Customer Capital and Aggregate Welfare*

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Abstract

Using a novel dataset that links production and sales of Chinese exporting firms, we document the value of export goods that a firm produces is often different from the value of export goods that the firm sells in foreign markets. Interpreting this fact as evidence of the trade of customer capital (e.g., accumulated customer base), we build a model in which firms can borrow and lend their customer capital via outsourcing. The estimated model suggests customer-capital trade generates substantial welfare gains.

Keywords: Customer Capital, Demand Capital, Outsourcing, Productivity

JEL classification codes: D24, F11, L11, O47

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1 Introduction

Firms invest a large number of resources in expanding their customer base.[1] Understanding the heterogeneity in firms' accumulated customer base − also called customer capital − is a key to understanding firm/industry dynamics.[2] In this paper, we argue that customer capital can be traded across firms and that the trade of customer capital generates substantial welfare gains. As far as we know, this paper is the first to quantify the implications of the trade of customer capital.

Using a novel dataset that links production and sales of Chinese exporting firms, we document the value of export goods that a firm produces is often different from the value of export goods that the firm sells in foreign markets. This fact suggests outsourcing is prevalent among Chinese exporting firms. For example, more than 62% of Chinese exporting firms sold a different amount of products from what they produced in 2006. This pattern holds even in a narrowly defined homogeneous industry.

The exporter age is a key determinant of the outsourcing pattern across firms; older firms tend to export more than they produce, even after controlling for the firms' productivity. Assuming older firms have a larger customer capital (as suggested by Foster et al. (2016)), this outsourcing pattern can be explained by the trade of customer capital; firms with a large amount of customer capital "lend" their customer capital to firms with a small amount of customer capital with better production capability.[3] In doing so, the exporters with a small

[1]For example, US firms' marketing expenditure is about 8% of GDP (Gourio and Rudanko (2014)).

[2]Foster et al. (2016) show the customer-base heterogeneity can explain the price and productivity dynamics over a firm's life cycle. Gourio and Rudanko (2014) show customer-base heterogeneity explains firms' investment dynamics. Arkolakis (2010) argues the cost of accumulating a customer base explains many trade patterns.

[3]In most customer-capital literature, older firms have a larger customer base conditional

amount of customer capital avoid the high cost of reaching foreign customers.

To understand the implications of customer-capital trade, we develop a framework in which firms can borrow and lend their customer capital via outsourcing. The outsourcing price is determined at an equilibrium in which the aggregate demand and supply of customer capital are equalized. We also incorporate the cost of trading customer capital and let the data tell us the size of the cost.

We calibrate the model by matching data moments from the textile and garment industry in which relatively homogeneous goods are produced. The calibrated model suggests frictions prevent firms from trading their customer capital at the optimal level. Even if so, the current status of customer-capital trade generates substantial welfare gains; without it, the aggregate welfare would reduce by 14%. When the customer capital is not traded, a firm's production cost increases and the aggregate supply reduces. As a result, the equilibrium output price increases, and consumer surplus decreases.

Next, we ask whether the joint distribution of customer capital and firm productivity matter for aggregate welfare. In other words, we investigate how much it matters for a firm with a large amount of customer capital to have low versus high productivity for the aggregate welfare. We first document that the estimated distribution of customer capital and productivity indicates a high correlation between the two: the correlation between log customer capital and log productivity is estimated at 0.86. Nevertheless, if the correlation is 1, the aggregate welfare increases by 2% mainly due to the reduction of the cost involved in trading customer capital. This finding implies a low-productivity

on their productivity. Due to different frictions on the product market, such as information friction (Perla (2016)), search friction (Gourio and Rudanko (2014)), or adjustment cost (Foster et al. (2016)), the customer base needs time to build.

firm's behavior of accumulating high customer capital may be inefficient if the firm has to rely primarily on outsourcing. Related, a government should target a high-productivity firm when they subsidize firms for entering an exporting market.

This paper contributes to the literature on demand-side frictions and firm performances. Foster et al. (2016) show demand-side frictions (asymmetric information, search, or other frictions) lead a firm to accumulate a customer base, and this behavior explains a well-known fact that new businesses are smaller than the established businesses conditional on firm productivity. Gourio and Rudanko (2014) and Luttmer et al. (2006) model search frictions between customers and firms, and show an accumulated customer base is essential in understanding firm dynamics and firm distribution. Related, Bronnenberg et al. (2012) show brand capital, which is in large part shaped by consumers' experience, explains a substantial share of geographic variation in the purchase of consumer goods. Pozzi and Schivardi (2016) show the extent to which a demand shock leads to a firm's growth is larger than that of a supply shock. Our main contribution to this line of literature is to show the accumulated customer base can be traded in the form of outsourcing, and the trade of customer capital substantially mitigates the welfare loss induced by demand-side frictions.

This paper is also related to the literature on trade costs and international trade. Drozd and Nosal (2012) develop a model of search frictions in the exporting market and show building a customer base in the exporting market is the key to understanding the price dynamics of exporting goods. Related, Arkolakis (2010) develops a model of a marketing cost in the exporting market (in the presence of search friction) as a specific trade cost, and shows the model can reconcile many features of exporting firms' dynamics. Although both papers emphasize the importance of the accumulated customer base due to frictions in the exporting market, they abstract the possibility that the accumulated customer base in the exporting market can be traded in the form of outsourcing. Ahn et al. (2011) and Bai et al. (2017) emphasize a role of trade intermediaries on mitigating trade cost. The trade intermediaries that they focused on are those that export but do not produce. They abstract the fact that the trade arrangement can be possible among direct exporters. Using Belgium trade data, Bernard et al. (2018) document exporting products that exporters do not produce is common in their data, and argue the demand-side factors explain such behavior. Our paper complements the findings of Bernard et al. (2018) in two important dimensions. First, empirically, we show the amount of goods produced is often different from the amount of goods exported even within a narrowly defined product level. Second, theoretically, we develop a framework by which we can investigate the welfare implications of firms' outsourcing behaviors.

The paper is organized as follows. Section 2 documents motivating facts for this study. Section 3 presents a model of customer-capital trade. The quantitative results are shown in section 4. Section 5 concludes.

2 Motivating Facts

In this section, we explain the dataset for this study and document key empirical findings.

2.1 Data

For this study, we merge the Annual Surveys of Industrial Production in China (ASIP) with Chinese customs data between 2000 and 2006. The ASIP covers all state-owned and privately wned manufacturing firms whose annual sales are above 5 million RMB (0.71 million USD).[4] In addition to a firm's characteristics, the ASIP provides information on the value of export goods that the firm produced. This variable captures both the value of export goods that are directly sold by the surveyed firm and the value of export goods that are sold through other channels.[5]

The Chinese customs data contain a firm's export value, price, and the destination information of each product in the 6-digit Harmonized System (HS6) at the transaction level. The customs data only record the firms that carry the goods abroad. As a result, some exporters in the customs data may be trade intermediaries or manufacturing firms that carry products that they do not produce.

Given that the two datasets do not share the same firm identifier, we impose strict criteria when we match firms in the two datasets following Bai et al. (2017). Based on (1) firm name, (2) region code, (3) address, (4) phone number, and (5) legal representative, two firms in each dataset are classified as the same firm only if a majority of that information is matched. Bai et al. (2017) conduct several robustness checks for their matching criteria that we follow in this study and find the matching criteria reliable.

