Exchange Rates and Export Structure

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Abstract

This paper studies whether changes in the exchange rate affect a country's export structure, using an arguably exogenous sudden appreciation of renminbi on July 21, 2005 as the main source of identification. Employing combined regression discontinuity and difference-in-differences approach, we show that China's export structure became more similar to that of the developed countries after the currency appreciation. We also find that the majority of the appreciation effect comes from the inter-firm resource reallocation rather than the inter-region or intra-firm resource reallocation.

Keywords: export structure, currency appreciation, regression discontinuity design, difference-in-differences estimation, China's exchange-rate reform, resource reallocation
JEL Classification Codes: F31; F14; D22

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1 Introduction

Exchange rates have been an important tool of trade policies. A weaker currency is widely believed by politicians and government officials to stifle import competition, helping to relieve domestic political pressures from high unemployment rates and boosting the performance of export sectors, subsequently leading to economic growth. Substantially hit by the 2008-09 financial crisis, developed economies like the U.S., Japan, and European countries have altered their monetary policies, which has deliberately or unintentionally led to depreciation of their currencies. Many developing countries also purposely undervalue their currencies by a fixed-exchange-rate regime or constant interventions to pursue a long-run export-led growth strategy.[1] International politics hence often involves the scenario where the developed countries ask the developing ones to appreciate their currencies.

Nevertheless, firms and industries respond to exchange-rate movement differently. For example, Berman, Martin, and Mayer (2012) find that by reducing their markups, more productive exporters can absorb negative shocks of currency appreciation better than their less productive counterparts. At the sectoral level, if appreciation of a developing country's currency moves its export structure towards the industries in which developed countries are concentrated in, the corresponding depreciation of developed countries' currencies may thus have limited effect on restraining imports and promoting exports.

To the best of our knowledge, there is no work on how the exchange rate changes a country's export structure (i.e., the distribution of export values across different industries), despite numerous studies on the effect of the exchange rate on aggregate export values and individual firm behaviors (e.g., Amiti, Itskhoki, and Konings, 2014; Berman, Martin, and Mayer, 2012; Chatterjee, Dix-Carneiro, and Vichyanond, 2013; Dekle, Jeong, and Ryoo, 2010; Li, Ma, and Xu, 2013). This paper fills this void by using a sudden and unexpected currency revaluation in China to examine whether and how the exchange rate affects export structure.

On July 21, 2005, the Chinese government unexpectedly revalued its currency against the U.S. dollar, which resulted in an immediate appreciation of 2.1 percent (for a detailed description on this episode and the unexpectedness, see Section 3). The sharp change in China's exchange rate provides us an opportunity to have an arguably clean identification of the effect of currency appreciation using a regression discontinuity (RD) estimation. Specifically, the exogeneity of currency appreciation makes export structure before currency appreciation

[1] In the case of China, reliable estimates show that Chinese currency was undervalued by around 40% as of 2000 (Frankel 2006) and around 25% as of 2005 (Rodrik 2010). Rodrik (2008) explains this rationale by showing the clear positive associations between undervalued currencies, large exports, and rapid growth in developing countries.

(i.e., January 2005-July 2005) a good counterfactual to the one after currency appreciation (i.e., August 2005-December 2005). Meanwhile, to purge the monthly effect (e.g., differences in U.S. demand across months), we add data of a year during which Chinese currency was fixed against the U.S. dollar, as a control group, and conduct a difference-in-differences (DD) estimation.

In our empirical investigation, we use an index developed by Hausmann, Hwang, and Rodrik (2007) which measures how relatively heavily a good is exported by developed countries. In particular, we use this index to construct an *export similarity index* that measures how similar China's exports are to developed countries (see details in Section 3). Our RD-DD estimation results show that after the currency appreciation, China's export structure to the U.S. becomes more similar to that of developed countries.[2] These results remain robust to a battery of sensitivity checks, including a difference-in-difference-in-differences (DDD) estimation, a placebo test, an examination of U.S. exports to China, and an exclusion of processing trade.

To illustrate how the exchange rate changes export structure, we present a trade model with monopolistic competition in which two sectors of differentiated goods differ mainly in their elasticities of substitution. As the Chinese currency is heavily controlled and undervalued, we take the fact of an undervalued South's currency as the key feature defining the North-South structure. As explained in Section 2.4, there is strong evidence that developed countries export relatively heavily in goods with low elasticity of substitution (high markups). Given that the North exports relatively heavily in goods with high markups, we show that if the South's currency appreciates, the South's export structure becomes closer to the North's. The intuition is that when the South's exports become more expensive due to currency appreciation, the reductions in the North's expenditure on these goods are larger in the sector with higher price elasticity. Whereas this argument based on the intensive margin with entry fixed in the short run fits our empirical results, the same result holds in the long run when free entry is allowed.

