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Effects of Exchange Rate Volatility on Export Diversity: The Role of Production Constraints [*]

Ngo Van Long [†], *Yifan Li* [‡], *Zhuang Miao* [§]

Abstract

We develop a model of product-variety adjustment in which a firm's choice of the number of varieties exported to each market (export scope) reflects a trade-off between short-run responses to demand shocks associated with exchange rate fluctuations and the costs of making investment in the production capacity. Firms reduce their export scopes when markets suffer negative demand shocks but, in the case of positive shocks, are unable to expand them adequately, due to insufficient pre-investment in production capacity. As a result, we observe asymmetric export responses to exchange rate fluctuations, and negative effect of exchange rate volatility on exports. Data on Chinese exporters support our predictions.

Keywords: Multiproduct Firms, Exchange Rate Volatility

JEL Codes: F12, F14, F31

Résumé

Nous développons un modèle d'ajustement de la variété des produits dans lequel le choix d'une entreprise du nombre de variétés exportées vers chaque marché reflète un compromis entre les réponses à court terme aux chocs de la demande associés aux fluctuations des taux de change et les coûts d'investissement dans la capacité de production. Les entreprises exportent moins de produits lorsque les marchés subissent des chocs de demande négatifs mais, dans le cas de chocs positifs, ne sont pas en mesure d'augmenter le nombre de produits, car la capacité de production a été déterminée. En conséquence, nous observons des réponses asymétriques des exportations aux fluctuations des taux de change et un effet négatif de la volatilité des taux de change sur les exportations. Les données sur les exportateurs chinois confirment nos prévisions.

Mots-clés : Entreprises multiproduits, Volatilité du taux de change

Codes JEL : F12, F14, F31

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1 Introduction

The effects of exchange rate appreciation/depreciation and of exchange rate volatility on exporting firms have been a subject of intensive study. Earlier empirical work on this topic relied on aggregative data. As is widely acknowledged, studies using aggregate data are subject to problems such as aggregation bias and endogeneity of regressors. Thanks to the increasing availability of data, recently there have been a number of empirical papers that use firm-level data to shed light on firm export behavior.[1] Firm-level data also reveals that many exporting firms are multiproduct firms, a phenomenon that earlier models of trade abstract from. Not surprisingly, taking the cue from these observations, several authors have recently developed theoretical models of multi-product firms that guide empirical research on firm behavior and strategies in the globalized world.[2]

How does the degree of volatility of the bilateral real exchange rate (RER) between a destination country's currency and an exporting country's currency affect the latter's firm-level export volumes and the number of products that these firms sell to the destination market? How do these effects depend on the distance and size characteristics of destination markets? In what ways do responses to RER volatility depend on exporting firms' characteristics? The purpose of our paper is to add fresh theoretical and empirical contributions to the literature that investigates firm-level responses to RER volatility, in particular questions relating to firm product scope (the number of products a firm chooses to be in its portfolio, by investing in R&D) and firm's destination-specific export scopes (the number of products to be sold at a destination market in a given period, depending on the destination's characteristics).

To address our research questions, we extend the standard multi-product firm model (see Eckel and Neary, 2010; Bernard et al. 2011; Mayer et al., 2014) in two directions. First, we suppose that when a firm widens its brand by adding another variety, it must incur upfront a variety-specific R&D cost, which then becomes a sunk cost.[3] Second, we add a temporal aspect to the existing model, by distinguishing short run decisions from long run decisions. The long run decision (which we call the *product scope decision*, i.e., how many varieties to invest in) must be made before the realizations of the exchange rates of destination countries are known; the short run decisions (which we call year-and-destination-specific *export scope*

[1] See, e.g., Berman et al. (2012), Park et al. (2010), Berthou and Fontagné (2013), Cheung and Sengupta (2013), Li et al. (2015), Herincourt and Poncel (2015).

[2] See, for example, Eckel and Neary (2010), Bernard et al. (2011), Qiu and Zhou(2013), Mayer et al. (2014), Nocke and Yeaple (2014).

[3] Our R&D cost, which becomes sunk, is different from Qiu and Zhou (2013)'s fixed cost associated with a variety which is incurred only in periods in which the actual output of that variety is strictly positive; i.e., the fixed cost is avoidable in each period.

decisions) are made only when the uncertainty has been resolved. Using this distinction and the temporal structure of decision sequence, our model gives rise to a number of predictions. They are: (i) the response of export scope to exchange rate variations is asymmetric: the expansion of export scope induced by an appreciation of the currency of the destination market is less pronounced than the contraction of export scope induced by a depreciation; (ii) the effect of exchange rate volatility on firms' export scopes is more pronounced for firms with lower product scope, for markets with lower trade costs; and for markets with greater population mass; and (iii) firms' export scopes are, on average, smaller for destination markets whose exchange rates display a higher degree of volatility.

At the empirical level, using a rich firm-level data set on Chinese exporting firms over the period 2000-2006, we test our model's predictions and estimate responses of firm export scopes and export volume to changes in real exchange rate volatility. We merge the customs transaction-level database (supplied by the Chinese Customs) with a firm-level data base drawn from the Annual Survey of Industrial Firms (by the National Bureau of Statistics of China).[4] To the best of our knowledge, there has been no previous firm-level empirical investigation of how firms' export scope varies across destinations with different degrees of destination-specific RER volatility. The nearest empirical work to ours is Herincourt and Poncel (2015), who studied the relationship between, on the one hand, RER volatility and, on the other hand, (a) firms' export value (which they refer to as the intensive margin), and (b) firms' decision to enter an export market (what they call the 'extensive margin'). In contrast, using our merged data, we are able to study how RER volatility impact what we call "*within-firm extensive margin*" which refers to a multi-product firm's decision to increase/decrease the number of products it ships to a destination market. Moreover, we interact RER volatility with firm characteristics such as firm size, asset turnover, collateral ratio, and ownership structure, and with destination characteristics such as distance and market size.[5]

Some of our main empirical findings are:

(a) a one-standard deviation increase in RER volatility in a destination country *reduces* an average Chinese firm's export value to that destination by as much as 6%;

(b) a one-standard deviation increase in RER volatility lowers the export scope by about

[4]In merging the two datasets, we used firm names, name of legal representatives, phone numbers and zipcodes.

[5]Our work is also related to Berthou and Fontagné (2013) who used a rich data set of French firms to study the firm-level impacts of the introduction of the euro (which eliminates the problem of bilateral exchange rate volatility between France and some export destinations). They found that the euro has positive trade creation effects that are heterogeneous with respect to destination countries within the euro zone.

2.2% for a typical exporter, meaning that a firm that sells 4 varieties to a destination market that has zero volatility would sell only about 2 varieties to a destination market (with the same distance and the same GDP) that has a RER volatility of 0.415 (the maximal volatility in our sample);

(c) firms' downward adjustments of their export values and export scopes in response to increases in RER volatility tend to be more pronounced in time of depreciation of the currency of the destination market than in time of appreciation[6];

(d) while higher RER volatility leads to lower export value and lower export scope, this effect is more pronounced for destinations that are closer to the exporting firms or that have a larger market size[7].

Our theoretical framework is built on the recent models of multi-product exporting firms, in particular Eckel and Neary (2010), Bernard et al. (2011) and Mayer et al. (2014). Eckel and Neary (2010) developed a theory of flexible manufacturing where each firm is endowed with a core competence in a certain product and is able to produce a spectrum of differentiated products with different marginal costs. These products are indexed by the magnitude of their marginal cost, such that products with higher marginal costs are further away from the firm's core competence.[8] Each firm decides on the number of products it actually produces (i.e., its optimal scope) as well as on its output level for these products (i.e., the scale decision), taking into account both the intensity of competition from other firms in the same industry and the so-called cannibalization effects (as its offer of an additional product reduces consumer demand for its existing products). Eckel and Neary (2010) showed that trade liberalization induces firms to cut back on the number of products they produce in order to concentrate on their core competence. Eckel and Neary postulate (i) a fixed entry cost that is independent of both scale and scope and (ii) the absence of fixed cost for each variety. Like Eckel and Neary (2010), we assume that for each variety, the marginal cost is independent of its output level, and that marginal costs are higher for varieties that are further away from the firm's core competence. However, different from Eckel and Neary (2010), we assume that when a firm wants to add a new variety to its product portfolio, it

[6]See Table 7, Columns (2) and (6).

[7]See Table 6.

[8]Eckel and Neary's emphasis on core competence makes their model different from related papers on multi-product firms: Allanson and Montagna (2005) assume that firms incur variety-specific fixed costs as well as firm-specific fixed costs; Bernard et al. (2011) and Mayer et al. (2014) assume that marginal costs of all varieties are random and independently distributed. In contrast, Nocke and Yeaple (2014) assumed that the marginal cost of each variety is decreasing in the amount of 'organizational capital' allocated to it, and that for each variety the firm has to incur an irrecoverable one-time development cost.

must incur a variety-specific R&D cost, which becomes a sunk cost.[9] Another difference is that we assume monopolistic competition rather than oligopoly.

A novel feature of our model is that decisions are made in sequence in real time. Indeed, we suppose that a firm's decision on the range of varieties it is capable of producing as a long-term decision: it must be made before the firm observes the short-term realizations of the exchange rates of the destination countries. These observations will drive the year-to-year short-run decisions concerning how many varieties it should ship to various markets (the destination-specific export scopes). This temporal dimension of our two-stage optimization framework is key to our results of non-linearity of response of export scope to RER volatility.[10]

There is a large empirical literature on how exporting firms respond to changes in real exchange rate *levels*, i.e., to real appreciation and depreciation. Recent papers that studied the impacts of changes in RER level (rather than RER volatility) include Berman et al., 2012; Park et al., 2010; Li et al., 2015, all using firm-level data. Berman et al. (2012), using a very rich French firm-level dataset with destination-specific export values and volumes over the period 1995-2005, found that, following exchange rate movements, more productive firms tend to do more pricing to market, and to adjust the quantity export less. They conclude that this heterogeneity in pricing to market may partly explain the weak impact of exchange rate movements on aggregate exports. Using firm-level data for the period 1995-2000, Park et al. (2010) found that Chinese exporting firms (with positive foreign ownership shares) whose export destinations experience greater currency depreciation have lower export growth. Li et al. (2015) examine how bilateral RER movements affect Chinese exports and exporters. Following the method of Berman et al. (2012), they found (i) moderate export volume elasticity, and (ii) almost complete exchange rate pass through into RMB export price.[11]

Compared to the strand of literature on firm responses to changes in real exchange rate *levels,* the strand that focuses on responses to real exchange rate *volatility* is less abundant.[12] Earlier work on the effect of exchange rate volatility on trade relied on macroeconomic data and reported mixed results. (See e.g. Greenaway and Kneller, 2007; Rose, 2000; Grier and Smallwood, 2007; Byrne et al. 2008; Broda and Romalis, 2011.) As is well known,

[9] It is important to draw the distinction between R&D cost of adding a new variety to the firm's product portfolio and (destination-specific) fixed entry cost for a variety.

[10] Long and Miao (2020) assume a similar two-stage decision for multi-quality oligopolists facing heterogeneous consumers with unit demand functions.

[11] They estimate that a ten percent RER appreciation of the destination market's currency reduces Chinese firms' export price (denoted in RMB) by less than 0.5%.