Of 405,374 firm-year observations for firms in the ASIP that produced export goods, about 48% (194,072) are in the Chinese customs data. For the

[4]The monetary values are expressed in constant 2000 Chinese Yuan.

[5]For the definition of the export value in the ASIP, we refer to http://www.autostats.org.cn/gytjzbjs.htm (in Chinese).

firms in the ASIP and the customs data, we compare the value of export goods that a firm produced, as contained in the ASIP, and the value of goods that the firm exported, as contained in the customs data. For convenience, we call the value of export goods that a firm produced in the ASIP the "production" value and the value of goods that the firm exported in the customs data the "sales" value.

2.2 Main findings

The main motivating fact for this paper is shown in Figure 1. Figure 1 (a) shows the histogram for log value of production per sales for all firm-year observations. We observe a substantial variation in exporting firms' production-per-sales value. Relatively more measures are observed around zero, but many firms exhibit either negative or positive log production-per-sales value. Figure 1 (b) shows the histogram for the log value of production per sales for the textile and garment-production industry in which goods are relatively homogeneous. Even among firms that produce relatively homogeneous products, we observe a large variation in production-per-sales value.

Table 1 shows the specific number (and the proportion) of firms for the production-per-sales value in each year. Consistent with Figure 1 (a), exporting firms' sales value is often different from their production value. For example, more than 62% of Chinese exporting firms sold more or less than what they produced in 2006.

2.3 Discussion of measurement error

Some may be concerned our findings in Figure 1 and Table 1 mainly reflect measurement errors. We believe they do not, because of the following reasons.

First, the aggregate export values in the two datasets are comparable. As shown in Table 2, the aggregate export values in the ASIP are about 80% of the aggregate export values in the Chinese customs data in all years. The 20% gap is likely due to the ASIP not covering small firms whose annual sales are less than 5 million RMB.

Second, to reduce the possibility of matching two different firms as the same firm, we impose strict criteria when matching firms in the two datasets. By doing so, we may not be able to identify the same firm in both datasets. However, as long as the matching error is random, the findings in Figure 1 and Table 1 will reflect the true statistics.[6]

Finally, recognizing a possible measurement error, we classify firms whose production-per-sales value is between 0.9 and 1.1 into the same category in Table 1. Even if so, a substantial number of firms exhibit different values for production than for sales.

2.4 Comparison to the previous findings

Using Belgium customs data, Bernard et al. (2018) document that a firm often exports a greater *variety* of products than it produces. Bernard et al. (2018) argue the export goods that are not produced by the firm are highly *complementary* to the export goods that the firm produces, and this complementarity explains the trade pattern they found.

We document the *value* of export goods that a firm produces is often different from the value of export goods that the firm sells in foreign markets. Our findings even hold for firms that export the same variety of products that they produce. In the ASIP, firms report the 4-digit industry into which their main

[6] We believe some firms are not matched, because of a misspelling of names or capital/non-capital letter difference, and assume such cases randomly happen.

products (core products) are categorized. On the other hand, in the customs data, we can identify an industry categorization for every transaction level.

We further categorize firms that export more than they produce into two types: (1) firms whose sales of products within their registered industry (core sales) are greater than their production and (2) firms whose core sales are less than or equal to their production (Table 3). Among firms whose production per sales are less than 0.9, about one third of firms export more products, categorized as their core products, than they produce. The 4-digit industry is a finely defined industry categorization. For example, within the 2-digit textile industry, silk spinning and finishing is a 3-digit industry. Within the 3-digit silk-spinning and finishing industry, (1) silk spinning and weaving, (2) silk-filament processing, and (3) silkscreen dyeing and finishing are 4-digit sub-industries. Those firms (whose export value is greater than their production value within the 4-digit industry) are more likely to have been able to produce the products themselves, but chose not to do so. In other words, they export products (produced by other firms) that are highly *substitutable* to their products.

Our findings are also different from the factory-less goods-producing firms (FGPFs); e.g., Apple, Dyson, which design the goods they sell and outsource the production activities through the purchase of contract manufacturing services (Bernard and Fort (2015)). The FGPFs are likely to be observed in an industry in which differentiated goods are produced. However, our findings are also observed in an industry in which highly homogeneous goods are produced, such as cotton and chemical fiber products or textile and garment manufacturing.

2.5 Exporter age and outsourcing

In this section, we document that exporter age is a strong predictor of the tendency to export more than the amount that the firm produces.

Throughout the seven years (2000-2006), we observe when a firm first entered the exporting market (i.e., the year a firm is first observed in the customs data). We calculate exporter age as the current year minus the initial exporting year.[7] In Table 4, we conduct several regression analyses for the log value of production per sales on exporter age with a variety of fixed effects. In the first column, we first control for the year-industry fixed effect. The industry refers to the core industry reported in the ASIP. For two exporting firms in the same industry and the same year, if a firm started exporting one year earlier than the other, its production per sales is about 6% lower. In the second column, we also control for a firm's main destination, which is defined as the country where its export value is highest in a given year. By controlling the year-industry-destination fixed effect, we compare firms in the same industry, the same year, and with the same main destination. The results are similar to those in the first column; older firms are more likely to have lower production per sales. In the third column, we control for the firm fixed effect. Consistent with the previous findings, as a firm ages, its production per sales decreases. In all specifications that exploit different variations, the production per sales negatively correlate with exporter age.

The ASIP provides detailed information about a firms' input and output (including domestic output) measures. Using this information, we construct a firm's total factor productivity (TFP) following Olley and Pakes (1996). In columns (4) through (6), we conduct otherwise identical regressions to the first

[7]We remove firms first observed from 2000, because we do not know their previous sales in the exporting market.

three, except we include log TFP as an additional control variable. Even after controlling for a firm's TFP, exporter age is strongly (negatively) correlated with the firm's production-per-sales value.

2.6 Discussion of possible mechanisms

Existing theories are hard to reconcile with our empirical findings. One possible explanation for outsourcing is the specialization of the value chain (Grossman and Helpman (2005); Oshri et al. (2015)). However, the outsourcing pattern is still prevalent within a narrowly defined homogeneous industry. Similarly, bundling complementary goods together to expand the demand (Bernard et al. (2018)) cannot explain the outsourcing pattern within the homogeneous-goods sector either. Moreover, neither of these theories can reconcile why older firms tend to outsource more, even after controlling for their productivity.

We are not the first to mention that customers are costly to reach and use this fact to explain some interesting data patterns. Given that building customer capital takes time, the age of firms measures the customer capital well. For instance, Foster et al. (2016) recover the customer capital from the pricing data and show the age of firms strongly correlates with the customer capital across firms. Borrowing their findings, we argue the heterogeneity in customer capital is a key driving force of the observed outsourcing pattern.

To rationalize our empirical findings, in the next section, we develop a framework in which firms with a large amount of customer capital "lend" their customer capital to firms with a small amount of customer capital with better production capability.

3 Model

The model is based on Lucas (1978), a canonical model of firm distribution. In Lucas (1978), the distribution of firms' output is determined by heterogeneous entrepreneurial productivity. We impose two additional assumptions.