One direct implication of our empirical results is that since developed countries (or the U.S.) concentrate on and export relatively more of those goods with low elasticity of substitution, the competition in these goods from China is reduced, but *not by much*. Whereas our empirical results are necessarily short-term by the identification strategy, changes in export structure may have important long-run implications, especially with the resource reallocation and learning-by-doing effects so that Chinese producers may gradually become more

[2] We focus on China's exports to the U.S. as China's sudden exchange-rate change is against the U.S. dollar. We do not examine China's exports to the world because the weighted average of exchange rates against various countries was quite volatile in 2005, as well as in other years.

productive and provide fiercer competition in these, so to speak, high-end sectors. Another long-run implication is related to the result in Hausmann, Hwang, and Rodrik (2007) that when a country's export structure becomes similar to that of developed countries, the ensuing economic growth of the country would be higher. Similar empirical findings are uncovered by Jarreau and Poncet (2012) in the context of China. The rationale is based on a "cost discovery" story or more generally, the idea of "countries become what they produce". In sum, whereas consumers in the South obviously would benefit from the South's currency appreciation, appreciation may not be all that bad even from the viewpoint of production.

While the model displays a mechanism of resource reallocation across firms within a locality, our empirical estimates capture the whole spectrum of resource reallocation. That is, our estimates captures three margins of the changes in export structure: across cities, within city and across firms, and within firm and across products. Meanwhile, by further exploring the data, we can decompose the appreciation effect on export structure into these three margins. We find that resource reallocation within city and across firms accounts for the majority of our appreciation effect (i.e., 72.22 percent), while resource reallocation across cities as well as within firm and across products explain 16.67 percent and 11.11 percent, respectively.

The paper is organized as follows. Section 2 provides a theory of how export structure is affected by the exchange rate. Section 3 describes our data, variables, and empirical strategy, including details of the reform of China's exchange-rate regime in July 2005. Empirical results including robustness checks are reported in Section 4, and Section 5 concludes.

2 A Model of Exchange Rate and Export Structure

We extend a standard monopolistic competition model of trade *à la* Krugman (1980) and Helpman and Krugman (1985) to provide a plausible mechanism regarding how export structure is affected by the exchange rate.

2.1 Model Setup

There are two countries, North and South, with population L_n and L_s, respectively. Here, we think of China as the South, who sets up a fixed-exchange-rate regime, and therefore the exchange rate between two countries is a policy (exogenous) variable. There are three goods/industries in the economy, and the utility of a representative agent in country j follows a Cobb-Douglas form:

$$U_j = Q_{j0}^{\alpha_0} Q_{j1}^{\alpha_1} Q_{j2}^{\alpha_2},$$

where $\alpha_i \in (0,1)$, for $i \in \{0,1,2\}$, Q_{ji} is the consumption of good i in country j, and $\sum_i \alpha_i = 1$. Labor is the only production input. Good 0 is the numeraire good produced with a constant returns technology and is freely traded within and between countries. This numeraire good is not subject to currency exchange. We normalize the labor productivity of good 0 to 1, and hence wages are also normalized to 1 in both countries.

Goods 1 and 2 are both differentiated and tradeable, and the composite Q_{ji} is made by

$$Q_{ji} = \left(\int_{\Omega_{ji}} \left[q_{ji}(\omega) \right]^{\frac{\sigma_i - 1}{\sigma_i}} d\omega \right)^{\frac{\sigma_i}{\sigma_i - 1}},$$

where $q_{ji}(\omega)$ is the consumption of variety ω, and Ω_{ji} denotes the set of the varieties of good i consumed in country j. The elasticity of substitution is σ_i in industry i. We assume that $\sigma_2 < \sigma_1$, so that good 2 has a lower price elasticity than good 1. Trade in the two differentiated industries is subject to currencies and the exchange rate, i.e., people sell and buy the goods with the country's currency if the trade is within the country, and if trade is between countries, then currency exchange is needed. Barring frictions, the real exchange rate of these goods across countries is 1. However, there are numerous factors/distortions that will create a bias of the real exchange rate from 1. Especially in the fixed-exchange-rate regime, the real exchange rate may differ significantly from 1. Say, a unit of a good in the U.S. can be exchanged for $e < 1$ units of the same good in China (hence one unit of good in China can be exchanged for $e^{-1} > 1$ units in the U.S.). From here onward, we assume that the real exchange rate from a North's to a South's good is $e < 1$, which captures the fact that the South often uses the exchange rate as a policy tool to implement an export-oriented development strategy.