[12] Volatility may be computed, for example, as the yearly *standard deviation* of monthly log differences in the real exchange rate.

econometric studies of trade responses using aggregate data are beset with difficulties such as simultaneity and aggregation bias. Notable work on the effects of RER volatility using firm-level data includes Berman et al. (2012), Cheung and Sengupta (2013), Herincourt and Poncet, (2015), and Berthou and Fontagné (2013).[13] Specifically, Herincourt and Poncet (2015) study how firm-level export performance (in terms of the total free-on-board export sales, or in terms of the decision to begin exporting to a market) is affected by RER volatility. They found that RER volatility has negative effects on exports, and such effects are more severe for firms that are more dependent on external finance,[14] and that the level of financial development provides some mitigation. They argue that a well functioning financial market allows firms to hedge against exchange rate risk. Cheung and Sengupta (2013) focus on the effects of exchange rate movements on exports, using a firm-level data set on about 4000 Indian exporters. They investigate mainly the effect on the intensive margin of exports. They find that *one standard deviation decline* in RER volatility would increase an Indian firm's export share of its total sales by 13%.

Our paper differs from the works cited above in two main respects: a theoretical one, and an empirical one. First, we develop a theoretical model to account for the role of capacity constraint on firms' export responses in the short run. In our model, the capacity decision takes the form of a long-run decision on the product scope: the firm must decide on how many products it wants to include in its portfolio, and take R&D actions to concretize its portfolio choice. Thus, to acquire the capability to produce an additional variety, the firm must incur in advance a lumpy investment cost, which becomes sunk cost. In the short run, a firm cannot produce more varieties than the upper bound defined by the number of variety-specific lumpy investments that it has made. This feature of our model plays a crucial role in yielding the testable predictions that we mentioned above.

Second, our empirical investigations provide strong evidence that Chinese exporting firms' responses to exchange rate variations are asymmetric and that the strength of these responses depends on both firm characteristics and those of destination markets.

The rest of the paper is organised as follows. In Section 2, we present our theoretical model and derive testable predictions. Section 3 describes our dataset. Section 3 reports our empirical findings.

[13] See also Nguyen (2012), Lopez and Nguyen (2015), Tunc and Solakoglu (2016), Bekes et al. (2017).

[14] Along a similar vein, Carranza et al. (2003), using a dataset consisting of 250 Perouvian firms over the period 1994-2001, found that firms' investments are negatively affected by RER depreciation, because of the balance sheet effect, as firm debts are mostly denominated in US dollars.

2 The Theoretical Framework

Unlike Eckel and Neary (2010) who assume that firms are oligopolists (each being large enough in their industry to influence the industry's price index and output, and yet at the same time negligible in the economy which consists of a continuum of industries), our model assumes monopolistic competition: each firm has practically no impact on its industry's aggregate output and price index, but it can influence the prices of all the varieties of its own brand. This is a common assumption in the literature on international trade involving multi-product firms (see, e.g., Bernard et al., 2011; Mayer et al., 2014; Nocke and Yeaple 2014).[15] The novel feature of our model is that the time dimension plays a crucial role: firms must make the 'product scope' decision (the number of varieties in its portfolio) and carry out the investment activities that it entails before the realization of the exchange rate of each destination countries. Decisions concerning export quantities and the number of varieties to be exported to various destinations (the destination-specific 'export scope') are made after the exchange rate realizations become known.

2.1 Households

Following Melitz and Ottaviano (2008), Dhingra (2013), Qiu and Zhou (2013), and Mayer et al. (2014), we assume that the representative consumer of country j has linear quadratic preferences.[16] Let q_{j0} and q_{ji} denote her consumption of the numeraire good and of the differentiated variety i. Her utility is

$$U_j = q_{j0} + \alpha \int_{i\in\Omega_j} q_{ji} di - \frac{\beta}{2}\left(\int_{i\in\Omega_j} q_{ji} di\right)^2 - \frac{\gamma}{2}\int_{i\in\Omega_j} q_{ji}^2 di$$

where Ω_j is the set of all varieties that are sold in country j, where α, β and γ are all positive.The parameter γ measures the degree of product differentiation between the varieties. (In the limiting case where $\gamma = 0$, consumers only care about their consumption over all the varieties). Then, as shown in Mayer et al. (2014, p. 499), the consumer's inverse demand function for variety i is

$$p_{ji}(q_{ji}) = [\alpha - \beta Q_j] - \gamma q_{ji} \tag{1}$$

where $Q_j \equiv \int_{i\in\Omega_j} q_{ji} di$ is the quantity index of consumption of the differentiated varieties.

[15] A related work on multiproduct firms under monopolistic competition is Dhingra (2013). She focuses on the tradoff between product innovations and process innovations.

[16] Bernard et al. (2011), Nock and Yeaple (2014), and Dhingra (2013) assume CES preferences, a natural extension of Melitz (2003).

Let L_j denote the population size of country j. Then using (1), country j's the market demand function for variety i is

$$q^L_{ji} \equiv L_j q_{ji} = L_j \left(\frac{\alpha}{\gamma} - \frac{1}{\gamma} p_{ji} - \frac{\beta}{\gamma} Q_j \right) \tag{2}$$

2.2 Firms, product scope, and export scopes

We consider a world consisting of J countries that engage in intra-industry trade. Let us focus on the exporting decision of firms that produce differentiated goods. For convenience, consider a given exporting country, which we call the Home country. In this country (as in all other countries) each firm in the monopolistic competition sector is a multi-product firm. Each firm creates its own brand and within each brand there is a continuum of varieties.[17] A multi-product firm m (which owns brand m) can potentially produce any range of varieties within this brand. We denote this potential range by the positive real interval $[0, \infty)$. Following Eckel and Neary (2010), we assume that the marginal cost, c_i, of producing a unit of variety i is independent of the output level of that variety and that c_i is increasing in i. Specifically, for simplicity, we suppose that $c_i = i\omega$ where $\omega > 0$. (We may think of ω as the wage rate and i is the unit labor requirement for variety i; for simplicity, in what follows we set $\omega = 1$.) This formulation captures the idea of "core competency" which Eckel and Neary (2010) emphasize: production cost per unit of varieties that are further away from the firm's core competency is higher. However, different from Eckel and Neary (2010) who assume that for each variety, there is only variable production cost, we suppose that, to acquire the technical knowledge that enables the production of a given variety i, firm m must incur upfront a one-time $R\&D$ investment cost F_i. Once this cost has been incurred, it becomes a sunk cost. In what follows, for simplicity, we assume that $F_i = \mu > 0$ for all i.

We assume that when a Home firm exports a variety i to a destination market j, it incurs a transport cost t_j (in terms of the Home currency) per unit. That is, we assume that this cost is independent of the bilateral exchange rate ε_j, which we define as the price of a unit of the currency of country j in terms of the Home currency.[18] This "independence" assumption

[17] To borrow an example from Dhingra (2013), Dannon and Yoplait are two different brands, each owned by a different firm. Within the Yoplait brand, there are many varieties of Yoplait yogurt. However, unlike Dhingra (2013), we follow Mayer et al. (2014, p.499) by assuming that consumers' substitution between any two varieties produced by the same firm is the same as substitution between any two varieties produced by two different firms. They wrote that "we do not see any clear reason to enforce that varieties produced by a firm be closer substitutes than varieties produced by different firms."

[18] An increase in ε_j is an appreciation of the destination country's currency relative to the Home currency.

may be justified if the shipping costs consist mainly of (Home-country) labor cost with rigid wages.

The firm makes two types of decision, a long run decision, and a short run decision. The long run decision concerns the choice its "*product scope,*" i.e., the range of product varieties $[0, s]$ for which it is prepared to incur the investment cost μ. (In what follows, we omit the subscript m for simplicity.) The total sunk cost incurred is μs. After spending μs, the firm learns about the realization of the exchange rates of the destination countries. It then makes the short-run decisions for each destination country j: the range of varities $i_j^* \leq s$ to be exported to destination j, and the export price p_{ji} for each variety $i \in \left[0, i_j^*\right]$, where p_{ji} is expressed in terms of the currency of the destination country j. We assume that to be able to sell a strictly positive quantity of variety i in destination country j, a (destination-specific) fixed cost $f_{ji}^x \geq 0$ per period must be incurred. (We may think of f_{ji}^x as the cost of destination-country labor used in the advertising or marketing variety i). If a variety i is not exported to a destination j in a given period, then the fixed cost f_{ji}^x is avoided for that period. (In what follows, for simplicity, we assume that $f_{ji}^x = f_j^x$, the same for all i.)

2.2.1 Determination of export scopes, given the product scope

The gross profit (where the hat in $\widehat{\pi}$ indicates that it is in terms of the currency of the destination market j) earned by the Home firm from the sales of a quantity q_{ji} (per household) in market j is

$$\widehat{\pi}_{ji} = L_j \left[p_{ji}(q_{ji}) - \frac{c_i + t_j}{\varepsilon_j} \right] q_{ji}$$

where $p_{ji}(q_{ji})$ is the representative household's inverse demand function (1) and L_j is the number of households in destination country j. Using

$$p_{ji}(q_{ji}) = [\alpha - \beta Q_j] - \gamma q_{ji} \equiv B_j - \gamma q_{ji}$$

and assuming $B_j > 0$, it is clear that if the following condition holds,

$$B_j > \frac{c_i + t_j}{\varepsilon_j}, \tag{3}$$

then a positive gross profit can be earned by exporting variety i. Given (3), the profit-maximizing quantity q_{ji} to be sold to each household in destination j is given by

$$q_{ji}^{opt} = \frac{\varepsilon_j B_j - c_i - t_j}{2\varepsilon_j \gamma} > 0 \ .$$

This implies that the associated export price (in the destination country's currency units) is[19]

$$p_{ji}^{opt} = B_j - \frac{\varepsilon_j B_j - c_i - t_j}{2\varepsilon_j} = \frac{B_j}{2} + \frac{c_i + t_j}{2\varepsilon_j}.$$

The (optimized) gross profit, expressed in the local currency, is

$$\widehat{\pi}_{ji} = L_j \gamma \left[q_{ji}^{opt}\right]^2 = L_j \left[\frac{\left(\varepsilon_j B_j - c_i - t_j\right)^2}{4\gamma\varepsilon_j^2}\right] = L_j \left[\frac{\left(\varepsilon_j B_j - i - t_j\right)^2}{4\gamma\varepsilon_j^2}\right] \tag{4}$$

Given the realization ε_j, let us define the (unconstrained) marginal variety in market j as the variety i_j^* such that the gross profit is just equal to the destination-specific fixed cost f_j^x. If i_j^* exists and is positive, it must satisfy the condition that the net profit in exporting that variety to market j is zero:

$$L_j \left[\frac{\left(\varepsilon_j B_j - i_j^* - t_j\right)^2}{4\gamma\varepsilon_j^2}\right] = f_j^x$$

Thus, provided that $\varepsilon_j \left(B_j - 2\sqrt{\gamma f_j^x / L_j}\right) > t_j$, the (unconstrained) marginal variety for destination j is given by

$$i_j^* = \varepsilon_j \left(B_j - 2\sqrt{\gamma f_j^x / L_j}\right) - t_j \equiv i_j^u(\varepsilon_j) \tag{5}$$

Our notation $i_j^u(\varepsilon_j)$ refers to the *unconstrained export scope* to destination t_j when the exchange rate realization is ε_j as the number of varieties that would bring non-negative profit to the Home firm. (The superscript u stands for "unconstrained".)

If $i_j^u(\varepsilon_j)$ is smaller than the firm's product scope s (which was determined at an earlier stage), then all the varieties in the range $\left[0, i_j^u(\varepsilon_j)\right]$ are profitable, and the remaining varieties, those in the range $\left(i_j^u(\varepsilon_j), s\right]$ are unprofitable. In this case, the firm's export scope to destination j, given the realization ε_j is equal to $i_j^u(\varepsilon_j)$. If $i_j^u(\varepsilon_j) > s$, then the export scope is simply equal to the product scope s. Thus, letting $i_j^x(\varepsilon_j, s)$ denote the firm's export scope in market j, we have

$$i_j^x(\varepsilon_j, s) = \min\left\{s, i_j^u(\varepsilon_j)\right\}. \tag{6}$$

Lemma 1 below lists some properties of $i_j^x(\varepsilon_j, s)$.