First, we assume each firm is endowed with the number of customers, and a firm can only sell to the given number of customers. This assumption is to incorporate the findings in the previous literature, which shows that, conditional on firm productivity, a firm's outcome differs depending on its customer capital (e.g., Foster et al. (2016)) induced by frictions in the product market (e.g., asymmetric information or search friction).

Second, we allow firms to outsource the production to maximize their profits, given their productivity and given customers. We incorporate friction involved with outsourcing in a parsimonious way: a firm has to incur a fixed cost per outsourcing unit. The market price of outsourcing (in addition to the exogenous cost capturing friction) is determined when the demand and supply of outsourcing are equalized.

3.1 Environment

The industry has a unit measure of firms. A firm is characterized by (n, z), where n and z refer to the number of customers and productivity. $G(n, z)$ is the distribution of n and z. Each firm has decreasing-returns-to-scale production technology to produce homogeneous goods. We assume the cost of producing q units of output is $\frac{1}{(1+\alpha)z}q^{1+\alpha}$, where $\alpha > 0$ is the curvature of the firm production cost implied by the decreasing-returns-to-scale technology.

Friction exists in the export market; only n customers in the export market, whom we call the firm's customer capital, know each firm. A firm cannot sell to anyone other than its given customers. The aggregate demand in the export market is $D(p)$.

An outsourcing market exists, and the firm can outsource its production to other firms. For each firm i, we define the share of goods that the firm produce as

$$S_i = \frac{\text{Export Goods that firm } i \text{ produces}}{\text{Goods that firm } i \text{ exports}}.$$

If $S_i = 1$, the firm only sells its product. If $S_i < 1$, the firm outsources some of its production to other firms. A special case is $S_i = 0$. A firm with $S_i = 0$ acts as a trade intermediary. The firm produces nothing and exports other firms' products.

A firm delegating production to other firms needs to pay a cost h per unit of outsourcing. h captures friction associated with outsourcing per unit (e.g., business-stealing effect). Suppose $S_i > 1$; the firm receives production orders from other firms and exports simultaneously. The firm's production is greater than its sales.

All the above firms are direct exporters because they directly participate in the export market (Bai et al. (2017)). The direct exporters need to pay a fixed export-cost F as in Melitz (2003). We call a firm with $S_i = +\infty$ an indirect exporter. The indirect exporters rely purely on other firms to export and not pay F.

Direct exporter's problem

We first consider a firm with $S < 1$. We denote q as the export. The firm produces Sq and outsources the production of $(1 - S)q$ to other firms:

$$\pi^S(n, z) = \max_{q, 0 \leq S \leq 1} \left\{ pq - (p^* + h)(1 - S)q - \frac{1}{(1+\alpha)z}(Sq)^{1+\alpha} - F \right\} \qquad (1)$$

$$s.t. \quad q \le n,$$

where p is the price in the export market and p^* is the per-unit cost of outsourcing products. The constraint describes the restriction that a firm's sales cannot exceed its customer capital n.

Next, we consider a firm with $1 < S < +\infty$. The firm exports q directly and produces more than what it produces $Sq > q$. The firm receives a production order of $(S-1)\,q$ from other firms:

$$\pi^B(n, z) = \max_{q, S>1} \{pq + p^*(S-1)\,q - \frac{1}{(1+\alpha)\,z}(Sq)^{1+\alpha} - F\} \tag{2}$$

$$s.t. \quad q \le n,$$

where pq is the revenue from direct export, and $p^*(S-1)\,q$ is the revenue from the production order. The difference between problem (1) and (2) is that a firm with $1 < S < +\infty$ does not need to pay h.

By unifying problems (1) and (2), the value of direct exporter is defined as

$$\pi^D(n, z) = \max_{q, S\ge 0} \{pq - (p^* + \chi(S<1)\,h)(1-S)\,q - \frac{1}{(1+\alpha)\,z}(Sq)^{1+\alpha} - F\} \tag{3}$$

$$s.t. \quad q \le n,$$

where $\chi(S<1)$ is an indicator function, that takes value 1 if $S < 1$, and 0 otherwise.

Indirect exporter's problem

An indirect exporter does not need to pay the fixed cost for exporting. The indirect exporter's problem is

$$\pi^{I}(z) = \max_{q}\{p^{*}q - \frac{1}{(1+\alpha)z}q^{1+\alpha}\}. \tag{4}$$

Direct vs. indirect exporter

The firm chooses either to be a direct exporter or an indirect exporter:

$$\pi(n,z) = \max\{\pi^{D}(n,z), \pi^{I}(z)\}, \tag{5}$$

where $\pi(n,z)$ is the optimal profit function of an exporter with customer capital n and productivity z.

Equilibrium

The industry equilibrium is defined as two prices p and p^{*} such that (1) the total sales from the direct exporter should satisfy the total demand in the export market, and (2) the market for customer capital is cleared.

3.2 Characterization

We show in Appendix A that the firm's optimal solution is characterized by Proposition 1.[8]

Proposition 1. *A cutoff $\bar{n}(z)$ exists such that (i) if $n < \bar{n}(z)$, the firm chooses to be an indirect exporter, and if $n \geq \bar{n}(z)$, the firm chooses to be a direct exporter. (ii) When the firm chooses to be an indirect exporter, the production*

[8]The graphical representation of Proposition 1 is shown in Figure 2.

is $q^I(z) = (p^* z)^{\frac{1}{\alpha}}$. *(iii) When the firm chooses to be a direct exporter,* $q^D(n) = n$. *If* $n < (p^* z)^{\frac{1}{\alpha}}$, *the direct exporter chooses* $S > 1$; *if* $n > ((p^* + h) z)^{\frac{1}{\alpha}}$, *the direct exporter chooses* $S < 1$; *and if* $n \in [(p^* z)^{\frac{1}{\alpha}}, ((p^* + h) z)^{\frac{1}{\alpha}}]$, *the direct exporter chooses* $S = 1$.

A special case is when $z = 0$. If a firm with zero productivity has enough customer capital, the firm will choose to be a direct exporter with $S = 0$. In other words, the firm becomes an intermediary.

Given the firm's optimal solution, the industry equilibrium is characterized by the following two equations:

$$D(p) = \int_{n > \bar{n}(z)} n dG(n, z) \tag{6}$$

$$\int_{n > \bar{n}(z)} n [1 - S(n, z)] dG(n, z) = \int_{n < \bar{n}(z)} q^I(z) dG(n, z), \tag{7}$$

where q^I is the indirect exporters' production. The first equation suggests the total sales from direct exporters should satisfy the total demand. The second equation suggests the total net amount of outsourcing from the direct exporters should equal the indirect exporters' production.

The existence and the uniqueness of the equilibrium are guaranteed when $F = 0$, as shown in the next section. In general, multiple solutions of p and p^* to the system of non-linear equations (6) and (7) may exist. We explain how we handle multiple equilibria, when we calibrate the model in section 4.1.