On top of the exchange-rate distortion, trade between countries is also subject to standard iceberg trade cost so that to deliver one unit to the other country, $\tau > 1$ units needs to be shipped. By paying an entry cost κ, each firm draws a distinct variety (and hence is a monopolist for it) and can produce the good with constant marginal cost c. Firms can price discriminate across countries. The probability that a variety will be in industry i is given by λ_i, and $\lambda_1 + \lambda_2 = 1$. Free entry determines the number of firms M_j in each country j. The number of firms in industry i in country j is therefore $M_{ji} = \lambda_i M_j$.

Note a key difference between e and τ in the model.[3] Here, an increase of the trade cost τ increases import prices in both countries and the degree of separation between the two markets, whereas an decrease in e increases the South's import prices while decreasing

[3] As will be more clear after Proposition 1, the role of trade cost τ is indispensible, because without it, i.e., $\tau = 1$, there won't an equilibrium, since all the firms will earn more profit in the South than the North, making it impossible for the free entry condition to hold in both countries.

the North's import prices. Hence, e has an asymmetric effect, whereas the effect of τ is symmetric. Having multiple sectors with different σ_i and the asymmetric effect of e considerably increases the complexity of the model, and hence for tractability and for our purpose of illustrating sectoral shifts, we opt to go with a homogeneous-firm model, instead of a heterogeneous-firm one.

2.2 Equilibrium and the Effect of the Exchange Rate

Let $p_{ji}(\omega)$ be the price of variety ω of industry i that faces the consumers in j. The Cobb-Douglas-CES structure implies that the total sales of variety ω of industry i in country j is

$$r_{ji}(\omega) \equiv p_{ji}(\omega) q_{ji}(\omega) = \alpha_i L_j \left(\frac{p_{ji}(\omega)}{P_{ji}}\right)^{1-\sigma_i},$$

where P_{ji} is the standard price index $P_{ji} = \left(\int_{\Omega_{ji}} p_{ji}(\omega)^{1-\sigma_i} d\omega\right)^{\frac{1}{1-\sigma_i}}$. Let p^I_{ni} denote the price of an imported good in the North (from a South firm).[4] A South's firm profit is

$$\begin{aligned}\pi_{si} &= (p_{si} - c) q_{si}(p_{si}) + \left(e^{-1}p^I_{ni} - \tau c\right) q_{ni}\left(p^I_{ni}\right) \\ &= (p_{si} - c)(p_{si})^{-\sigma_i} \frac{\alpha_i L_s}{P_{si}^{1-\sigma_i}} + \left(e^{-1}p^I_{ni} - \tau c\right)\left(p^I_{ni}\right)^{-\sigma_i} \frac{\alpha_i L_n}{P_{ni}^{1-\sigma_i}}.\end{aligned}$$

Equilibrium pricing follows a standard markup rule, where the markup is denoted as $\mu_i = \frac{\sigma_i}{\sigma_i - 1}$. In particular, the effective (delivered) marginal cost τc is incurred in the South, and the price in the South's viewpoint is $e^{-1}p^I_{ni} = \mu_i \tau c$. Hence, $p_{si} = \mu_i c$, $p^I_{ni} = \mu_i e \tau c$, and the profit of a South's firm is

$$\pi_{si} = \alpha_i (\mu_i - 1) \mu_i^{-\sigma_i} c^{1-\sigma_i} \left(\frac{L_s}{P_{si}^{1-\sigma_i}} + e^{-\sigma_i}\tau^{1-\sigma_i}\frac{L_n}{P_{ni}^{1-\sigma_i}}\right).$$

Similarly, for the North, we have $p_{ni}(c) = \mu_i c$, $p^I_{si}(c) = \mu_i e^{-1}\tau c$, and π_{ni} is similarly derived. The price indices are rewritten as

$$\begin{aligned}P_{si}^{1-\sigma_i} &= \lambda_i (\mu_i c)^{1-\sigma_i}\left[M_s + M_n\left(e^{-1}\tau\right)^{1-\sigma_i}\right], \\ P_{ni}^{1-\sigma_i} &= \lambda_i (\mu_i c)^{1-\sigma_i}\left[M_n + M_s (e\tau)^{1-\sigma_i}\right]\end{aligned}$$

[4] Note that p^I_{ni} is the sales of one unit of a good with the North currency (but denominated in numeraire), and these convert to more than enough South currency to buy one unit ($e^{-1} > 1$).