Lemma 1: *Given the firm's product scope s and the exchange rate realization ε_j, the Home exporting firm's export scope for destination country j is given by*

$$i_j^x(\varepsilon_j, s) = \min\left\{s, \varepsilon_j \left(B_j - 2\sqrt{\gamma f_j^x / L_j}\right) - t_j\right\} \tag{7}$$

[19] Notice that a fall in ε_j i.e., an appreciation of the Home country's currency (say, the RMB) relative to the destination country's currency, will lead to an increase in the (local currency) price p_{ji}, and a decrease in $\varepsilon_j p_{ji}$ (in the export price measured in RMB). This is consistent with Li et al. (2015), who reported that a 10% appreciation of the RMB would reduce the export price (denoted in RMB) by about 0.5%.

if $\varepsilon_j \left(B_j - 2\sqrt{\gamma f_j^x / L_j}\right) - t_j > 0$. *If* $\varepsilon_j \left(B_j - 2\sqrt{\gamma f_j^x / L_j}\right) - t_j \leq 0$, then *the Home firm does not export any variety to destination* j.

As a result, given the (pre-determined) product scope s, *if* $i_j^x(\varepsilon_j, s) \in (0, s)$ *then*

(i) an appreciation of the destination country's currency (an increase in ε_j*) will increase the Home firm's export scope, while a depreciation will reduce it;*

(ii) the larger the market size L_j, *the more pronounced will be the increase in the export scope corresponding to a given increase in* ε_j*; and*

(iii) the response of export scope to real exchange rate changes is more pronounced when ε_j *falls than when it rises, because the number of varieties exported cannot increase beyond the upper bound* s.

2.2.2 Determination of the product scope

As is clear from Lemma 1, the export scope $i_j^x(\varepsilon_j, s)$ depends on the realization ε_j, the distance t_j from the Home country, and also on the quantity index Q_j, the market size L_j and the fixed cost f_j^x. To simplify the analysis, let us now assume that $L_j = L$, $f_j^x = f^x$ and $\alpha - \beta Q_j = B$ for all j. Instead of considering a finite numbers of destinations t_j, it turns out to be more convenient to characterize a market by a pair (t, ε) where $t \in [0, t_{\max}]$ is the distance from the Home country, and ε is the realization of the bilateral exchange rate. Assume that countries are distributed along the interval $[0, t_{\max}]$. The fraction of destination markets whose distance from the Home country is not greater than t is given by a cumulative distribution function $G(t)$, with $G(0) = 0$, $G(t_{\max}) = 1$, and $G'(t) = g(t) \geq 0$ for $0 \leq t \leq t_{\max}$.

For simplicity, let us assume that at each location t, there are two groups of destination countries: those that maintain a fixed exchange rate $\overline{\varepsilon}$ with the Home country, and those that adopt a floating exchange regime. The ratio of the first group to the second group is $(1 - \upsilon)/\upsilon$, where $0 < \upsilon \leq 1$. (The first group is an empty set if $\upsilon = 1$.) We assume that bilateral exchange rate between the Home country and a destination country belonging to the second group is random variable ε with a probability density function $h(\varepsilon) > 0$ (independent of t), where ε is bounded above by $\varepsilon_{\max}$ and bounded below by $\varepsilon_{\min}$. We assume that $\overline{\varepsilon}$ is equal to the mean of ε.

Then, using Lemma 1, for a given the product scope s, the Home firm's export scope for floating-rate countries that are t units distance away from the Home country is dependent on the realization ε, for given t and s :

$$i^x(\varepsilon, t, s) = \min\left\{s, \varepsilon\left(B - 2\sqrt{\gamma f^x / L}\right) - t\right\} \tag{8}$$

provided that $\varepsilon\left(B-2\sqrt{\gamma f^x/L}\right)>t$. For simplicity, we assume that $\varepsilon_{\min}\left(B-2\sqrt{\gamma f^x/L}\right)>t_{\max}$, so that, given $s>0$, the export scope $i^x(\varepsilon,t,s)$ is strictly positive for all admissible pair (ε,t). (For the fixed-exchange rate countries, we simply replace the ε in eq. (8) with the constant $\overline{\varepsilon}$.)

From equation (4), the net profit (in terms of the destination market currency) from the sale of the *marginal variety* $i^x(\varepsilon,t,s)$ to a destination market at location t when the exchange rate realization is ε is given by

$$L\left[\frac{(\varepsilon B-i^x(\varepsilon,t,s)-t)^2}{4\gamma\varepsilon^2}\right]-f^x$$

And in terms of the Home currency, the corresponding net profit is

$$\pi(\varepsilon,t,i^x(t,\varepsilon,s))=L\left[\frac{(\varepsilon B-i^x(\varepsilon,t,s)-t)^2}{4\gamma\varepsilon}\right]-\varepsilon f^x$$

The net profit from the sales of an intramarginal *variety* $i<i^x(t,\varepsilon,s)$ to the destination (ε,t) is

$$\pi(\varepsilon,t,i)=L\left[\frac{(\varepsilon B-i-t)^2}{4\gamma\varepsilon}\right]-\varepsilon f^x$$

Given s and ε, the total profit obtained from the sales of all varieties $i\leq i^x(t,\varepsilon,s)$ to (flexible-rate) destinations with characteristics (ε,t) is then

$$\Pi(\varepsilon,t,s)\equiv\int_0^{i^x(t,\varepsilon,s)}\pi(\varepsilon,t,i)di.$$

while for destinations at location t with the fixed exchange rate $\overline{\varepsilon}$, we have

$$\Pi(\overline{\varepsilon},t,s)\equiv\int_0^{i^x(t,\overline{\varepsilon},s)}\pi(\overline{\varepsilon},t,i)di.$$

Given s, the Home firm's expected aggregate profit in all destination markets is

$$\Pi^{agg}(s)=(1-\upsilon)\int_0^{t_{\max}}\Pi(\overline{\varepsilon},t,s)g(t)dt+\upsilon\int_0^{t_{\max}}\left[\int_{\varepsilon_{\min}}^{\varepsilon_{\max}}\Pi(t,\varepsilon,s)h(\varepsilon)d\varepsilon\right]g(t)dt$$

The firm's long run decision is to choose its product scope s to maximize its expected aggregate profit in all the markets, net of the cost of investing in the product scope:

$$\max_s \Pi^{agg}(s)-\mu s.$$

The following Proposition states that the optimal product scope, s^*, must be such that there is a non-negligible subset Θ of the set A of all admissible (ε,t),

$$A\equiv\{(\varepsilon,t)|\ \varepsilon_{\min}\leq\varepsilon\leq\varepsilon_{\max}\text{ and }0\leq t\leq t_{\max}\}$$

such that for any point (ε, t) in the subset Θ, the export scope $i^x(\varepsilon, t, s^*)$ is exactly equal to the product scope s^*, that is, the product scope s^* is a binding constraint on the export scope $i^x(\varepsilon, t, s^*)$ for all $(\varepsilon, t) \in \Theta \subset A$.

Proposition 1: *For a product scope s^* to be optimal, it is necessary that there is a strictly positive probability that ex post, the firm finds that the unconstrained export scope $i^u(\varepsilon, t)$ is greater than the product scope.*

Proof: See Appendix A.

The intuition behind Proposition 1 is simple: since investment in capacity is costly, the optimal capacity must be set at a level such that for some exchange rate realizations, the firm would wish, ex post, to have a greater capacity. Figure 1 gives a graphic depiction of the essence of Proposition 1. The lower dotted line, which may be labelled as $i^u(\varepsilon_{\min,}t)$, indicates the unconstrained export scope for destination markets located at t units distance from the Home firm, if the exchange rate realization is $\varepsilon_{\min}$. Similarly, the upper dotted line,[20] which may be labelled as $i^u(\varepsilon_{\max,}t)$, indicates the unconstrained export scope for destination markets located at t units distance from the Home firm, if the exchange rate realization is $\varepsilon_{\max}$. The optimal product scope, s^*, is smaller than $i^u(\varepsilon_{\max,}0)$.

Our next Proposition states that on average the Home firm tends to export more product varieties to destination markets with stable exchange rates:

Proposition 2: *The expected export scope for markets with floating exchange rates is smaller than that for markets with a fixed exchange rate.*

Proof: See Appendix B.

2.2.3 Response of export scope to an increase in exchange rate volatility

Proposition 2 compares the average export scope for markets with a fixed exchange rate $\overline{\varepsilon}$ with the average export scope for markets with exchange rate volatility, under the assumption that the volatility is the same in all markets that do not have a fixed exchange rate. In this sub-section, we proceed further by showing that if the exchange rate is distributed according to the Pareto distribution, then markets with a *higher degree of exchange rate volatility* will display, on average, smaller export scope.

Suppose that the country j's exchange rate ε_j is governed by a Pareto distribution,

$$H_j(\varepsilon_j; \lambda_j) = 1 - \left(\frac{\varepsilon_j}{\varepsilon_j^{\min}}\right)^{-\lambda_j} \quad \text{for } \varepsilon_j \in \left[\varepsilon_j^{\min}, \infty\right)$$

[20] This line can be extended all the way so that it cuts the vertical axis at a point, $i^u(\varepsilon_{\max,}0)$, directly above s^*.

where $\varepsilon_j^{\min} > 0$ and $\lambda_j > 2$. Then the mean and the standard deviation are given by

$$E(\varepsilon_j) \equiv \overline{\varepsilon}_j = \frac{\lambda_j \varepsilon_j^{\min}}{(\lambda_j - 1)} > 0 \text{ and } \sigma_j = \overline{\varepsilon}_j \left(\frac{1}{1 - (2/\lambda_j)} \right)^{1/2} > 0$$

Consider now another country, country i, whose ε_i also distributed according to the Pareto distribution such that the mean exchange rate is the same as that of country j but the standard deviation is smaller, $\sigma_i < \sigma_j$, i.e., $\lambda_i > \lambda_j$.[21]

In the Appendix, we show that given the product scope, s^*, the Home firm's expected export scope to destination countries with a bigger standard deviation of the exchange is lower. We state this result as Proposition 3.

Proposition 3:

(i) Consider two destination countries i and j located at equal distance from the Home firm. Assume that their random exchange rates (in terms of the Home country's currency), ε_i and ε_j, are governed by Pareto distribution functions with positive and finite mean and *and standard deviation. Suppose that the means are the same, $E(\varepsilon_i) = E(\varepsilon_j)$ but the standard deviation of country i's exchange rate is smaller. Then the Home firm's expected export scope toward the country with a more volatile exchange rate (country j) is smaller than that toward the country a less volatile exchange rate.*

(ii) The adverse impact of an increase in exchange rate volatility (an increase in σ_j) on the expected export scope for market j is smaller, the larger is the home firm's product scope, s^*.

Proof: See Appendix C.

2.3 Discussion and extension of the theoretical results

This sub-section provides an intuitive explanation and some extensions to the theoretical results obtained above.