The producer surplus is

$$
\begin{aligned}
\int \pi(n,z)\, dG(n,z) &= pD(p) - \int_{n>\bar{n}(z)} \left(\frac{1}{(1+\alpha)z} (Sn)^{1+\alpha} + F \right) dG(n,z) \\
&\quad - \int_{n<\bar{n}(z)} \frac{1}{(1+\alpha)z} q^I(z)^{1+\alpha}\, dG(n,z) \\
&\quad - h \int_{n>\max(\bar{n}(z),((p^*+h)z)^{\frac{1}{\alpha}})} (1-S)\, n dG(n,z).
\end{aligned}
$$

The first term is the revenue $pD(p)$ of the industry. The second-to-the-last terms are the three cost components of the industry, including the production cost

$$
\int_{n>\bar{n}(z)} \left(\frac{1}{(1+\alpha)z} (Sn)^{1+\alpha} \right) dG(n,z) + \int_{n<\bar{n}(z)} \frac{1}{(1+\alpha)z} q^I(z)^{1+\alpha}\, dG(n,z),
$$

the fixed entry cost

$$
\int_{n>\bar{n}(z)} F dG(n,z),
$$

and the outsourcing cost

$$
h \int_{n>\max(\bar{n}(z),n>((p^*+h)z)^{\frac{1}{\alpha}})} (1-S)\, n dG(n,z).
$$

Finally, we can define consumer surplus as $\int_p^{+\infty} D(x)\, dx$. The aggregate welfare of the industry is defined as the sum of the producer and consumer surplus.

Why do firms trade customer capital? Some firms can reduce their production cost, and other firms can access more foreign consumers. As we show in the next subsection, reducing the production cost is not sufficient to guarantee the existence of customer-capital trade. The reason is that if all firms have enough customer capital (or cost to accessing the foreign consumers is 0), firms will charge high outsourcing cost p^* such that no firms want to outsource in the equilibrium.

What is the implication of customer-capital trade on aggregate welfare? If friction in the export market prevents firms from finding customers, they are constrained to sell to their (accumulated) customers. Suppose more productive firms have a small number of customers (whereas less productive firms have many customers). In that case, the aggregate welfare will decrease compared to the first-best allocation. The trade of customer capital can mitigate this inefficiency.

3.3 Special case

In this section, we consider a special case in which the fixed cost does not exist ($F = 0$) and all firms have positive productivity. If $F = 0$, all firms will choose to be direct exporters ($\bar{n}(z) = 0$). On the other hand, if all firms have positive productivity, no pure intermediary firm exists.

Under the assumptions of the special case, the equilibrium conditions become

$$D(p) = \int n dG,$$

$$\int n [1 - S(n, z)] dG = 0.$$

The first equilibrium condition suggests the international export price p only depends on the mean of n.

Substituting the definition of $S(n, z)$, we can rewrite the second equilibrium condition as

$$\int ndG = p^{*\frac{1}{\alpha}} \int_{n<(p^* z)^{\frac{1}{\alpha}}} z^{\frac{1}{\alpha}} dG + (p^* + h)^{\frac{1}{\alpha}} \int_{n>((p^*+h)z)^{\frac{1}{\alpha}}} z^{\frac{1}{\alpha}} dG + \int_{n\in[(p^* z)^{\frac{1}{\alpha}}, ((p^*+h)z)^{\frac{1}{\alpha}}]} ndG.$$

The left-hand side (LHS) is the industry's total exports, and the right-hand side (RHS) is the total production of the industry. The above condition could be written as

$$E[n] = E[\min\{\max(n, (p^* z)^{\frac{1}{\alpha}}), ((p^* + h) z)^{\frac{1}{\alpha}}\}].$$

We can see the RHS is an increasing function of p^*, suggesting the production goes up if p^* increases. Hence, the first result is easy to see:

Proposition 2. *A unique equilibrium exists.*

We consider the relationship between $corr(n, z)$ and aggregate welfare. The RHS function is a sub-modular function for n and z, suggesting that when the correlation between n and z becomes stronger, the RHS becomes smaller.[9] Hence, fixing $E[n]$, when the correlation between n and z increases, p^* becomes smaller. Intuitively, when the high n firm also has high productivity, the demand for outsourcing will decrease. Thus, p^* will go down.

We can see the importance of the outsourcing cost h. If $h = 0$, $\min\{\max(n, (p^* z)^{\frac{1}{\alpha}}), ((p^* + h) z)^{\frac{1}{\alpha}}\}$ collapses to $(p^* z)^{\frac{1}{\alpha}}$. In this case, p^* only depends on $E[n]$ and $E\left[z^{\frac{1}{\alpha}}\right]$. The correlation between n and z does not change p^*.

Given the aggregate supply is fixed at $E[n]$, consumer surplus will depend on the shape of the aggregate demand curve $D(p)$. The producer surplus

[9] The proof is provided in Appendix A.

equals

$$\begin{aligned}
\text{Producer surplus} &= pD(p) - \int \frac{1}{(1+\alpha)z}(Sn)^{1+\alpha}dG - h\int_{n>((p^*+h)z)^{\frac{1}{\alpha}}}(1-S)\,ndG \\
&= pD(p) - \frac{1}{1+\alpha}E[\frac{1}{z}\left[\min\{\max(n,(p^*z)^{\frac{1}{\alpha}}),((p^*+h)z)^{\frac{1}{\alpha}}\}\right]^{1+\alpha}] \\
&\quad -h\int_{n>((p^*+h)z)^{\frac{1}{\alpha}}}\left(n-((p^*+h)z)^{\frac{1}{\alpha}}\right)dG.
\end{aligned}$$

When p^* decreases, the second term decreases because the production cost becomes cheaper than before. At the same time, more firms will choose to outsource so that the total outsourcing cost increases. The producer surplus will depend on the magnitude of these two effects.

3.4 The role of customer-capital restriction

We investigate the role of the customer-capital restriction ($q \le n$). We show that when the customer-capital restriction does not exist, every firm will choose to sell what they produce, and trading of customer capital will not be observed.

From Appendix A, we have the direct exporter's profit:

$$\pi^D(z) = \begin{cases} (p-p^*)\,q + \frac{\alpha}{1+\alpha}(p^*)^{1+\frac{1}{\alpha}}z^{\frac{1}{\alpha}} & \text{if } S>1 \\ (p-p^*-h)\,q + \frac{\alpha}{1+\alpha}(p^*+h)^{1+\frac{1}{\alpha}}z^{\frac{1}{\alpha}} & \text{if } S<1 \\ \frac{\alpha}{1+\alpha}p^{1+\frac{1}{\alpha}}z^{\frac{1}{\alpha}} & \text{if } S=1. \end{cases}$$

Intuitively, when a firm chooses $S \neq 1$, the firm trades customer capital to make the cost function (and the profit function) become flat for the production of q. If the firm chooses $S = 1$, its production function is still convex, and the profit function generates an interior solution.

First, we can easily see that any $p > p^*$ cannot be an equilibrium. Otherwise, all firms find it profitable to choose $S > 1$ and choose q as much as they can. Second, if $p < p^*$, no firms will want to choose $S > 1$, and the outsourcing market cannot be equalized. Therefore, in the equilibrium, all firms choose $S = 1$ and $p = p^*$.

To summarize, the outsourcing behavior makes the production cost constant regardless of the number of output q. However, without the customer-capital restriction, outsourcing will not be observed, because firms that produce for other firms will charge a price high enough that no firm has an incentive to outsource its production.

4 Quantitative Evaluation

In this section, we calibrate the model to conduct counterfactual simulations.

4.1 Calibration

Sample construction

The model considers an industry in which homogeneous goods are produced. For estimation, we use products categorized as Chinese industry code 1810 (Textile and garment manufacturing), an industry into which relatively homogeneous goods are categorized.