An entrant's expected profit in the South is

$$\begin{aligned} E\pi_s &= \lambda_1 \pi_{s1} + \lambda_2 \pi_{s2} - \kappa \\ &= \lambda_1 \alpha_1 (\mu_1 - 1) \mu_1^{-\sigma_1} c^{1-\sigma_1} \left(\frac{L_s}{P_{s1}^{1-\sigma_1}} + e^{-\sigma_1} \tau^{1-\sigma_1} \frac{L_n}{P_{n1}^{1-\sigma_1}} \right) \\ &\quad + \lambda_2 \alpha_2 (\mu_2 - 1) \mu_2^{-\sigma_2} c^{1-\sigma_2} \left(\frac{L_s}{P_{s2}^{1-\sigma_2}} + e^{-\sigma_2} \tau^{1-\sigma_2} \frac{L_n}{P_{n2}^{1-\sigma_2}} \right) - \kappa. \end{aligned}$$

Zero expected profit condition is then $E\pi_s = 0 = E\pi_n$, which entails

$$\frac{\alpha_1}{\sigma_1} \left[\frac{L_n \left(1 - e^{-\sigma_1} \tau^{1-\sigma_1}\right)}{m + (e\tau)^{1-\sigma_1}} + \frac{L_s \left(e^{\sigma_1} \tau^{1-\sigma_1} - 1\right)}{1 + m \left(e^{-1}\tau\right)^{1-\sigma_1}} \right] = \frac{\alpha_2}{\sigma_2} \left[\frac{L_n \left(e^{-\sigma_2} \tau^{1-\sigma_2} - 1\right)}{m + (e\tau)^{1-\sigma_2}} + \frac{L_s \left(1 - e^{\sigma_2} \tau^{1-\sigma_2}\right)}{1 + m \left(e^{-1}\tau\right)^{1-\sigma_2}} \right], \tag{1}$$

where $m \equiv \frac{M_n}{M_s}$ is the ratio of entry between the two countries. The equilibrium entry ratio m^* satisfies (1), and the level of M_s and M_n can be determined by $E\pi_s = 0$ (or, equivalently, $E\pi_n = 0$). In the following proposition, we show that when trade cost τ is sufficiently large, there is a unique finite equilibrium entry ratio $m^* > 0$, which implies that equilibrium entries in both countries are positive. Moreover, m^* strictly increases with an appreciation of the South's currency.

Proposition 1 *Denote $\ell = L_n/L_s$. Let τ_a is the solution of τ to the following equation.*

$$e^{\sigma} \left[\tau^{\sigma-1} \left(e^{-1}\ell\right) + \tau^{1-\sigma} \right] = e^{-1}\ell + 1,$$

and

$$\tau_b \equiv \begin{cases} \max \left\{ 1, 2^{\frac{1}{1-\sigma}} \left[e^{\sigma} \left(1 + \ell e^{-1}\right) + \sqrt{e^{2\sigma} \left(1 + \ell e^{-1}\right)^2 - 4\ell e^{-1}} \right]^{\frac{1}{\sigma-1}} \right\} & \text{if} \quad 4\ell e^{-1} \le e^{2\sigma} \left(1 + \ell e^{-1}\right)^2 \\ 1 & \text{if} \quad 4\ell e^{-1} > e^{2\sigma} \left(1 + \ell e^{-1}\right)^2 \end{cases}.$$

Let $\hat{\tau}_i = \max\{\tau_{ai}, \tau_{bi}\}$, where τ_{ai} and τ_{bi} are the values of τ_a and τ_b when $\sigma = \sigma_i$. Suppose the trade cost τ is such that $\tau > \hat{\tau} \equiv \max\{\hat{\tau}_1, \hat{\tau}_2\}$. Then, there exists a unique finite equilibrium entry ratio $m^* > 0$ (positive entries in both countries), and m^* strictly increases in e.