2.3.1 An intuitive explanation

Suppose the home country faces a collection of destination markets (countries) that operate under different exchange rate regimes. Some of these countries adopt a scheme that ensures relatively stable exchange rate, while others allow their exchange rate to be freely flexible. A depreciation of the value of the currency of an importing country in terms of the currency of the home (exporting) country will impede the home country's exports, while an appreciation

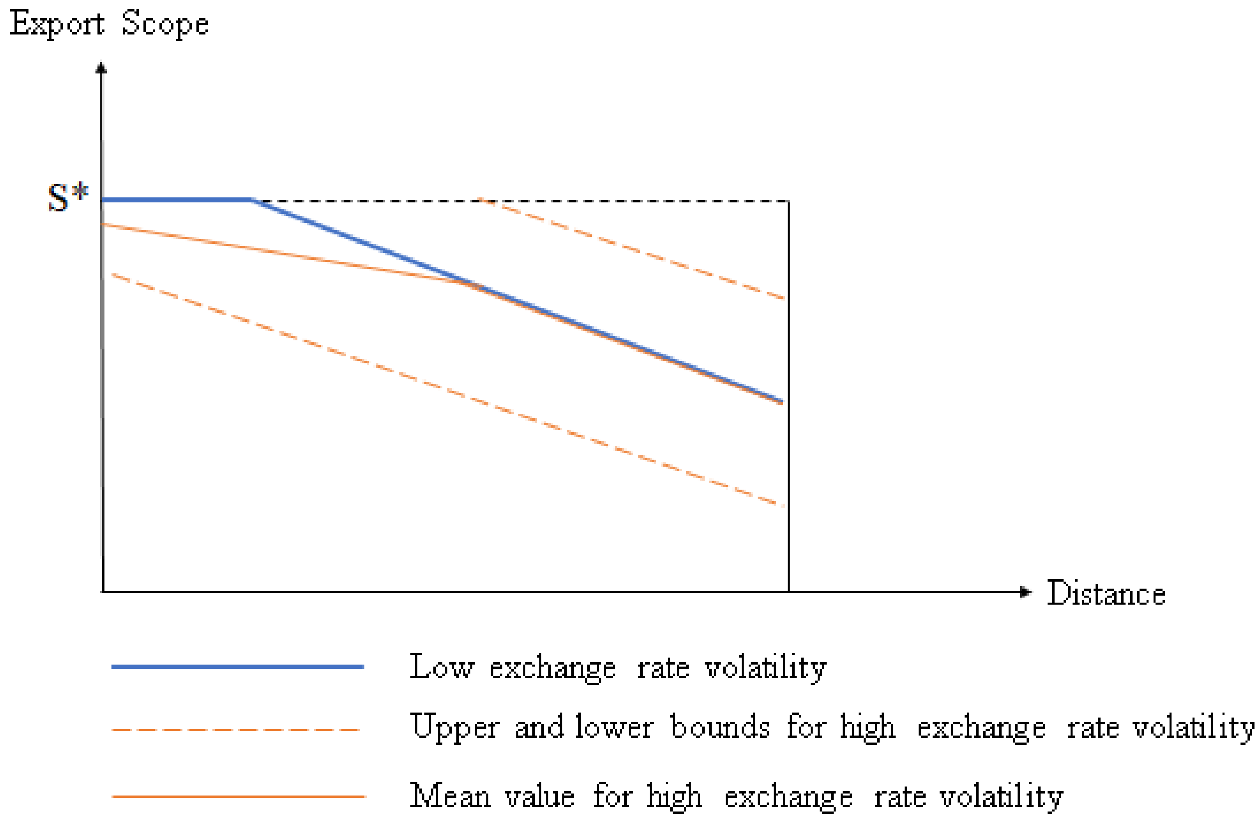
[21] Note that this implies that $\frac{\lambda_i \varepsilon_i^{\min}}{(\lambda_i - 1)} = \frac{\lambda_j \varepsilon_j^{\min}}{(\lambda_j - 1)}$.

will favor its exports. Home country's firms take the potential exchange rate fluctuations into account when deciding their optimal product scopes, knowing that their export scopes to various destination markets depend on both the exchange rate realization and the pre-determined product scope. A firm can adjust its export scopes immediately in reaction to the realized exchange rates (though upward adjustment is constrained by the product scope). In contrast, it takes a longer time to adjust the product scope: the introduction of a new variety requires prior investment in $R\&D$ for that variety. Firms determine their $R\&D$ investments based on expectations of future market conditions. An optimal investment strategy in production capacity must strike a judicious balance between, on the one hand, the potential losses from the waste of production capacity when if there is a negative demand shock, and, on the other hand, the cost of failing to exploit the potential benefits of a positive demand shock due to insufficient production capacity.

Thus, a firm's optimal product scope typically does not include high-cost varieties that would be profitable in all its export markets only in the unlikely event that all the exchange rate realizations are favorable. Instead, the marginal variety of the optimal product scope would be at the margin of profitability under average market condition, i.e., its gross profit under normal condition is just enough to cover the $R\&D$ cost. As a result, firms are generally unable to fully adjust upwards their export scopes in response to positive demand shocks. Therefore one would expect the following features of firms' adjustments to exchange rate variations: (i) an asymmetric expansion/contraction of export scope in response to currency appreciation/depreciation (i.e., the downward adjustment of export scope when the foreign currency depreciates tends to be more pronounced than the upward adjustments when it appreciates); and (ii) on average, firms tend to export fewer varieties to markets with greater exchange rate volatility, and consequently, the export volume to these markets tend to be smaller.

Figure 1 illustrates how a home firm's export scopes to countries with volatile exchange rates are, on average, smaller than its export scopes to risk-free countries, given that the firm's pre-determined product scope is s^*. Trade cost (or distance from the home country) is measured along the horizontal axis. The home firm's export scope to a market depends on its distance from the home country and on the realization of the appreciation/depreciation of that market's currency (relative to the currency of the exporting country). A high realization (an appreciation) increases that market's demand for the firm's output, thus inciting the firm to expand its export scope to that market. The upper dashed red line depicts the case where the appreciation is maximal. The lower dashed red line corresponds to the case of maximal

Figure 1: Exchange Rate Volatility, Transportation Cost and the Export Scope



Notes. Figure 1 above illustrates how the export scope towards the risky countries are, on average, less than that towards the risk-free countries. The red dashed lines are the upper and lower bounds for the export scopes to the risky markets – i.e., when the foreign currency appreciates, the export scope increases, and when it depreciates, the change will be opposite. The red solid line refers to the average export scopes towards these countries. The blue line denotes the export scopes towards the risk-free markets. All export scopes are constrained by the upper bound of the product scope. The horizontal axis measures the heterogeneous transportation cost among countries (to simplify our analysis, without loss of generality, we assume that all countries impose the same import tariff).

depreciation. The red solid line depicts the average export scope for countries with volatile exchange rate. The blue line depicts the firm's export scope to countries with stable exchange rate. Since all export scopes are bounded above by the firm's product scope, s^*, it follows that, on average, the firm's export scopes for risky markets are below the ones for riskless countries.

2.3.2 Export scope and size of the destination market

From equation (5) we infer that, in the presence of market-specific entry cost for each variety, firms tend to export *more varieties to larger countries.* The intuition is as follows. Larger markets mean greater demand. Thus, not only do firms export a greater quantity of each varieties to larger markets, but also they export more varieties to them. That is, if population size of a firm's export market increases, the firm responds in two margins: the intensive margin (by increasing the volume of sale of each existing variety), and the extensive margin (increasing the number of varieties to be shipped to that market).

2.3.3 Testable predictions

The above analysis of our model yields the following testable hypotheses:

Hypothesis 1: *Firms' export scopes are, on average, smaller for destination markets whose exchange rates display a higher degree of volatility.*

Hypothesis 2: *The effect of exchange rate volatility on firms' export scopes is more pronounced (i) for firms with lower product scope; (ii) for markets with lower trade costs; and (iii) for markets with greater population mass.*

Hypothesis 3 (Asymmetric responses to currency appreciation/depreciation): *The response of export scope to exchange rate variations is asymmetric: the expansion of export scope induced by an appreciation of the currency of the destination market is less pronounced than the contraction of export scope induced by a depreciation.*

In the next section, we construct econometric models based on our theoretical predictions, and bring the model to Chinese firm-level data.

3 Data and Specification

In this section we use firm-level data to provide evidence on how firms adjust their export strategies in response to varying exchange rate volatility and study how the magnitude of these adjustments depend on firm characteristics and destination country characteristics. Our empirical analysis proceeds in three steps. First, we describe our dataset and discuss some stylized facts. Second, we specify our econometric models for testing our theoretical predictions. Finally, we summarize and explain our findings.

3.1 Firm and Trade Data

Our main data source is the customs transactional level database maintained by China's Customs. This database records firm-country-product level of export value and export quantity each year.[22] Data are at very disaggregated product categories (six-digit HS classification). As the trade patterns of processing firms are quite different from those of ordinary firms, we restrict our sample to ordinary exporters. The firm-level data on firms' characteristics were drawn from the Annual Survey of Industrial Firms by the National Bureau of Statistics of China. This dataset contains the operation information of all enterprises with annual revenues of five million RMB or more, including annual firm-level balance sheet information and income statement variables such as owenership, assets, fixed assets, liabilities, and revenue. We merge these two datasets so that we can control for firm-level chracteristics and examine firm-specific effects of RER volatility. We first merge firm-level data to customs data, using firm names; next, we update the unmerged transaction data using the name of legal representatives, phone numbers and zip codes. Around 49.34% of transaction data are merged with firm-level data. Since such an operation may create bias towards relatively large firms, we also report in an Appendix (available upon request) our baseline estimation using only the sample from customs data as additional checks. We focus on Chinese exporting firms between 2000 and 2006, the period for which we have access to both customs and firm-level data.

Table 1 presents descriptive statistics of firm-country level trade data and firm-level characteristics. As our main dependent variables of interest are export value and export scope, observations reported here are only firm-country pairs that have positive trade in at least one year between 2000 and 2006. Following China's accession to the WTO in 2001, both total export value and export scope spike sharply. As the trade surges from China, both the numbers of exporters and trade partners also rise rapidly in lockstep. In our sample, the number of exporters range from 62,289 to 169,398 and the number of destinations vary from 164 to 169 between 2000 and 2006. The mean number of firm-country pairs is 928,833, with a standard deviation of 335,563. None of the firm-country pairs are present for all the years in the sample. About 41.67% firm-country pairs are present for two years in the sample and about 58.24% are present only for one year. This suggests that firms are highly flexible in changing their destination countries when the external economic environment changes.

Firm-level charateristics follow the same pattern as trade soars after China's accession

[22] Although the data are available at monthly frequency, we use annual data because of concerns of seasonality and lumpiness in shipping: most firms do not ship to the same markets one month after another.

to the WTO in 2001. The average firm size as measured by sales is around 5.4 millon RMB. As alternative measures of firms' financial capability, we use the average asset turnover ratio (defined as the ratio of sales over assets) and the collateral ratio (measured by the ratio of net fixed assets to total assets). The average of the former measure is 1.28 while that for the latter is 0.439.

Table 1: Summary of Key Variables for Firm Characteristics

	Mean	St. Dev.	Min	Max
Firm-country Export Value	10.690	2.216	0	23.236
Firm-country Export Scope (HS6)	4.248	13.149	1	46
Firm-country Export Scope (HS8)	4.385	13.991	1	45
Firm Size	5.404	0.005	0	185088
Asset Turnover	1.280	1.400	-12.246	13.269
Collateral Ratio	0.439	0.513	-12.234	10.302
Number of firms	120430	38086.63	62289	169398
Number of destinations	168.282	1.617	164	170
Number of firm-country pairs	928833.4	335563.7	415939	1368946

Notes. Firm-country export value is the export value of a Chinese export to a destination and is reported in logs. Firm-country Export Scope (HS6) and Firm-country Export Scope (HS8) is the number of varieties exported to a destination measured by HS6 and HS8 code respectively.The firm size is measured by total assets in million RMB. The asset turnover ratio is measured by the ratio of sales to total assets and the collateral ratio is measured by the ratio of net fixed assets to total assets.