We first take the ASIP as our primary estimation sample and keep firm-year observations if a firm's main industry is categorized as 1810. China joined WTO in 2003, and data moments before and after 2003 are quite different. For this reason, we use observations between 2003 and 2006. We then merge the primary sample with the customs data. Those firms that show up both in the ASIP and the customs data are, by our definition, direct exporters.

Specification

We first impose a parametric assumption on some model elements. First, we assume the elasticity of demand to price is constant. Specifically, the demand curve is $D(p) = Dp^{-\beta}$, where $\beta > 1$ is the price elasticity and D is a constant. Following Hayashi (1982), we set $\alpha = 1$ so that the cost function is a quadratic function with respect to z.

Second, we impose a parametric assumption on the joint distribution of n and z. Conditional on $z > 0$, n and z are assumed to follow a joint log-normal distribution with the mean μ_n, μ_z and the co-variance matrix $[\sigma_n^2, \rho\sigma_n\sigma_z; \rho\sigma_n\sigma_z, \sigma_z^2]$, where μ_n and μ_z are the means of $\ln(z)$ and $\ln(n)$ respectively, σ_z and σ_n are the standard deviations of $\ln(z)$ and $\ln(n)$, respectively, and ρ is the correlation coefficient between $\ln(z)$ and $\ln(n)$. To incorporate trade intermediaries in the data, we assume one firm exists whose $z = 0$ and whose customer capital is n^I.

To guarantee the uniqueness of the equilibrium during the calibration process, we normalize the equilibrium price (p) as 1.[10] Because the equation (7) is monotone with respect to p^* when fixing p, we can get an unique equilibrium. We also normalize the money value by the average of direct exporters' sales.

Mapping model to the data

First, the price elasticity (β) can be identified by the relationship between price and export value. To estimate the demand elasticity, we consider the

[10]Normalizing p is possible because D can be adjusted so that the equilibrium condition is always satisfied.

following regression equation:

$$\ln q_{jit} = \alpha - \beta \ln p_{jit} + \tau_j \times \tau_t + \epsilon_{jit}, \tag{8}$$

where j, i, and t refer to the HS6-level product, firm, and year, respectively. We estimate the demand elasticity by controlling for the product-year fixed effect ($\tau_j \times \tau_t$). We can observe the unit price and the total value of each export transaction in the Chinese customs data. By dividing the export value by the unit price, we can get the quantity for each transaction. A possible endogeneity issue may arise. Different firms may face different demand shocks for a given product in a year and adjust prices accordingly. As a result, ϵ_{jit} and p_{jit} can be positively correlated. To solve this endogeneity problem, we use the average wage within the city where a firm headquarter is located as an instrumental variable (IV) for the price. The city-level wage affects the production cost and hence affects the output price, and it is less likely to be affected by the demand shocks in the foreign markets.

In the first-stage estimation, we regress the log value of price on city-level wages' log value. The coefficient before the log value of city-level wages is about 0.35 and significant at the 1% level, suggesting a 10% increase in the city-level wage leads to a 3.5% increase in the output price. The F-statistics is 2,031 in the first-stage regression. The price elasticity in the second stage is estimated at 0.69 and significant at the 1% level.

The remaining parameters are calibrated by matching the target moments. Specifically, the proportion of each type of (non-intermediary) exporters can inform the value of h and F. For example, as h increases, fewer firms will choose to outsource. Similarly, when F decreases, more indirect exporters become direct exporters that export less than what they produce (because their n is small). The total export value of intermediaries can discipline the customer capital of the pure intermediary firm (n^I).[11] Other parameters for the joint distribution of (n, z) ($\{\mu_n, \mu_z, \sigma_n, \sigma_z, \rho\}$) affect the joint distribution of sales and production values for direct exporters, and therefore can be pinned down by those moments. In Appendix B, we show the numerical details of our estimation.

The target moments and model fit are shown in Table 5. The model fit for the targeted moments is reasonably good. We also report the second moment of sales and production of direct exporters, which we do not target. The standard deviations from the model simulation are higher than the ones from the data. However, the order of magnitude of the standard deviations across different groups is in line with the actual data.

4.2 Results

Parameter estimates are shown in Table 6. The outsourcing cost h is estimated at 0.58, meaning the outsourcing cost per unit is about 58% of the unit price p. On the other hand, the price of customer capital p^* is about 0.3, which is much smaller than h. In other words, firms that outsource their production incur much higher costs than the actual payment for outsourcing. Given other parameter values, the model predicts higher customer-capital trading if h is 0. The model can match the observed data pattern because of a higher h, which may capture frictions that prevent firms from trading customer capital.

The fixed exporting cost F is estimated at 0.12, suggesting about 12% of the average direct exporters' sales value is needed for direct exporting. The

[11] Given that the unmatched firms in the two datasets may include not only indirect exporters but also direct exporters that we failed to match, we set the total export value by intermediaries as 32%, which is from Ahn et al. (2011).

correlation between $\ln n$ and $\ln z$ is estimated at 0.86, showing that firms with higher productivity are more likely to have more customer capital.

4.3 Counterfactual experiments

We conduct two counterfactual simulations using the parameter estimates.[12] In the first simulation, we remove the market for customer capital by making h infinity so that the trading of customer capital is not observed. The impact on welfare, output price, and export value, relative to the benchmark economy, is reported in the second column of Table 7.

The aggregate welfare decreases about 14%, to which the reduction in consumer surplus contributes the most. By contrast, producer surplus increases by about 3%. When the trading of customer capital is prohibited, firms with low productivity and high customer capital will produce output that is less than their customer capital. As a result, the aggregate supply will decrease. In turn, the equilibrium price will increase by 90% and the equilibrium quantity will decrease. Given that the estimated price elasticity of consumer demand is low, consumers will lose their surplus, and firms benefit more due to a higher equilibrium price.

In the second counterfactual analysis, we set the correlation between a firm's customer capital and productivity as 1. In other words, the most productive firm has the highest customer capital. The impact on welfare, output price, and export value, relative to the benchmark economy, is reported in the third column of Table 7.

The aggregate welfare increases by about 2%. First, more firms become direct exporters, the aggregate export quantity increases, and the output price

[12] In the counterfactual analyses, we need to find both p and p^*, and multiple equilibria could exist. We search for the new equilibrium near the prices in the baseline case.

decreases. As a result, consumer surplus increases by about 1% due to the lower price. Second, when the most productive firm has the highest customer capital, the trading of customer capital is minimal, and hence the cost of trading customer capital (h) is low. As a result, producer surplus increases by about 1%. Overall, these findings imply a low-productivity firm's behavior of accumulating high customer capital may be inefficient if the firm has to rely on outsourcing.

Some countries provide various supports for nascent exporters. Our second counterfactual simulation has an important implication for such policies. When governments try to help export firms accumulate customer capital (n in our model), they should prioritize productive firms. Supposing the cost of trading customer capital exists, aggregate welfare improves more when the policies target more productive firms (so that the correlation between customer capital and productivity becomes higher).

5 Conclusion

We find the value of export goods that a firm produces is often different from the value of export goods that the firm sells in foreign markets. We interpret this observation as firms trading their customer capital in the foreign markets. To understand the equilibrium consequence of customer-capital trade, we build a model in which firms can borrow and lend their customer capital via outsourcing. Firms whose foreign customer capital is high can facilitate trade by outsourcing their export demand to a productive firm with limited customer capital, despite frictions that prevent firms from trading their customer capital at the optimal level. The estimated model implies gains from customer-capital trade are substantial.

