},\\
g_M(X,M,\tau) &= -\frac{XP'(X)}{M^2\tau},\\
g_\tau(X,M,\tau) &= -\frac{P(X)+\frac{XP'(X)}{M}}{\tau^2},\\
g_{XX}(X,M,\tau) &= \frac{XP''(X)(M+1+\rho)}{M\tau},\\
g_{XM}(X,M,\tau) &= -\frac{P'(X)(1+\rho)}{M^2\tau},\\
g_{X\tau}(X,M,\tau) &= -\frac{P'(X)(M+1+\rho)}{M\tau^2}.
\end{aligned} \tag{A.3}$$

(i) Differentiating (6) with respect to τ,

$$\frac{\partial X}{\partial \tau} = \frac{Nct}{\tau(N+1+\rho)g_X(X,M,\tau)},$$

Using (A.3) and $X=Q$, we get

$$\begin{aligned}
\frac{\partial X}{\partial \tau} &= \frac{MNct}{P'(X)(M+1+\rho)(N+1+\rho)} < 0,\\
\frac{\partial q}{\partial \tau} &= \frac{1}{M}\frac{\partial Q}{\partial \tau} = \frac{Nct}{P'(X)(M+1+\rho)(N+1+\rho)} < 0,\\
\frac{\partial x}{\partial \tau} &= \frac{1}{N}\frac{\partial X}{\partial \tau} = \frac{Mct}{P'(X)(M+1+\rho)(N+1+\rho)} < 0.
\end{aligned}$$

(ii) Differentiating (6) with respect to N and rearranging,

$$\frac{\partial X}{\partial N} = -\frac{g(X,M,\tau)-ct}{(N+1+\rho)g_X(X,M,\tau)}.$$

Using (6) and (A.3) in the above equality,

$$\begin{aligned}
\frac{\partial X}{\partial N} &= \frac{x}{N+1+\rho} > 0,\\
\frac{\partial q}{\partial N} &= \frac{1}{M}\frac{\partial Q}{\partial N} = \frac{q}{N(N+1+\rho)} > 0,\\
\frac{\partial x}{\partial N} &= \frac{1}{N}\frac{\partial X}{\partial N} - \frac{x}{N} = -\frac{(N+\rho)x}{N(N+1+\rho)} < 0.
\end{aligned} \tag{A.4}$$

Similarly, differentiating (6) with respect to M and rearranging,

$$\frac{\partial X}{\partial M} = -\frac{Ng_M(X,M,\tau) + Xg_{XM}(X,M,\tau)}{(N+1+\rho)g_X(X,M,\tau)}.$$

Using (A.3) in the above equality,

$$\begin{aligned}
\frac{\partial X}{\partial M} &= \frac{q}{M+1+\rho} > 0, \\
\frac{\partial q}{\partial M} &= \frac{1}{M}\frac{dQ}{dM} - \frac{q}{M} = -\frac{(M+\rho)q}{M(M+1+\rho)} < 0, \\
\frac{\partial x}{\partial M} &= \frac{1}{N}\frac{\partial X}{\partial M} = \frac{x}{M(M+1+\rho)} > 0.
\end{aligned} \tag{A.5}$$

(iii) Differentiating (4) with respect to τ and using $g_X(X,M,\tau)$ in (A.3),

$$\frac{\partial r}{\partial \tau} = g_X(X,M,\tau)\frac{\partial X}{\partial \tau} + g_\tau(X,M,\tau) = -\frac{1}{\tau}\left(r - \frac{Nct}{N+1+\rho}\right). \tag{A.6}$$

Moreover, rearranging the first-order condition of Foreign firms (6) and using the definition of the elasticity of demand $\varepsilon \equiv -\frac{P(Q)}{QP'(Q)}$, the input price is expressed as

$$r = \frac{Nct}{N - \frac{1}{\varepsilon}}.$$

Substituting this equality, we find that $\frac{\partial r}{\partial \tau} < 0$ if and only if

$$\frac{1}{\varepsilon} + 1 + \rho > 0, \tag{A.7}$$

which holds as long as the elasticity of demand is decreasing in aggregate output. Differentiating ε with respect to Q, we find that ε is decreasing in Q if and only if (A.7) holds. In a similar vein, let $\tilde{\varepsilon} \equiv -\frac{g(X,M,\tau)}{Xg_X(X,M,\tau)}$ denote the elasticity of demand for the intermediate good. Differentiating this with respect to X, we find that $\tilde{\varepsilon}$ is decreasing in X if and only if (A.7) holds. While the input price is decreasing in tariffs by raising the elasticity of demand, the tariff-inclusive input price is increasing in tariffs. From (A.6), we get