3.2 Exchange Rate Volatility

China's exchange rate regime makes it particularly interesting to study the effect of exchange rate volatility of trade partners. The RMB has long been a currency that does not have a floating exchange rate determined by market forces. Before the Economic Reform and Open Policy (instituted in 1978), the RMB's exchange rate was fixed at an overvalued level along with direct controls of imports and export by the state. After 1978, the spike of inflows of foreign capital called for a change in China's exchange rate regime. As described by Goldstein (2009), the system is characterized by "sharp changes in the official exchange rates, the use of dual system and the introduction of gradual expansion of markets for foreign exchanges." The nominal exchange rate (RMB per USD) has been frequently adjusted until the level of 8.27 RMB per dollar was reached in 1994 and this level was maintained for about a decade.

Following a currency regime reform announced on July 21, 2005, the RMB was moved to a "managed float" system against a basket of major currencies that includes the USD.

Since then, the RMB has entered into a period of gradual appreciation and has steadily appreciated against the USD. Over the year 2005, the RMB appreciated by 2.56% relatively to the USD, reaching 8.07 RMB per USD at the end of 2005. Over the following three years, the RMB further appreciated by about 21% reaching the level of 6.83 RMB per USD. The Central Bank of China has made the system more reflective of the market forces. Our sample period 2000-2006 covers both a pre-reform phase and a post-reform phase.

We draw monthly data on the real exchange rates (RER) of destination markets from the International Financial Statistics (IFS). We compute RER volatility as annual standard deviation of monthly log difference in the real exchange rate. We do not account for changes in China's price level, in view of the potential data quality issue mentioned in Héricourt and Poncet (2013). However, to provide additional checks, in an Appendix (available upon request) we report the results of our baseline estimation with RER changes and RER volatility adjusted for China's CPI.

For other characteristics of destination markets such as GDP, per capita GDP, price index (CPI), country-sector imports, country-sector tariff rates, and distance, we use multiple data sources. The data for GDP, per capita GDP, and price index are drawn from the PennWorld Table 9.0. The data for distance and country-sector (HS2) imports are drawn from the CEPII. The tariff data are from the World Intergrated Trade Solutions (WITS) Tariff Schedule. Table 2 reports the summary statistics of RER volatility, RER changes, along with these country-level variables. To match the span of firm and trade data, the country-level data are restricted to the period 2000-2006.

Table 2: Summary of the Key Variables for National Characteristics

Variables	Mean	Standard Dev.	Minimum	Maximum	Obs
RER Volatility	0.022	0.023	0	0.415	1,389
RER Change	0.075	0.520	-7.090	5.492	1,389
NER Volatility	0.019	0.024	0	0.414	1,389
NER Change	-0.009	0.260	-8.267	0.889	1,389
GDP	25.825	3.257	17.177	32.017	1,179
GDP per capita	8.988	1.204	6.302	11.683	1,179
Price Index	-0.524	0.472	-2.448	0.474	1,179
Distance	8.808	0.838	-0.0048	9.901	1,179
Country-sector Imports	8.795	3.294	0	19.561	139,701
Country-sector Tariff	0.117	0.125	0	5.333	139,701

Notes. The RER (NER) change and RER (NER) Volatily is measured based on the indirect quoting of foreign currencies against RMB. The RER (NER) volatility is computed as as annual standard deviation of monthly log differences in the real (nominal) exchange rate. The RER (NER) change is the first order difference in the annual exchange rate. Distance is the physical distance between the foreign country and China. GDP, GDP per capita, Price Index and Country-Sector Imports are presented in logrithm.

3.3 Baseline Specification

Following Héricourt and Poncet (2013), our baseline estimation model for the effect of RER volatility on the export scope is as follows:[23]

$$\Delta Y_{fct} = \beta_0 + \beta_1 \Delta RER_{ct} + \beta_2 RER\_Vol_{ct} + \beta_3 \Delta X_{ct} + \varphi_{fc} + \varphi_t + \varepsilon_{fct} \tag{9}$$

where f, c, and t are the subscripts for firm, destination country, and time respectively; ΔY_{fct} is the one-period difference of firm-country level export value or scope; ΔRER_{ct} is the one-period difference of the real exchange rate; RER_Vol_{ct} measures the exchange rate volatility of country c, ΔX_{ct} controls for other country-level characteristics, in one-period difference; φ_{fc} and φ_t control for firm-country level fixed effects and time fixed effects respectively; and ε_{fct} is the error term.

We are interested in firm-country level export value and export scope (the number of varieties defined at HS8 level) as dependent variables. While firm-country level export value is the aggregation of values across all the varieties exported by a firm to a destination, export scope measures the number of exported varieties at the firm-country level. The product varieties are distinguished by the HS8 codes. All variables are in

[23] Our model differs from Hericourt and Poncet (2013) by including the distance and the tariff rate.

logs except for the exchange rate volatility. For example, the export scope is computed as the (log) number of varieties by the firm-country-year level; that is $Export\_scope_{fct} \equiv \ln(number\_of\_varieties)_{fct}$. Our key explanatory variables of interest include the exchange rate volatility ($exchange\_rate\_volatility_{ct}$) and the change of RER. Exchange rate volatility is computed as the yearly standard deviation of the exchange rate for country c in year t using monthly data. X_{ct} is a set of destination controls including GDP, per capita GDP, and Price Index, as typically used in standard trade models.[24] We also include country-sector import shares (defined as the ratio of a sector's imports over total imports) to control for the destination's demand for the goods that a firm mainly produces, with the sector being the HS2 sector that has the highest export share of the firm in the period. As the export scope and product adjustments in response to exchange rate shocks may be slow, we focus on the difference specification given by equation (9). We report in an Appendix (available upon request) the results that are obtained when levels (instead of differences) are used in the regression equation.

4 Results

In this section, we present the results of our estimation of the effects of RER volatility on firm-level destination exports and export scope using a sample of ordinary Chinese exporters. We begin with our baseline specification and then explore the mechanism indicated by our theoretical model. To do this, we estimate a set of variants of equation (9) by examining the effects of firm-specific variables related to credit availability and by examining the role of export scope constraints with respect to a set of destination-specific trade cost measures and the asymmetric effects of exchange rate movements. We will also discuss our robustness checks with variant measures of export scope and RER volatility and with different sub-samples to separate regional impacts.

4.1 Baseline regression

In Table 3, we estimate the specification in equation (9) with the individual effects of RER volatility on export values and export scope respectively. In column (1), we report the estimates based only on the two proxies for the market size and the price index of the destination country. As expected, Chinese export is higher for destination countries with higher demand as measured by size and price level. The significantly positive coefficient of

[24]GDP and per capita GDP control for the firm-country level trade scale and taste heterogeneity among countries, e.g., the parameters in the utility function may differ across countries.

ΔRER indicates that the bigger is the appreciation, the greater is the growth in exports. In columns (2) and (3), we show that Chinese export was lower, on average, in countries with higher exchange rate volatility, controlling for firm-destination fixed effect and year fixed effect. In terms of magnitude, we find that a one-standard deviation increase in RER volatility in a destination country reduces an average Chinese firm's export value to that destination by as much as 6%.[25]

Columns (4) to (6) of Table 3 reports estimates for equation (9) when the dependent variable is the change in export scope. Here we also find that RER volatility works as a drag on export scope. Columns (5) and (6) in Table 3 shows that a one-standard deviation increase in the volatility lowers the export scope by about 2.2% for a typical exporter.[26] This means that a firm that sells 4 varieties to a destination market that has zero volatility would sell only about 2 varieties to a destination market (with the same distance and the same GDP) that has a RER volatility of 0.415 (the maximal volatility in our sample).

Table 3: Effect of Exchange Rate Volatility on Export Value and Scope

Dependent Variable	$\Delta Exports_{fct}$			$\Delta Export\_Scope_{fct}$		
	(1)	(2)	(3)	(4)	(5)	(6)
RER Volatility		-2.789***	-2.808***		-0.958***	-0.990***
		(0.188)	(0.191)		(0.092)	(0.093)
ΔRER	0.014***	0.014***	0.016***	0.006***	0.005***	0.006***
	(0.004)	(0.004)	(0.004)	(0.002)	(0.002)	(0.002)
ΔCountry GDP	0.515***	0.241***	0.216***	0.188***	0.096***	0.089***
	(0.040)	(0.044)	(0.044)	(0.020)	(0.022)	(0.022)
ΔCountry Price Index	0.547***	0.435***	0.426***	0.189***	0.155***	0.150***
	(0.021)	(0.025)	(0.026)	(0.010)	(0.012)	(0.012)
ΔCountry-Sector Imports			-0.005***			-0.002***
			(0.001)			(0.000)
Fixed Effects	Firm-Destination and Year					
Observations	2220148	1984240	1913456	2220148	1984240	1913456
$R2$	0.251	0.251	0.252	0.203	0.203	0.204

Notes. (* p-value< 0.1; ** p-value<0.05; *** p-value<0.01) Standard errors in parenthesis. Columns (1) - (3) show the results on the change of firm-destination export value and Columns (4) - (6) show the results on the change of firm-destination export scope. The exchange rate volatility is computed as the log standard deviation of the annual exchange rate of the destination country's currency against the Chinese yuan. The independent variables i clude the first-order difference of the exchange rate, GDP, price index (CPI) and country-sector imports in the destination country. All variables are in logs except the exchange rate volatility. All the regressions include firm-destination and year fixed effects. The results are consistent with the results above if we run the level regressions, or control for the firm-year fixed effects, or use the nominal exchange rate against Chinese yuan. Standard errors clustered at the firm level are in parentheses.

[25]This is obtained by multiplying -2.789 in Table 3 with 0.023 (the standard deviation of RER volatilty, see Table 2).

[26]This is obtained by multiplying -0.958 in Table 3 with 0.023 (the standard deviation of RER volatilty, see Table 2).

4.2 The Role of Credit Capacity

In our estimation reported in the above sub-section, we did not control for the time-varying firm characteristics. This may result in omitted variable bias. Moreover, in our theoretical formulation in Section 2, the product scope is determined by the investment decision in the first stage of our two-stage optimization problem, and it was assumed that there was no constraint on that decision. In practice, however, credit availability often is a key factor that influences the extent to which investment can be made to expand the product scope to the desired level. Therefore the export scopes are indirectly affected by credit availability. For this reason, we find it sensible to modify our baseline specification to control for a vector of variables related to credit availability. Our modified specification is as follows:

$$\begin{aligned}\Delta Y_{fct} &= \beta_0 + \beta_1 RER\_Vol_{ct} \times K_{ft-1} + \beta_2 \Delta RER_{ct} + \beta_3 RER\_Vol_{ct} + \beta_4 \Delta X_{ct} \\ &\quad + \beta_5 K_{ft-1} + \varphi_{fc} + \varphi_t + \varepsilon_{fct} \qquad (10)\end{aligned}$$

where K_{ft-1} denote a vector of variables related to credit availability to each individual firm. Following Cheung and Sengupta (2013), the vector of firm characteristics include (i) the firm's size (measured by total assets), which is often interpreted as a proxy for a firm's success in obtaining credit, or its ability to cope with financial constraints; (ii) the asset turnover ratio (measured by the ratio of sales to total assets) which measures a firm's efficiency in capital utilization, the underlying hypothesis being that more efficient firms are more able to cope with unfavorable exchange rate movements; (iii) the collateral ratio (measured by the ratio of net fixed assets to total assets), which measures the firm's ability to raise external funding. All variables are in logs and lagged by one period.