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Tables and Figures

Table 1: Number of Firms Conditional on Production per Sales (s)

	Number (Share) of firms			
	(1) $s \in (0.9, 1.1)$	(2) $s \in (0, 0.9]$	(3) $s \in [1.1, \infty)$	Total
2000	4,494 (28.5%)	2,250 (14.3%)	9,030 (57.2%)	15,774
2001	5,321 (30.0%)	2,601 (14.6%)	9,856 (55.4%)	17,778
2002	5,981 (29.1%)	3,105 (15.1%)	11,456 (55.8%)	20,542
2003	7,174 (29.5%)	3,515 (14.5%)	13,644 (56.0%)	24,333
2004	14,950 (38.3%)	5,011 (12.8%)	19,066 (48.9%)	39,027
2005	12,942 (35.0%)	5,520 (15.0%)	18,470 (50.0%)	36,932
2006	14,803 (37.3%)	6,727 (16.9%)	18,156 (45.8%)	39,686

Note. This table shows the number (and proportion) of firms conditional on production per sales. Sales value refers to the value recorded in the customs data.

Table 2: Total Export Values from the ASIP and the Customs Data

Year	(1) ASIP	(2) Customs Data	$\left(\frac{(1)}{(2)} \times 100\right)$
2000	1,460	1,880	78%
2001	1,610	2,020	80%
2002	2,010	2,510	80%
2003	2,700	3,390	80%
2004	4,050	4,600	88%
2005	4,770	5,990	80%
2006	6,050	7,630	80%

Unit: one billion CNY.

Table 3: Number of Firms Conditional on Core Sales

	Among firms whose $\frac{\text{Production}}{\text{Sales}} \in (0, 0.9]$	
	(1)	(2)
	Core sales > Production	Core sales $\leq$ Production
2000	872 (39%)	1,378 (61%)
2001	1,027 (40%)	1,574 (60%)
2002	1,197 (39%)	1,908 (61%)
2003	1,363 (39%)	2,152 (61%)
2004	1,905 (38%)	3,106 (62%)
2005	2,017 (37%)	3,503 (63%)
2006	2,344 (35%)	4,383 (65%)

Note. This table shows the number (and proportion) of two types of firms among exporters whose production value is greater than their sales value. The core-sales value is the sales value (recorded at customs data) of goods categorized within the manufacturing survey's registered industry.

Table 4: Regression Estimates for Production-per-Sales Value

VARIABLES	(1) $\ln(\frac{\text{Production}}{\text{Sales}})$	(2) $\ln(\frac{\text{Production}}{\text{Sales}})$	(3) $\ln(\frac{\text{Production}}{\text{Sales}})$	(4) $\ln(\frac{\text{Production}}{\text{Sales}})$	(5) $\ln(\frac{\text{Production}}{\text{Sales}})$	(6) $\ln(\frac{\text{Production}}{\text{Sales}})$
Exporter age	-0.0638	-0.0555	-0.0700	-0.0835	-0.0734	-0.0724
	(0.00392)	(0.00431)	(0.00334)	(0.00396)	(0.00435)	(0.00340)
ln(TFP)				0.800	0.760	0.0722
				(0.0256)	(0.0292)	(0.0565)
Year FE			Y			Y
Year-Ind. FE	Y			Y		
Year-Ind.-Des. FE		Y			Y	
Firm FE			Y			Y
Observations	124,150	107,358	106,681	123,824	107,081	106,384
R-squared	0.063	0.202	0.746	0.071	0.208	0.747

Note. This table shows the regression estimates for the log value of production per sales. The main destination of a firm (Des.) is the destination in which sales value is the highest. The industry refers to the 4-digit registered industry in the ASIP.

Table 5: Model Fit

Target Moments	Data	Model
Proportion of firms that export what they produce	0.32	0.29
Proportion of firms that export more than they produce	0.25	0.20
Avg. production of firms that export less than they produce	1.61	1.87
Avg. sales of firms that export what they produce	1.18	1.25
Avg. sales of firms that export more than they produce	1.41	1.56
Avg. sales of firms with that export less than they produce	0.62	0.63
corr(production, sales) among non-intermediaries	0.71	0.69
Value share of intermediaries	0.32	0.32
Untargeted Moments	**Data**	**Model**
Std. of production of firms that export less than they produce	3.43	6.47
Std. of sales of firms that export what they produce	2.19	4.38
Std. of sales of firms that export more than they produce	2.96	5.27
Std. of sales of firms that export less than they produce	1.77	2.38

Note. This table compares the simulated moments with data moments. We normalize the money value by the average sales for direct exporters. To account for a possible measurement error in the data, we classify firms with $0.9 < S < 1.1$ as firms that export what they produce, firms with $0 < S \leq 0.9$ as firms that export more than what they produce, and firms with $S \geq 1.1$ as firms that export less than they produce.

Table 6: Calibrated Parameters

	Parameters	Values
Outsourcing cost	h	0.58
Fixed exporting cost	F	0.12
Demand curve		
Price elasticity	β	0.69
Constant term	D	23.36
Distribution		
Mean of $\ln(n)$	μ_n	0.22
Mean of $\ln(z)$	μ_z	2.34
Std. of $\ln(n)$	σ_n	1.46
Std. of $\ln(z)$	σ_z	2.43
Correlation	ρ	0.86
Intermediary customer capital	n^I	7.48

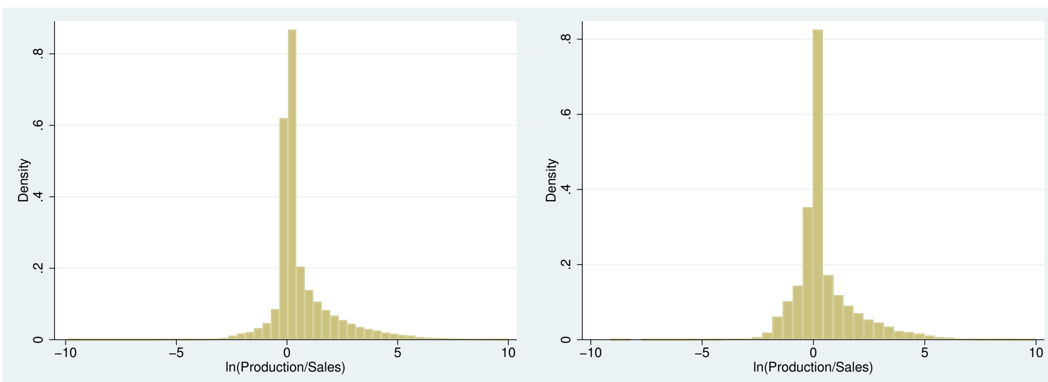
Note. This table shows the calibrated parameter values.

Table 7: Counterfactual Simulation

	Benchmark	No trading	$\text{corr}(n, z) = 1$
Welfare	100	86.03	102.06
Consumer surplus	81.54	64.23	82.28
Producer surplus	18.46	21.79	19.78
Price (p)	1	1.90	0.97
Price for customer capital	0.3	-	0.35
Total export quantity	100	64.11	102.16

Note. This table shows the welfare implication of (1) removing the market for customer capital ($h = \infty$) and (2) making the correlation between n and z 1. The numbers are normalized by the ones in the estimated (benchmark) economy.