$$\frac{\partial(r\tau)}{\partial \tau} = \frac{Nct}{N+1+\rho} > 0.$$

While we mainly consider the effect of tariffs on the input price in Lemma 1, it is straightforward to examine the effect of the number of firms M, N. For the future reference, we derive these comparative statics results. Regarding the effect of N, using (A.3) and (A.4) for $r = g(X,M,\tau)$,

$$\begin{aligned}
\frac{\partial r}{\partial N} &= g_X(X,M,\tau)\frac{\partial X}{\partial N} \\
&= \frac{xP'(X)(M+1+\rho)}{M(N+1+\rho)} < 0.
\end{aligned}$$

The result reflects that the input price falls with the number of Foreign firms due to tough competition in the upstream sector.

As for the effect of M, using (A.3) and (A.5), we get

$$\begin{aligned}\frac{\partial r}{\partial M} &= g_X(X,M,\tau)\frac{\partial X}{\partial M} + g_M(X,M,\tau) \\ &= \frac{P'(X)(M+1+\rho)}{M}\cdot\frac{q}{M+1+\rho} - \frac{XP'(X)}{M^2} = 0.\end{aligned} \tag{A.8}$$

Surprisingly, a change in the number of Home firms has no effect on the input price. This is very special to demand with constant convexity, and the same does not necessarily hold for general demand.

A.2.2 Proof of Proposition 1

(i) Totally differentiating (6), (7) and (8) with respect to τ and using (A.3),

$$\begin{aligned}(N+1+\rho)\hat{X} &= \left(\frac{N+1+\rho}{M+1+\rho}\right)\hat{M} + \hat{N} + \left(\frac{Nct}{Xg_X(X,M,\tau)}\right)\hat{\tau}, \\ (2+\rho)\hat{X} &= 2\hat{M}, \\ (2+\rho)\hat{X} &= \left(\frac{1+\rho}{M+1+\rho}\right)\hat{M} + 2\hat{N} + \hat{\tau},\end{aligned}$$

where a "hat" denotes a proportional change in a variable, e.g., $\hat{X} \equiv \frac{dX}{X}$. Solving for $\hat{X}$ and rearranging, the elasticity of aggregate output (which is often referred to as the "trade elasticity" in the literature) is

$$\frac{d\ln X}{d\ln\tau} = \frac{-2(M+1+\rho)\left(1-\frac{2Nct}{Xg_X(X,M,\tau)}\right)}{(2M+\rho)(2N+\rho)-(2+\rho)} < 0. \tag{A.9}$$

Moreover, using (A.9), the elasticity of the extensive margin is

$$\begin{aligned}\frac{d\ln M}{d\ln\tau} &= \left(\frac{2+\rho}{2}\right)\frac{d\ln X}{d\ln\tau} < 0, \\ \frac{d\ln N}{d\ln\tau} &= -\frac{1}{2} + \left(\frac{(2+\rho)(2M+1+\rho)}{4(M+1+\rho)}\right)\frac{d\ln X}{d\ln\tau} < 0.\end{aligned} \tag{A.10}$$

Thus, a reduction in tariffs always increases the number of firms, leading to co-movement of firm entry in the vertically related sectors. Finally, differentiating $Q = Mq, X = Nx$ and using (A.9) and (A.10), the elasticity of the intensive margin is

$$\begin{aligned}\frac{d\ln q}{d\ln\tau} &= -\frac{\rho}{2}\frac{d\ln X}{d\ln\tau}, \\ \frac{d\ln x}{d\ln\tau} &= \frac{1}{2} + \left(\frac{(2+\rho)-\rho(2M+\rho)}{4(M+1+\rho)}\right)\frac{d\ln X}{d\ln\tau}.\end{aligned} \tag{A.11}$$

The first equality in (A.11) implies that $\frac{dq}{d\tau} < 0$ if and only if demand is strictly convex ($\rho < 0$). In contrast, using (A.3) and (A.9), the second equality in (A.11) implies that $\frac{dx}{d\tau} < 0$ if and only if

$$\frac{2M+\rho}{(2+\rho)-\rho(2M+\rho)} < -\frac{g(X,M,\tau)}{Xg_X(X,M,\tau)}. \tag{A.12}$$

Using (4) and (6), the inequality is expressed in terms of the input price as given in (9).