Table 4 reports the results of estimating equation (10). In columns (1) to (6), we include various measures of firm characteristics into our regression and look at their effects on the change in export value and export scopes respectively. We observe that the negative effects of exchange rate volatility on export value and export scope remain highly significant. Moreover, the magnitudes of the coefficients become much larger, indicating that these time-varying firm characteristics do have important impacts on the export outcomes and their inclusion helps in the alleviation of omitted variable bias. It is worth noting that the interaction terms of firm size, asset turnover ratio and collateral ratio express different impacts on export value and scopes. The coefficients of interaction terms involving firm size and asset turnover ratio are not significantly different from zero when the dependent variable is export value, but they are significantly positive when the dependent variable is the export scope. The opposite holds for the interaction term involving the collateral ratio. These results indicate that, for firms that are larger or that have higher asset turnover ratios, their export scope will, on average, be less affected by exchange rate volatility, while for firms that have higher asset collateral ratios, their export value will be less affected by exchange rate volatility. Note that these firm-specific characteristics are intentionally lagged for one period in order to incorporate the time lag for the adjustment of export value and scope in practice. To ensure that these operations do not drive our results, we also estimated the same model with contemporaneous firm-specific variables, and found that the effects are quantitatively similar; they are not reported here for brevity.

Table 4: Exchange Rate Volatility and Export Scopes: the Impacts of Capital Utilization

Dependent Variable	$\Delta Exports_{fct}$			$\Delta Export\_Scope_{fct}$		
	(1)	(2)	(3)	(4)	(5)	(6)
RER Volatility	-3.539***	-5.137***	-5.228***	-1.238**	-2.925***	-2.868***
	(1.292)	(1.803)	(1.829)	(0.606)	(0.811)	(0.831)
× L.Firm Size	0.048	0.177	0.219	0.050	0.184**	0.186**
	(0.130)	(0.165)	(0.168)	(0.059)	(0.072)	(0.074)
× L.Asset Turnover		0.315	0.387		0.332***	0.365***
		(0.230)	(0.238)		(0.103)	(0.107)
× L.Col.Ratio			0.719**			0.239
			(0.320)			(0.162)
Lagged Firm Size	-0.019***	-0.072***	-0.076***	-0.007***	-0.019***	-0.020***
	(0.005)	(0.006)	(0.006)	(0.002)	(0.003)	(0.003)
Lagged Asset Turnover		-0.104***	-0.107***		-0.025***	-0.027***
		(0.007)	(0.007)		(0.003)	(0.004)
Lagged Collateral Ratio			-0.024***			-0.009**
			(0.009)			(0.004)
ΔRER	0.022***	0.022***	0.022***	0.005*	0.005*	0.006*
	(0.007)	(0.007)	(0.007)	(0.003)	(0.003)	(0.003)
ΔCountry GDP	-0.016	-0.008	0.012	0.047	0.049*	0.047
	(0.065)	(0.065)	(0.066)	(0.029)	(0.029)	(0.030)
ΔCountry Price Index	0.414***	0.417***	0.425***	0.129***	0.130***	0.132***
	(0.038)	(0.038)	(0.039)	(0.017)	(0.017)	(0.017)
ΔCountry-Sector Imports	0.001	0.001	0.001	-0.000	-0.000	-0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)
Fixed Effects	Firm-Destination and Year					
Observations	900,459	900,235	864,552	900,459	900,235	864,552
$R2$	0.281	0.283	0.288	0.229	0.23	0.236

Notes. (* p-value< 0.1; ** p-value<0.05; *** p-value<0.01) Standard errors in parenthesis. Columns (1) - (3) show the results on the change of firm-destination export value and Columns (4) - (6) show the results on the change of firm-destination export scope. The exchange rate volatility is computed as the log standard deviation of the annual exchange rate of the destination country's currency against the Chinese yuan. The firm-level independent variables include one-period lagged terms of firm size (measured by sales), asset turnover, and collateral ratio. The country-level independent variables include the first-order difference of the exchange rate, GDP, price index (CPI) and country-sector imports in the destination country. All variables are in logs except the exchange rate volatility. All the regressions include firm-destination and year fixed effects. Standard errors clustered at the firm level are in parentheses.

Our estimation results of firm-specific capital utilization in Table 4 reveal a strong connection between firms' capitalization and their export outcomes. Since a firm's capital utilization in China is likely to depend on its organizational form, we further test the sensitivity of the effects of exchange rate volatility to the firm's ownership structure. We group the firms into four different ownership categories: (i) state-owned enterprises (SOE), (ii) private (PRI), (iii) foreign-owned enterprises (FOE), and (iv) others.

Table 5 reports the estimation results of equation (10) for subsamples that differ in ownership structure. We examine the effects of RER volatility on the change of export value and export scope in columns (1)-(3) and columns (4)-(6) respectively. We observe that both the export values and scopes of state-owned firms are more affected by exchange rate volatility, as compared to private and foreign-owned enterprises.

Table 5: Exchange Rate Volatility and Export Scopes: the Effects of Ownership

Dependent Variable	$\Delta Exports_{fct}$			$\Delta Export\_Scope_{fct}$		
	(1)	(2)	(3)	(4)	(5)	(6)
RER Volatility	-3.208***	-1.283**	-2.377***	-1.437***	-0.652**	-0.279**
	(0.278)	(0.617)	(0.292)	(0.147)	(0.313)	(0.111)
ΔRER	0.014**	-0.040***	0.017**	0.006*	-0.020***	0.000
	(0.006)	(0.015)	(0.007)	(0.003)	(0.008)	(0.003)
ΔCountry GDP	0.345***	0.304***	0.034	0.162***	0.325***	0.089***
	(0.064)	(0.107)	(0.075)	(0.035)	(0.056)	(0.029)
ΔCountry Price Index	0.475***	0.372***	0.432***	0.246***	0.118***	0.113***
	(0.037)	(0.076)	(0.039)	(0.020)	(0.039)	(0.015)
ΔCountry-Sector Imports	-0.001	-0.000	0.001*	-0.000	-0.001	-0.000
	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)
Fixed Effects	Firm-Destination and Year					
Observations	900459	900235	864552	900459	900235	864552
$R2$	0.281	0.283	0.288	0.229	0.23	0.236

Notes. (* p-value< 0.1; ** p-value<0.05; *** p-value<0.01) Standard errors in parenthesis. Columns (1) - (3) show the results on the change of firm-destination export value and Columns (4) - (6) show the results on the change of firm-destination export scope. The exchange rate volatility is computed as the log standard deviation of the annual exchange rate of the destination country's currency against the Chinese yuan. The country-level independent variables include the first-order difference of the exchange rate, GDP, price index (CPI) and country-sector imports in the destination country. All variables are in logs except the exchange rate volatility. All the regressions include firm-destination and year fixed effects. Standard errors clustered at the firm level are in parentheses.

4.3 Interaction with National Characteristics

Our second theoretical prediction states that the effect of exchange rate volatility on firms' export scopes is less pronounced for markets with higher trade costs (or greater distances from the exporting firms), and for smaller importing countries. To test this prediction, we estimate the following model:

$$\Delta Y_{fct} = \beta_0 + \beta_1 RER\_Vol_{ct} \times M_{ct-1} + \beta_2 \Delta RER_{ct} + \beta_3 RER\_Vol_{ct} + \beta_4 \Delta X_{ct} + \beta_5 M_{ct-1} + \varphi_{fc} + \varphi_t + \varepsilon_{fct} \quad (11)$$

where M_{ct-1} denotes either the log of lagged GDP for country c or the log of distance between China and country c. If M_{ct-1} is the log of lagged GDP, we expect a significantly negative coefficient on the interaction term $RER\_Vol_{ct} \times M_{ct-1}$. If M_{ct-1} is the log of distance, we expect a significantly positive coefficient on the interaction term $RER\_Vol_{ct} \times M_{ct-1}$. The other variables are the same as in model 1.

Table 6 reports the results. As shown in columns (1), (3), (4) and (6), the coefficients for the interaction term involving distance are positive and significant. As for the interaction term involving GDP, columns (2), (3), (5) and (6) show that they are negative and significant. Thus our theoretical predictions are confirmed by the evidence.

Table 6: Exchange Rate Volatility and the Export Scope: Interaction of National Characteristics

Dependent Variable	$\Delta Exports_{fct}$			$\Delta Export\_Scope_{fct}$		
	(1)	(2)	(3)	(4)	(5)	(6)
ΔRER	-0.022***	-0.022***	-0.022***	-0.009***	-0.009***	-0.009***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
RER Volatility	-66.802***	-1.202	-58.319***	-60.303***	-2.175***	-61.255***
	(1.844)	(0.781)	(2.172)	(0.800)	(0.363)	(0.972)
×ln(Dist)	6.120***		5.961***	6.148***		6.166***
	(0.199)		(0.202)	(0.086)		(0.088)
×ln(GDP)		-0.732***	-0.536***		-0.142***	-0.060**
		(0.061)	(0.062)		(0.028)	(0.028)
Fixed Effects	Firm-Destination and Year					
Observations	900459	900235	864552	900459	900235	864552
$R2$	0.281	0.283	0.288	0.229	0.23	0.236

Notes. (* p-value< 0.1; ** p-value<0.05; *** p-value<0.01) Standard errors in parenthesis. All variables are in logs except the exchange rate volatility. The exchange rate volatility is computed as the log standard deviation of the annual exchange rate of the destination country's currency against the Chinese yuan. Panel A shows the results using the exchange rate against the Chinese yuan and Panel B shows the results using the exchange rate against the U.S. dollar. The distance is computed as the geographic distance between the largest city of the two countries. The tariff rate is the industry-level import tariff imposed by the destination market. The country-level controls include the GDP and GDP per capita. The estimation results show that the export scope is decreasing in the distance, tariff rate and exchange rate volatility. The results are consistent with the results above if we run the level regressions, or control for the firm-year fixed effects, or use the nominal exchange rate against Chinese yuan. Standard errors clustered at the firm level are in parentheses.

4.4 Asymmetric Responses to Exchange Rate Changes

Table 7 reports the results of interacting the change of interacting the change of exchange rate and volatility with a set of dummy variables. According to columns (2) and (6), the effect of increased volatility on export value and export scope is more pronounced in times of depreciation than in times of appreciation. This is in line with the prediction of our model and with the empirical findings on Indian firms (Cheung and Sengupta, 2013). Lastly, in columns (3)-(4) and (7)-(8), we interact two main independent variables with with a dummy variable indicating whether a firm's export value is above or below the median level of its main sector export (HS2). The results show that firms that export more are less affected by the negative effect of exchange rate volatility.