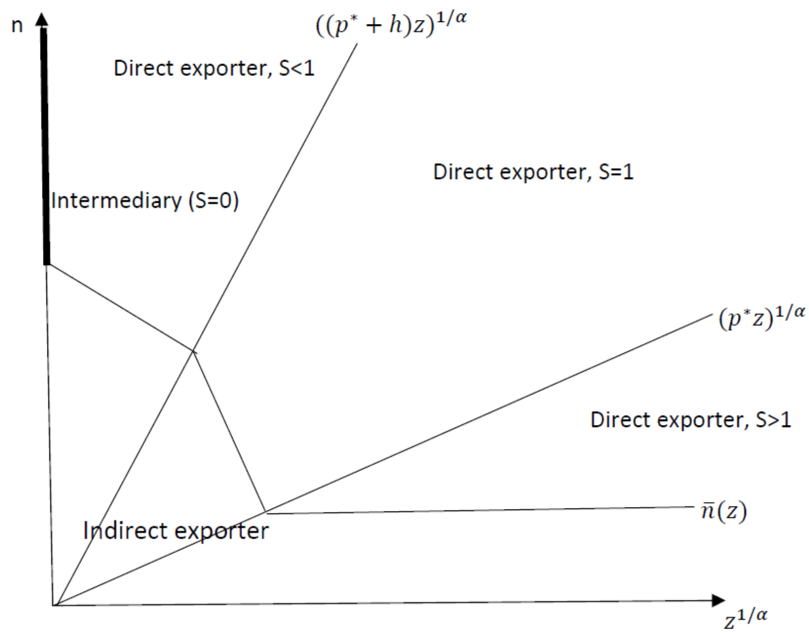
Figure 1: Histogram for Log production per Sales



(a) All industries (b) Textile and garment production

NOTE. This figure shows the histogram for the log value of production per sales for those with a positive sales value. Sales value refers to the export-goods value recorded at the customs data.

Figure 2: Model Solution



NOTE. This figures depicts the model solution stated in Proposition 1. A cutoff $\bar{n}(z)$ exists such that (i) if $n < \bar{n}(z)$, the firm chooses to be an indirect exporter, and if $n \geq \bar{n}(z)$, the firm chooses to be a direct exporter. (ii) When the firm chooses to be an indirect exporter, the production is $q^I(z) = (p^* z)^{\frac{1}{\alpha}}$. (iii) When the firm chooses to be a direct exporter, $q^D(n) = n$. If $n < (p^* z)^{\frac{1}{\alpha}}$, the direct exporter chooses $S > 1$; if $n > ((p^* + h) z)^{\frac{1}{\alpha}}$, the direct exporter chooses $S < 1$; and if $n \in [(p^* z)^{\frac{1}{\alpha}}, ((p^* + h) z)^{\frac{1}{\alpha}}]$, the direct exporter chooses $S = 1$.

Appendix

A Model Solution

A.1 Firm's optimal decision

We first focus on the direct exporter. Let $C(q, z; p^*)$ denote the cost of selling q:

$$C(q, z; p^*) = \min_{S \geq 0} (p^* + \chi(S < 1) h)(1 - S) q + \frac{1}{(1+\alpha) z} (Sq)^{1+\alpha}.$$

The direct exporter chooses S to minimize the cost. The optimal outsourcing behavior is

$$S = \begin{cases} \frac{1}{q}(p^* z)^{\frac{1}{\alpha}} & \text{if } q < (p^* z)^{\frac{1}{\alpha}} \\ 1 & \text{if } q \in \left[(p^* z)^{\frac{1}{\alpha}}, ((p^* + h) z)^{\frac{1}{\alpha}}\right] \\ \frac{1}{q}((p^* + h) z)^{\frac{1}{\alpha}} & \text{if } q > ((p^* + h) z)^{\frac{1}{\alpha}}. \end{cases}$$

The cost function is

$$C(q, z; p^*) = \begin{cases} p^* q - \frac{\alpha}{1+\alpha} p^{*1+\frac{1}{\alpha}} z^{\frac{1}{\alpha}} & \text{if } q < (p^* z)^{\frac{1}{\alpha}} \\ \frac{1}{(1+\alpha) z} q^{1+\alpha} & \text{if } q \in \left[(p^* z)^{\frac{1}{\alpha}}, ((p^* + h) z)^{\frac{1}{\alpha}}\right] \\ (p^* + h) q - \frac{\alpha}{1+\alpha}(p^* + h)^{1+\frac{1}{\alpha}} z^{\frac{1}{\alpha}} & \text{if } q > ((p^* + h) z)^{\frac{1}{\alpha}}. \end{cases}$$

The intuition is that if the customer capital is too small (high) relative to the productivity, the firm chooses S greater (smaller) than 1. If the customer capital fits the productivity, the firm does not outsource.

Denote q^D as the sales of the direct exporter. Given the cost function C, the direct exporter chooses q^D to maximize the profit π^D. Notice that in the equilibrium, $p - p^* - h \geq 0$. Otherwise, no firm would choose $S < 1$. We can show

$$q^D(n, z) = n.$$

Let $\Delta_p = p - p^*$. The direct exporter's profit is

$$\pi^D(n, z) = \begin{cases} \Delta_p n + \frac{\alpha}{1+\alpha}(p^*)^{1+\frac{1}{\alpha}} z^{\frac{1}{\alpha}} - F & \text{if } n < (p^* z)^{\frac{1}{\alpha}} \\ pn - \frac{1}{(1+\alpha)z} n^{1+\alpha} - F & \text{if } n \in \left[(p^* z)^{\frac{1}{\alpha}}, ((p^* + h) z)^{\frac{1}{\alpha}}\right] \\ (\Delta_p - h) n + \frac{\alpha}{1+\alpha}(p^* + h)^{1+\frac{1}{\alpha}} z^{\frac{1}{\alpha}} - F & \text{if } n > ((p^* + h) z)^{\frac{1}{\alpha}}. \end{cases}$$

There is a special case. If $z = 0$, we can see $S = 0$. In this case, the firm is a pure intermediary. The profit is $\pi^D(n, 0) = (\Delta_p - h) n - F$.

For the indirect exporter, it is straightforward to show

$$q^I(n, z) = (p^* z)^{\frac{1}{\alpha}},$$

$$\pi^I(z) = \frac{\alpha}{1+\alpha} p^{*1+\frac{1}{\alpha}} z^{\frac{1}{\alpha}}.$$

Now we can compare $\pi^D(n, z)$ and $\pi^I(z)$ to see whether the firm wants to be a direct exporter. The solution can be summarized as

(i) If $n < (p^* z)^{\frac{1}{\alpha}}$ and $n < \frac{F}{\Delta_p}$, the firm chooses to be an indirect exporter.

(ii) If $\frac{F}{\Delta_p} \leq n < (p^* z)^{\frac{1}{\alpha}}$, the firm chooses to be a direct exporter and $S > 1$.