(ii) Totally differentiating (4) with respect to τ,

$$\frac{dr}{d\tau} = g_X(X, M, \tau)\frac{dX}{d\tau} + g_M(X, M, \tau)\frac{dM}{dt} + g_\tau(X, M, \tau),$$

where the effect of tariffs on aggregate output is decomposed as

$$\frac{dX}{d\tau} = \frac{\partial X}{\partial \tau} + \frac{\partial X}{\partial M}\frac{dM}{d\tau} + \frac{\partial X}{\partial N}\frac{dN}{d\tau}.$$

Using this decomposition for the equality above and rearranging,

$$\frac{dr}{d\tau} = g_X(X, M, \tau)\frac{\partial X}{\partial \tau} + g_\tau(X, M, \tau) + \left(g_X(X, M, \tau)\frac{\partial X}{\partial M} + g_M(X, M, \tau)\right)\frac{dM}{dt} + g_X(X, M, \tau)\frac{\partial X}{\partial N}\frac{dN}{d\tau}.$$

Note that the first two terms are the same as $\frac{\partial r}{\partial \tau}$ in (A.6), while the value in the brackets in the third term is zero in light of (A.8). This gives us the expression of (10).

Though this expression is useful in understanding the differences between the short-run and long-run effects of tariffs on the terms-of-trade, it involves several derivatives making it hard to reduce the expression further. However, there is a simpler way to prove the result. Rewrite the free entry condition (8) as

$$r = c + \frac{K_F}{x}.$$

Differentiating this equality with respect to τ, we immediately get the desired result that

$$\frac{dr}{d\tau} > 0 \quad \Longleftrightarrow \quad \frac{dx}{d\tau} < 0.$$

A.2.3 Proof of Lemma 2

We first show that the elasticity of demand is exactly the same between the vertically related sectors, as in (11). Recall that the elasticity of the final and intermediate goods is defined as $\varepsilon \equiv -\frac{P(Q)}{QP'(Q)}$ and $\tilde{\varepsilon} \equiv -\frac{g(X,M,\tau)}{Xg_X(X,M,\tau)}$. Dividing both sides of the aggregate first-order condition in the downstream sector (3) by $P = P(Q)$ and that in the upstream sector (6) by $r = g(X, M, \tau)$,

$$M - \frac{1}{\varepsilon} - \frac{Mr\tau}{P} = 0,$$
$$N - \frac{1}{\tilde{\varepsilon}} - \frac{Nct}{r} = 0.$$

For the constant-elasticity demand $P(Q) = AQ^{-1/\sigma}$, the elasticity of demand is $\varepsilon = \sigma$ whereas the convexity of demand is $\rho = -(\frac{\sigma+1}{\sigma})$ which implies $\sigma = -(\frac{1}{1+\rho})$. Using the relationship between the elasticity and convexity of demand, the aggregate first-order condition in the downstream sector is expressed as follows:

$$M + 1 + \rho = \frac{Mr\tau}{P}. \tag{A.13}$$

Further, using $g_X(X, M, \tau)$ in (A.3), the elasticity of demand for intermediate input is given by

$$\tilde{\varepsilon} = -\frac{Mr\tau}{XP'(X)(M + 1 + \rho)} = -\frac{P(X)}{XP'(X)},$$

where the second equality comes from (A.13). Since $Q = X$, we obtain the result, $\varepsilon = \tilde{\varepsilon} = \sigma$, as stated in (11). This also implies a relationship similar to (A.13) in the upstream sector:

$$N + 1 + \rho = \frac{Nct}{r}. \tag{A.14}$$

Next, we show that the *relative* pass-through is decreasing in import tariffs for constant-elasticity demand. Taking the log and differentiating (A.13) and (A.14) with respect to τ, we get

$$\frac{d\ln P}{d\ln \tau} - \frac{d\ln(r\tau)}{d\ln \tau} = \left(\frac{1+\rho}{M+1+\rho}\right)\frac{d\ln M}{d\ln \tau} > 0,$$
$$\frac{d\ln r}{d\ln \tau} - \frac{d\ln(ct)}{d\ln \tau} = \left(\frac{1+\rho}{N+1+\rho}\right)\frac{d\ln N}{d\ln \tau} > 0,$$

where the sign follows from (A.10) and $1 + \rho < 0$ for constant-elasticity demand.