Table 7: Effect of Exchange Rate Volatility on Exports and Scopes: Asymmetric Effects

Dependent Variable	$\Delta Exports_{fct}$				$\Delta Export\_Scope_{fct}$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ΔRER×App_dummy	0.039***				0.009***			
	(0.005)				(0.002)			
ΔRER×Dpp_dummy	0.108***				0.044***			
	(0.006)				(0.003)			
RER_vol×App_dummy		-0.762***				-0.362***		
		(0.152)				(0.069)		
RER_vol×Dpp_dummy		-2.201***				-0.834***		
		(0.157)				(0.076)		
ΔRER×High_dummy			0.449***				0.108***	
			(0.005)				(0.002)	
ΔRER×Low_dummy			-0.587***				-0.121***	
			(0.010)				(0.003)	
RER_vol×High_dummy				22.056***				4.985***
				(0.320)				(0.119)
RER_vol×Low_dummy				-41.129***				-10.472***
				(0.378)				(0.139)
Other Controls	YES	YES	YES	YES	YES	YES	YES	YES
Fixed Effects	Firm-Destination and Year							
Observations	1,913,456	1,914,490	1,913,456	1,914,490	1,913,456	1,9144,90	1,913,456	1,914,490
$R2$	0.251	0.251	0.267	0.339	0.203	0.203	0.207	0.229

Notes. (* p-value< 0.1; ** p-value<0.05; *** p-value<0.01) Standard errors in parenthesis. Columns (1) - (4) show the results on the change of firm-destination export value and Columns (5) - (8) show the results on the change of firm-destination export scope. RER volatility and the change of RER are interacted with two set of dummy variables: a. The dummy variables denoting appreciation (depreciation) of the destination country; b. The dummy variables indicating whether the firm's export value is higher than the median of all the firms exporting the same main sector (HS2) goods. The exchange rate volatility is computed as the log standard deviation of the annual exchange rate of the destination country's currency against the Chinese yuan. The firm-level independent variables include one-period lagged terms of firm size (measured by sales), asset turnover, and collateral ratio. The country-level independent variables include the first-order difference of the exchange rate, GDP, price index (CPI) and country-sector imports in the destination country. All variables are in logs except the exchange rate volatility. All the regressions include firm-destination and year fixed effects. The results are consistent with the results above if we run the level regressions, or control for the firm-year fixed effects, or use the nominal exchange rate against Chinese yuan. Standard errors are clustered at the firm level.

5 Robustness Checks

Our main findings are that export values and export scopes are adversely affected by exchange rate volatility. In this section, we address several issues concerning the measurement of our main dependent and independent variables which might possibly drive our results. Moreover, we also establish the robustness of the baseline results to alternative samples and specifications.

5.1 Alternative Measures of Exchange Rate

We measure exchange rate volatility as the volatility of the real exchange rate between the destination country and China. In this way we account for the real changes in the sales and profits of individual firms. However, the adjustment of export scope may not be directly related to the real changes in the relative cost of the baskets of goods. It is possible that firms respond mainly to nominal exchange rates when they determine their scope adjustments, especially in the case of moderate changes in the price levels. Therefore, we also estimate our model with an alternative measure of exchange rate volatility: the volatility of the nominal exchange rates.

For this purpose, we calculate the annual standard deviation of the nominal exchange rate of the currency of the destination market in terms of the RMB. Table 8 reports the results for this estimation. As shown, Chinese firms' export volumes and varieties to countries with more volatile nominal exchange rate are, on average, smaller compared to exports to countries with less volatile nominal exchange rate. We include several controls and fixed effects in the various regressions and find a consistently negative and significant relationship between exchange rate volatility and export outcomes.

Table 8: Effect of Exchange Rate Volatility on Exports and Scopes: Nominal Exchange Rate

Dependent Variable	$\Delta Exports_{fct}$			$\Delta Export\_Scope_{fct}$		
	(1)	(2)	(3)	(4)	(5)	(6)
NER Volatility		-3.097***	-3.135***		-1.119***	-1.149***
		(0.189)	(0.191)		(0.093)	(0.094)
ΔRER	0.011***	0.011***	0.013***	0.003*	0.004**	0.004**
	(0.004)	(0.004)	(0.004)	(0.002)	(0.002)	(0.002)
ΔGDP	0.327***	0.247***	0.229***	0.126***	0.097***	0.090***
	(0.044)	(0.044)	(0.045)	(0.022)	(0.022)	(0.022)
ΔPrice Index	0.509***	0.438***	0.430***	0.183***	0.158***	0.155***
	(0.025)	(0.025)	(0.026)	(0.012)	(0.012)	(0.012)
ΔSector Imports			-0.001***			-0.001***
			(0.001)			(0.000)
Fixed Effects	Firm-Destination and Year					
Observations	1984240	1984240	1913180	1984240	1984240	1913180
$R2$	.251	.251	.252	.203	.203	.204

Notes. (* p-value< 0.1; ** p-value<0.05; *** p-value<0.01) Standard errors in parenthesis. Columns (1) - (3) show the results on the change of firm-destination export value and Columns (4) - (6) show the results on the change of firm-destination export scope. The exchange rate volatility is computed as the log standard deviation of the annual nominal exchange rate of the destination country's currency against the Chinese yuan. The firm-level independent variables include one-period lagged terms of firm size (measured by sales), asset turnover, and collateral ratio. The country-level independent variables include the first-order difference of the exchange rate, GDP, price index (CPI) and country-sector imports in the destination country. All variables are in logs except the exchange rate volatility. All the regressions include firm-destination and year fixed effects. Standard errors clustered at the firm level are in parentheses.

5.2 Controlling for Subsamples

Finally, we estimate our baseline specification with different subsamples. Table 9 reports the relevant estimation results. For example, we delete from our samples observations with too few destinations or products, or firms that export mostly to Macau (China) and Hong Kong (China). The estimations results are consistent with our main regressions: we find a robust negative relationship between country-level exchange rate volatility and export outcomes (both in terms of export values and export scopes) even after removing firm and destination outliers.

Table 9: Effect of Exchange Rate Volatility on Exports and Scopes: Controlling for Subsamples

Dependent Variable	$\Delta Exports_{fct}$			$\Delta Export\_Scope_{fct}$		
	Dest>1	Product >1	No HK & MAC	Dest >1	Product >1	No HK & MAC
	(1)	(2)	(3)	(4)	(5)	(6)
RER Volatility	-1.411***	-1.146***	-1.044***	-0.666***	-0.645***	-0.504***
	(0.122)	(0.152)	(0.121)	(0.054)	(0.074)	(0.053)
ΔRER	-0.001	-0.003	0.004	-0.007***	-0.010***	-0.005***
	(0.003)	(0.003)	(0.003)	(0.001)	(0.002)	(0.001)
ΔGDP	0.236***	0.302***	0.224***	0.082***	0.121***	0.063***
	(0.028)	(0.035)	(0.029)	(0.013)	(0.018)	(0.014)
ΔPrice Index	0.068***	0.069***	0.078***	0.014*	0.006	0.022***
	(0.017)	(0.020)	(0.017)	(0.007)	(0.010)	(0.007)
ΔSector Imports	0.000	-0.000	-0.000	0.000	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Fixed Effects	Firm-Destination and Year					
Observations	3196364	1650938	3100761	3196364	1650938	3100761
$R2$	0.768	0.812	0.765	0.794	0.797	0.785

Notes. (* p-value< 0.1; ** p-value<0.05; *** p-value<0.01) Standard errors in parenthesis. Columns (1) - (3) show the results on the change of firm-destination export value and Columns (4) - (6) show the results on the change of firm-destination export scope. The exchange rate volatility is computed as the log standard deviation of the annual exchange rate of the destination country's currency against the Chinese yuan. The firm-level independent variables include one-period lagged terms of firm size (measured by sales), asset turnover, and collateral ratio. The country-level independent variables include the first-order difference of the exchange rate, GDP, price index (CPI) and country-sector imports in the destination country. All variables are in logs except the exchange rate volatility. All the regressions include firm-destination and year fixed effects. Standard errors clustered at the firm level are in parentheses.

6 Conclusion

Our paper explores the implications of production constraints for the responses of exporting firms to exchange rate volatility. Abstracting from risk-aversion, we develop a tractable theoretical framework that predicts the negative effect of exchange rate volatility on export values and export scopes. We find that capacity constraints, modelled as the exporting firm's long-run decision on its product scope, is responsible for asymmetric responses of exports to currency appreciation/depreciation: the expansion of export scope induced by an appreciation of the currency of the destination market is less pronounced than the contraction of export scope induced by a depreciation. The intuition behind this result is transparent: Firms can easily reduce their export scopes when facing negative demand shocks, but may find it difficult to expand the export scopes when facing positive demand shocks, because their product scope decision, made at an earlier stage, places an upper bound on their export scopes.

Guided by our theoretical analysis, and using Chinese firm-level data from 2000 to 2006, we reach the following empirical findings: (i) firms export fewer varieties, and consequently their export volume is lower, to destination markets that have higher exchange rate volatility; (ii) the effect of exchange rate volatility on exports is less pronounced in markets with low trade cost and for firms with higher financial ability (an indicator for investment in production capacity); (iii) the depreciation of the destination country's currency has a more substantial impact on export than an appreciation.

By introducing production constraint as a conscious and optimally made decision in the first stage of a two-stage optimization problem that firms face, we have been able to shed light on asymmetric responses of exports to exchange rate realizations in destination markets. Moreover, by exploiting the rich firm-level dataset on Chinese firms' export values and scopes to various destinations, we provided empirical evidence that are consistent with our theoretical predictions.

APPENDICES

APPENDIX A

Proof of Proposition 1

Let us define

$$D \equiv B - 2\sqrt{\gamma f^x / L}$$

Then

$$\begin{aligned} i^x(\varepsilon, t) &= \min\left\{s, \left[\varepsilon\left(B - 2\sqrt{\gamma f^x/L}\right) - t\right]\right\} \\ &= \min\left\{s, \varepsilon D - t\right\} \end{aligned}$$

For any given $s > 0$,

$$i^x(\varepsilon, t, s) = \begin{cases} \varepsilon D - t & \text{for } \varepsilon_{\min} < \varepsilon < (s+t)/D \\ s & \text{for } \varepsilon_{\max} > \varepsilon \geq (s+t)/D \equiv \widehat{\varepsilon}(t, s^*) \end{cases}$$

and, for any variety $i \leq i^x(\varepsilon, t, s)$, the profit is

$$\pi(\varepsilon, t, i) = \frac{(\varepsilon B - i - t)^2 L}{4\varepsilon\gamma} - \varepsilon f^{\ x} \tag{A.1}$$

Note that

$$\frac{\partial \pi(\varepsilon, t, i)}{\partial i} = -\frac{2(\varepsilon B - i - t)L}{4\varepsilon\gamma} < 0$$

The aggregate profit from the sale of all the varieties $i \leq i^x(\varepsilon, t)$ to markets with a given characteristic (ε, t) (where ε is a given realization of a floating exchange rate) is obtained by integrating (A.1) over all $i \leq i^x(\varepsilon, t; s)$.

$$\Pi(\varepsilon, t, s) \equiv \int_0^{i^x(t,\varepsilon,s)} \pi(\varepsilon, t, i) di.$$

For destination markets at distance t with a fixed exchange rate $\overline{\varepsilon}$, if the aggregate profit is

$$\pi(\overline{\varepsilon}, t, i) = \frac{(\overline{\varepsilon} B - i - t)^2 L}{4\overline{\varepsilon}\gamma} - \overline{\varepsilon} f^{\ x}$$

and

$$\Pi(\overline{\varepsilon}, t, s) = \int_0^{i^x(t,\overline{\varepsilon},s)} \pi(\overline{\varepsilon}, t, i) di.$$

Integrating over all possible pair (ε, t) gives the home firm's expected profits from markets, given that the product scope is s:

$$\begin{aligned} E\Pi^{agg}(s) \ &\equiv \ \upsilon N \int_0^{t_{\max}} \left[\int_{\varepsilon_{\min}}^{\varepsilon_{\max}} \Pi^{agg}(\varepsilon, t, s) h(\varepsilon) d\varepsilon\right] g(t) dt \\ &\quad + (1-\upsilon) N \int_0^{t_{\max}} \Pi^{agg}(\overline{\varepsilon}, t, s) g(t) dt \end{aligned}$$