(iii) If $n \in \left[(p^* z)^{\frac{1}{\alpha}}, ((p^* + h) z)^{\frac{1}{\alpha}}\right]$ and $n \geq \hat{n}(z, p, p^*)$, the firm chooses to be a direct exporter and $S = 1$, where $\hat{n}(z, p, p^*)$ solves $p\hat{n} - \frac{1}{(1+\alpha)z}\hat{n}^{1+\alpha} - F = \frac{\alpha}{1+\alpha} p^{*1+\frac{1}{\alpha}} z^{\frac{1}{\alpha}}$.

(iv) If $n \in \left[(p^* z)^{\frac{1}{\alpha}}, ((p^* + h) z)^{\frac{1}{\alpha}}\right]$ and $n < \hat{n}(z, p, p^*)$, the firm chooses to be an indirect exporter.

(v) If $n > \left(\left(p^* + h\right) z\right)^{\frac{1}{\alpha}}$, and $n < \frac{F - \frac{\alpha}{1+\alpha}\left(\left(p^*+h\right)^{1+\frac{1}{\alpha}} - p^{*1+\frac{1}{\alpha}}\right) z^{\frac{1}{\alpha}}}{\Delta_p - h}$, the firm chooses to be an indirect exporter.

(vi) If $n > \left(\left(p^* + h\right) z\right)^{\frac{1}{\alpha}}$, and $n \geq \frac{F - \frac{\alpha}{1+\alpha}\left(\left(p^*+h\right)^{1+\frac{1}{\alpha}} - p^{*1+\frac{1}{\alpha}}\right) z^{\frac{1}{\alpha}}}{\Delta_p - h}$, the firm chooses to be a direct exporter and $S < 1$.

The above results could be summarized as the proposition in the model section where the cutoff $\bar{n}\left(z\right)$ is

$$\bar{n}\left(z\right) = \begin{cases} \frac{F}{\Delta_p} & \text{if } n < \left(p^* z\right)^{\frac{1}{\alpha}} \\ \hat{n}\left(z, p, p^*\right) & \text{if } n \in \left[\left(p^* z\right)^{\frac{1}{\alpha}}, \left(\left(p^* + h\right) z\right)^{\frac{1}{\alpha}}\right] \\ \frac{F - \frac{\alpha}{1+\alpha}\left(\left(p^*+h\right)^{1+\frac{1}{\alpha}} - p^{*1+\frac{1}{\alpha}}\right) z^{\frac{1}{\alpha}}}{\Delta_p - h} & \text{if } n > \left(\left(p^* + h\right) z\right)^{\frac{1}{\alpha}}. \end{cases}$$

For the pure intermediary, we have $\bar{n} = \frac{F}{\Delta_p - h}$. If $n > \bar{n}$, the pure intermediary will choose to export.

A.2 Sub-modularity of the min-max

We show the function $g\left(n, z\right) = \min\{\max(n, \left(p^* z\right)^{\frac{1}{\alpha}}), \left(\left(p^* + h\right) z\right)^{\frac{1}{\alpha}}\}$ is a submodular function of n and z. Consider $n_1 > n_2$ and $z_1 > z_2$. We then want to show

$$g\left(n_1, z_1\right) + g\left(n_2, z_2\right) \leq g\left(n_2, z_1\right) + g\left(n_1, z_2\right).$$

The relation $n < \left(p^* z\right)^{\frac{1}{\alpha}}$, $n \in \left[\left(p^* z\right)^{\frac{1}{\alpha}}, \left(\left(p^* + h\right) z\right)^{\frac{1}{\alpha}}\right]$ and $n > \left(\left(p^* + h\right) z\right)^{\frac{1}{\alpha}}$ divide the (n, z) into three regions, denoted as region I, II, and III, respectively.

We need to discuss nine possible cases. That is, (n_1, z_1) and (n_2, z_2) could fall into region I, II, and III, independently. To save space, we discuss one case for illustration. All other cases can be done similarly.

Let us consider both (n_1, z_1) and (n_2, z_2) as being in region I. In this case,

$g(n_1, z_1) + g(n_2, z_2) = (p^* z_1)^{\frac{1}{\alpha}} + (p^* z_2)^{\frac{1}{\alpha}}$. Because $n_1 > n_2$ and $z_1 > z_2$, (n_2, z_1) is also in region I and $g(n_2, z_1) = (p^* z_1)^{\frac{1}{\alpha}}$. Notice (n_1, z_2) can lie in any region, but $g(n_1, z_2) \geq (p^* z_2)^{\frac{1}{\alpha}}$. Therefore, $g(n_1, z_1) + g(n_2, z_2) \leq g(n_2, z_1) + g(n_1, z_2)$.

B Numerical Details

This section provides the details on how we solve and estimate the model. We first normalize $p = 1$, which is possible because D (the constant term in the aggregate demand) can be adjusted so that equation (6) is always satisfied. We then guess p^* and solve the cutoffs $\bar{n}(z)$. Notice p^* should satisfy $\Delta_p = p - p^* > h$:

$$\bar{n}(z) = \begin{cases} \frac{F}{\Delta_p} & \text{if } n < (p^* z)^{\frac{1}{\alpha}} \\ \hat{n}(z, p, p^*) & \text{if } n \in \left[(p^* z)^{\frac{1}{\alpha}}, ((p^* + h) z)^{\frac{1}{\alpha}}\right] \\ \frac{F - \frac{\alpha}{1+\alpha}\left((p^*+h)^{1+\frac{1}{\alpha}} - p^{*1+\frac{1}{\alpha}}\right) z^{\frac{1}{\alpha}}}{\Delta_p - h} & \text{if } n > ((p^* + h) z)^{\frac{1}{\alpha}}, \end{cases}$$

where $\hat{n}$ solves

$$(p^* + \Delta_p)\hat{n} - \frac{1}{(1+\alpha) z}\hat{n}^{1+\alpha} - F = \frac{\alpha}{1+\alpha} p^{*1+\frac{1}{\alpha}} z^{\frac{1}{\alpha}}. \tag{9}$$

Notice the left-hand side of equation (9)is an increasing function with $\hat{n}$. Hence, it at most has one solution. If $\hat{n}$ does not exist, let $\hat{n} = 0$.

Next, we solve $q^I(z) = (p^* z)^{\frac{1}{\alpha}}$ if $n \leq \bar{n}(z)$, and 0 otherwise. $S(n, z)$ is defined as

$$S(n,z) = \begin{cases} \frac{1}{n}(p^*z)^{\frac{1}{\alpha}} & \text{if } n < (p^*z)^{\frac{1}{\alpha}} \text{ and } n > \bar{n}(z) \\ 1 & \text{if } n \in [(p^*z)^{\frac{1}{\alpha}}, ((p^*+h)z)^{\frac{1}{\alpha}}] \text{ and } n > \bar{n}(z) \\ \frac{1}{n}((p^*+h)z)^{\frac{1}{\alpha}} & \text{if } n > ((p^*+h)z)^{\frac{1}{\alpha}} \text{ and } n > \bar{n}(z) \\ 0 & \text{if } n \leq \bar{n}(z) \end{cases}$$

Finally, check the residuals of $\int_{n>\bar{n}(z)} n[1-S(n,z)]\,dG(n,z) - \int_{n\leq\bar{n}(z)} q^I(z)\,dG(n,z)$. If the residual is greater (smaller) than 0, increase (decrease) p^*. After finding p^*, we can then infer D from $D(p) = \int_{n>\bar{n}(z)} n dG(n,z)$. We then calculate the following target moments.