Finally, we show that the *absolute* pass-through is decreasing in import tariffs for constant-elasticity demand. Dividing both sides of the free entry conditions (7) and (8) by $\frac{Q}{M} = q$ and $\frac{X}{N} = x$, respectively, and subsequently differentiating them with respect to τ, we get

$$\frac{d(P - r\tau)}{d\tau} = -\left(\frac{K_H}{q^2}\right)\frac{dq}{d\tau} > 0,$$
$$\frac{d(r - ct)}{d\tau} = -\left(\frac{K_F}{x^2}\right)\frac{dx}{d\tau} > 0,$$

where the first sign follows from $\frac{dq}{d\tau} < 0$ for constant-elasticity demand, and the second sign follows from $\frac{dx}{d\tau} < 0$ for this specific demand as the right-hand side of (A.12) reduces to $-\frac{1}{1+\rho}$ from (11).

A.2.4 Proof of Proposition 2

From (A.10) and (A.11), it is straightforward to see that

$$\frac{d\ln M}{d\ln \tau} - \frac{d\ln q}{d\ln \tau} = (1+\rho)\frac{d\ln X}{d\ln \tau},$$
$$\frac{d\ln N}{d\ln \tau} - \frac{d\ln x}{d\ln \tau} = -1 + \left(\frac{(1+\rho)(2M+\rho)}{2(M+1+\rho)}\right)\frac{d\ln X}{d\ln \tau}.$$

While the sign of the first equality is positive for constant-elasticity demand, the sign of the second equality is ambiguous at first and we need to derive the elasticity of aggregate output for this specific demand. Plugging (11) and (A.14) in (A.9), that elasticity is simplified to

$$\frac{d\ln X}{d\ln \tau} = \frac{\frac{2(M+1+\rho)(2N+1+\rho)}{1+\rho}}{(2M+\rho)(2N+\rho) - (2+\rho)} < 0.$$

Substituting this into the above relationships and rearranging, we get the results in (12):

$$\frac{d\ln M}{d\ln \tau} - \frac{d\ln q}{d\ln \tau} = \frac{2(M+1+\rho)(2N+1+\rho)}{(2M+\rho)(2N+\rho) - (2+\rho)} > 0,$$
$$\frac{d\ln N}{d\ln \tau} - \frac{d\ln x}{d\ln \tau} = \frac{2(M+1)}{(2M+\rho)(2N+\rho) - (2+\rho)} > 0.$$

A.3 Additional Tables

This appendix provides the detailed results for final goods trade that are omitted due to the space constraint. Tables A.1 and A.2 respectively correspond to Tables 4 and 5 in the main text.

Table A.1: Alternative DID estimations in (15)

	(1)	(2)	(3)
	$\ln Q_{pct}$	$\ln M_{pct}$	$\ln q_{pct}$
$\ln \tau_{pc2001} * d_{2001}$	-0.792^{***}	-0.346^{***}	-0.446^{**}
	(0.237)	(0.059)	(0.200)
$\ln \tau_{pc2001} * d_{2002}$	-1.518^{***}	-0.750^{***}	-0.768^{***}
	(0.286)	(0.094)	(0.236)
$\ln \tau_{pc2001} * d_{2003}$	-2.617^{***}	-1.252^{***}	-1.365^{***}
	(0.376)	(0.126)	(0.293)
$\ln \tau_{pc2001} * d_{2004}$	-2.647^{***}	-1.337^{***}	-1.310^{***}
	(0.399)	(0.142)	(0.307)
$\ln \tau_{pc2001} * d_{2005}$	-2.353^{***}	-1.270^{***}	-1.083^{***}
	(0.398)	(0.148)	(0.312)
$\ln \tau_{pc2001} * d_{2006}$	-1.911^{***}	-1.255^{***}	-0.656^{*}
	(0.515)	(0.179)	(0.389)
$\ln \tau_{pc2001} * d_{2007}$	-1.210^{**}	-1.157^{***}	-0.054
	(0.473)	(0.186)	(0.359)
No. of obs	247,099	247,099	247,099
Adj. R^2	0.752	0.871	0.686

Note: Total imports (Q_{pct}), extensive margin (M_{pct}), and intensive margin (q_{pct}) are in logarithm. Robust standard errors are clustered at the product level in parentheses. ***, **, and * indicate significance at the 1%, 5% and 10% level, respectively.

Table A.2: Poisson estimations in (16)

	(1)	(2)	(3)
	Q_{pct}	M_{pct}	q_{pct}
$\ln \tau_{pct-1}$	-2.440^{*}	-0.595^{**}	-2.911^{**}
	(1.341)	(0.268)	(1.210)
No. of obs	162,683	162,683	162,683

Note: Total imports (Q_{pct}), extensive margin (M_{pct}), and intensive margin (q_{pct}) are in real numbers. Robust standard errors are clustered at the product level in parentheses. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

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