The firm chooses its product scope by maximizing $E\Pi^{agg}(s) - \mu s$ with respect to s. The FOC is

$$\begin{aligned} 0 &= -\mu + \upsilon \int_0^{t_{\max}} \left[\int_{\varepsilon_{\min}}^{\varepsilon_{\max}} \left(\frac{d}{ds} \Pi^{agg}(\varepsilon, t, s) \right) h(\varepsilon) d\varepsilon \right] g(t) dt \\ &\quad + (1-\upsilon) \int_0^{t_{\max}} \left(\frac{d}{ds} \Pi^{agg}(\overline{\varepsilon}, t, s) \right) g(t) dt \end{aligned}$$

where

$$\frac{d}{ds} \Pi^{agg}(\overline{\varepsilon}, t, s) = \pi(\overline{\varepsilon}, t, i^x(t, \overline{\varepsilon}, s)) \frac{\partial i^x(t, \overline{\varepsilon}, s)}{\partial s} \geq 0$$

because

$$\begin{aligned} \frac{\partial i^x(t, \overline{\varepsilon}, s)}{\partial s} &= \begin{cases} 0 & \text{for } \varepsilon_{\min} < \overline{\varepsilon} < (s+t)/D \\ 1 & \text{for } \varepsilon_{\max} > \overline{\varepsilon} \geq (s+t)/D \end{cases} \\ \frac{\partial i^x(t, \varepsilon, s)}{\partial s} &= \begin{cases} 0 & \text{for } \varepsilon_{\min} < \varepsilon < (s+t)/D \\ 1 & \text{for } \varepsilon_{\max} > \varepsilon \geq (s+t)/D \end{cases} \end{aligned}$$

Thus, the FOC is that, when s is evaluated at s^*, the following equality holds

$$\begin{aligned} 0 &= -\mu + \upsilon \int_0^{t_{\max}} \left[\int_{\varepsilon_{\min}}^{\varepsilon_{\max}} \left(\pi(\varepsilon, t, i^x(t, \varepsilon, s)) \frac{\partial i^x(t, \varepsilon, s)}{\partial s} \right) h(\varepsilon) d\varepsilon \right] g(t) dt \\ &\quad + (1-\upsilon) \int_0^{t_{\max}} \left(\pi(\overline{\varepsilon}, t, i^x(t, \overline{\varepsilon}, s)) \frac{\partial i^x(t, \overline{\varepsilon}, s)}{\partial s} \right) g(t) dt \end{aligned}$$

For this condition to be satisfied, it is necessary that $\frac{\partial i^x(t,\varepsilon,s)}{\partial s} = 1$ for some non-negligible region in of the set $\{(s,t) : t \in [0, t_{\max}], \varepsilon \in [\varepsilon_{\min}, \varepsilon_{\max}]\}$. It is easy to check that the SOC is satisfied, because

$$\frac{\partial \pi(\varepsilon, t, i^x(t, \varepsilon, s))}{\partial s} = \frac{\partial \pi(\varepsilon, t, i^x(t, \varepsilon, s))}{\partial i^x} \times \frac{\partial i^x(t, \varepsilon, s)}{\partial s} \leq 0.$$

APPENDIX B: Proof of Proposition 2.

We refer to Figure 1. Ignore for the moment that the product scope s^* imposes an upper bound on the export scope. Then we can define the (unconstrained) export scope to a country with trade cost t and exchange rate realization ε as the threshold variety $i^u(\varepsilon, t)$ such that the hom firm's optimal exported quantity for varieties $i > i^u(\varepsilon, t)$ is zero, where

$$i^u(\varepsilon, t) \equiv \varepsilon D - t.$$

Note that $i^u(\varepsilon, t)$ is increasing in ε and decreasing in t. Then, for $\varepsilon = \overline{\varepsilon}$, we can graph $i^u(\overline{\varepsilon}, t)$ against t, where t is represented on the horizontal axis, with $0 \leq t \leq t_{\max}$,

$$i^u(\overline{\varepsilon}, t) = \overline{\varepsilon} D - t$$

The graph of $i^u(\overline{\varepsilon}, t)$ lies entirely below (respectively, above) the graph of $i^u(\varepsilon_{\max}, t)$ (respectively, $i^u(\varepsilon_{\min}, t)$). From Proposition 1, the optimal product scope s^* must be smaller than $i^u(\varepsilon_{\max}, t)$, as depicted in Figure 1.

Figure 1 illustrates the case where $i^u(\overline{\varepsilon}, 0) > s^*$. Since $i^u(\overline{\varepsilon}, t)$ is decreasing in t, there exists a unique value of $t > 0$ such that $i^u(\overline{\varepsilon}, t) = s^*$. Call this value $\widehat{t}(s^*)$. Then, for all trade costs such that $t \in \left[0, \widehat{t}(s^*)\right]$, the home firm's export scope to a country with the fixed exchange rate $\overline{\varepsilon}$ is equal to s^*. Similarly, the home firm's export scope to a flexible exchange rate country with any exchange rate realization ε in the interval $(\overline{\varepsilon}, \varepsilon_{\max}]$ is also equal to s^*. In contrast, its export scope to a flexible exchange rate country with low exchange rate realization $\varepsilon \in [\varepsilon_{\min}, \overline{\varepsilon})$ is smaller than s^* for all t such that $\widehat{t}(s^*) < t < \widehat{t}(s^*) - \delta$ for some $\delta > 0$. It follows that, for all $t \in \left[0, \widehat{t}(s^*)\right]$, the expected export scope is smaller than the export scope to countries with the fixed exchange rate $\overline{\varepsilon}$:

$$E_\varepsilon i^x(\varepsilon, t, s^*) \leq s^* = i^x(\overline{\varepsilon}, t, s^*) \text{ for } t \leq \widehat{t}(s^*) \tag{A.2}$$

Now, let us defined $\widetilde{t}(s^*)$ as the unique value such that $i^u(\varepsilon_{\max}, t) = s^*$. Clearly $\widetilde{t}(s^*) > \widehat{t}(s^*)$. Then, for all $t > \widetilde{t}(s^*)$, the export scope to countries with exchange rate realization $\varepsilon \in [\varepsilon_{\min}, \varepsilon_{\max}]$ is equal to $i^u(\varepsilon, t)$. Thus, for any $t \in \left(\widetilde{t}(I^*), t_{\max}\right]$, the expected export scope to a country with a floating exchange rate is:

$$E_\varepsilon i^x(\varepsilon, t, s^*) = \int_{\varepsilon_{\min}}^{\varepsilon_{\max}} (\varepsilon D - t)\, h(\varepsilon) d\varepsilon = i^u(\overline{\varepsilon}, t) = i^x(\overline{\varepsilon}, t, s^*) \text{ for } t \in \left(\widetilde{t}(I^*), t_{\max}\right] \tag{A.3}$$

where $h(\varepsilon)$ is the density function of ε.

Finally, for all $t \in \left(\widehat{t}(s), \widetilde{t}(s^*)\right)$

$$\begin{aligned} E_\varepsilon i^x(\varepsilon, t, s^*) &= \int_{\varepsilon_{\min}}^{\widehat{\varepsilon}(t,s^*)} (\varepsilon D - t)\, h(\varepsilon) d\varepsilon + \int_{\widehat{\varepsilon}(t,s^*)}^{\varepsilon_{\max}} s^* g(\varepsilon) d\varepsilon \\ &< \int_{\varepsilon_{\min}}^{\varepsilon_{\max}} (\varepsilon D - t)\, g(\varepsilon) d\varepsilon \leq i^u(\overline{\varepsilon}, t). \end{aligned} \tag{A.4}$$

where we have defined $\widehat{\varepsilon}(t, s^*) = (s^* + t)/D$. From eqs. (A.2), (A.3), and (A.4), we conclude that for all t, we have $E_\varepsilon i^x(\varepsilon, t, s^*) \leq i^x(\overline{\varepsilon}, t, s^*)$, with strict inequality holding for some t.

Appendix C: Proof of Proposition 3

Consider the distribution

$$H_j(\varepsilon_j; \lambda_j) = 1 - \left(\frac{\lambda_j \varepsilon_j}{(\lambda_j - 1)\overline{\varepsilon}}\right)^{-\lambda_i} = 1 - (\varepsilon_j)^{-\lambda_j} \left(\frac{\lambda_j}{(\lambda_j - 1)\overline{\varepsilon}}\right)^{-\lambda_j} \text{ for } \varepsilon_j \geq \frac{(\lambda_j - 1)}{\lambda_j}\overline{\varepsilon} \equiv \varepsilon_j^{\min}$$

The corresponding density function is

$$\lambda_j (\varepsilon_j)^{-\lambda_j - 1} \left(\frac{\lambda_j}{(\lambda_j - 1)\overline{\varepsilon}}\right)^{-\lambda_j} \text{ for } \varepsilon_j \geq \frac{(\lambda_j - 1)}{\lambda_j}\overline{\varepsilon} \equiv \varepsilon_j^{\min}$$

Then, from Lemma 1, for a given product scope $s^* > 0$, the export scope for a country with trade cost t_j and realised exchange rate ε_j is

$$i^x(\varepsilon_j, t_j, s^*) = \begin{cases} 0 & \text{if } \varepsilon_j \leq t_j/D \\ (D\varepsilon_j - t_j) & \text{if } \frac{t_j}{D} < \varepsilon_j < \widehat{\varepsilon}(t_j, s^*) \\ s^* & \text{if } \widehat{\varepsilon}(t_j, s^*) < \varepsilon_j \end{cases}$$

where

$$D \equiv B - 2\sqrt{\gamma f^x/L} \text{ and } \widehat{\varepsilon}(t_j, s^*) \equiv \frac{s^* + t_j}{D}.$$

Let us assume that $\varepsilon_j^{\min} > t_j/D$ so that $i^x(\varepsilon_j, t_j, s^*) > 0$ for all $\varepsilon_j \in \left[\varepsilon_j^{\min}, \varepsilon_j^{\max}\right]$

Define the random variable ι_j by

$$\iota_j = (D\varepsilon_j - t_j) > 0$$

Assume that $D\varepsilon_j^{\min} - t_j > 0$. Then the cumulative distribution of ι_j is a Pareto distribution, with

$$H(\iota_j) = 1 - \left(\frac{\iota_j}{\iota_j^{\min}}\right)^{-\lambda_j} \text{ for } \iota_j \in \left[\iota_j^{\min}, \infty\right)$$

where $\iota_j^{\min}$ is a function of λ_j, because we fix the mean $E(\varepsilon_j) = \overline{\varepsilon}$,

$$\iota_j^{\min}(\lambda_j) = \frac{D\overline{\varepsilon}(\lambda_j - 1)}{\lambda_j} - t_j > 0$$

Then the export scope for market j is

$$i^x(\varepsilon_j, t_j, s^*) = \begin{cases} \iota_j & \text{if } \iota_j^{\min} < \iota_j < \widehat{\iota}_j(t_j, s^*) \\ s^* & \text{if } \iota_j > \widehat{\iota}_j(t_j, s^*) \end{cases}$$

where $\widehat{\iota}_j(t_j, s^*) \equiv D\widehat{\varepsilon}(t_j, s^*) - t_j = s^*$. The probability that $\iota_j > s^*$ is, of course, $H(s^*)$. Then the Home firm's expected export scope for this destination country is

$$E\left[i^x(\varepsilon_j, t_j, s^*)\right] = s^* \times [1 - H(s^*)] + \int_{\iota_j^{\min}}^{s^*} \iota_j dH(\iota_j)$$

It is straightforward (though tedious) to verify that a smaller λ_j (i.e., a larger σ_j) implies a smaller expected export scope.

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