Proof. *See the appendix.* ■

To understand this proposition, think of the case of $\tau = 1$ and $L_n = L_s$. In this case, there is no separation between the two countries, and the two countries are symmetric, except that the South's firms enjoy an edge due to exchange-rate distortion ($e < 1$). Hence, all firms in the South enjoy larger profits than those in the North, and $m^* = 0$ in equilibrium ($M_n = 0$).

On the other hand, if $\tau \to \infty$, then the effect of $e < 1$ becomes nil and there must be positive entries in both countries. Hence, a sufficiently large τ is required to have enough separation between the two markets.[5] Since an increase in e implies that the South's firms' edge due to the exchange rate is reduced, and hence we expect less entry in the South and more in the North, leading to an increased m^*.

2.3 Export Structure and the Exchange Rate

Here, we first want to investigate the conditions under which $\frac{X_{s2}}{X_{s1}+X_{s2}} < \frac{X_{n2}}{X_{n1}+X_{n2}}$, that is, the more developed country's (North's) export in industry 2 is more than that of the less developed country (the South). This is equivalent to $\frac{X_{s2}}{X_{s1}} < \frac{X_{n2}}{X_{n1}}$. We also want to investigate whether $\frac{d}{de}\frac{X_{s2}}{X_{s1}} > 0$ and $\frac{d}{de}\frac{X_{n2}}{X_{n1}} < 0$ so that the export structure of the two countries become more similar when the South's currency appreciates. Note that export volume from the South in industry i is $X_{si} = M_{si}e^{-1}p^I_{ni}q_{ni}\left(p^I_{ni}\right)$. So,

$$\frac{X_{s2}}{X_{s1}} = \frac{\alpha_2\mu_2^{1-\sigma_2}\lambda_2}{\alpha_1\mu_1^{1-\sigma_1}\lambda_1}\frac{P_{n1}^{1-\sigma_1}}{P_{n2}^{1-\sigma_2}}\left(e\tau c\right)^{\sigma_1-\sigma_2}. \tag{2}$$

Similarly,

$$\frac{X_{n2}}{X_{n1}} = \frac{\alpha_2\mu_2^{1-\sigma_2}\lambda_2}{\alpha_1\mu_1^{1-\sigma_1}\lambda_1}\frac{P_{s1}^{1-\sigma_1}}{P_{s2}^{1-\sigma_2}}\left(e^{-1}\tau c\right)^{\sigma_1-\sigma_2}. \tag{3}$$

In the short run, M_n and M_s (and hence m) are fixed. If price indices were also fixed, then obviously $\frac{X_{s2}}{X_{s1}}$ increases with e, as $\sigma_1 > \sigma_2$. This is basically an intensive margin effect that when the South's goods become more expensive, the quantities demanded and sales in the North for these goods are reduced, but the effect is stronger for good 1 than good 2, because good 1 has a larger price elasticity. Proposition 2 shows that this effect at intensive margin is robust when taking into account the adjustment of price indices and free entry in the long run. It also provides two sufficient conditions under which $\frac{X_{n2}}{X_{n1}} > \frac{X_{s2}}{X_{s1}}$ holds, and hence the export structures in the two countries become more similar with a currency appreciation.

Proposition 2 *Suppose that $\sigma_2 < \sigma_1$, $e \leq 1$, and $\tau > \hat{\tau}$ so that there is a unique equilibrium with positive entries in both countries (Proposition 1). Then,*

1. *Both in the short run when entries M_n and M_s are fixed and in the long run when entries are determined by free entry, $\frac{d}{de}\left(\frac{X_{s2}}{X_{s1}}\right) > 0$ and $\frac{d}{de}\left(\frac{X_{n2}}{X_{n1}}\right) < 0$. That is, the*

[5] The condition also involves the ratio of country size $\ell = L_n/L_s$ because it is possible that given an e and τ, m^* becomes infinity ($M_s = 0$) when ℓ is very large so that the advantage of the South due to e is reversed due to the large population in the North and the home market effect. Nevertheless, regardless of the value of e and ℓ, as long as τ is sufficiently large, positive entries in both countries are guaranteed.

South's export in industry 2 relative to that in industry 1 increases when currency in the South appreciates.

2. *If one of the following conditions holds, then in equilibrium* $\frac{X_{n2}}{X_{n1}} > \frac{X_{s2}}{X_{s1}}$*, and the export structure in the South becomes closer to that in the North when the South's currency appreciates.*

   (a) *The two countries have the same population size, i.e.,* $L_n = L_s$*, and the real exchange rate is such that* $e < 1$*.*

   (b) *The South has a larger population, i.e.,* $L_s > L_n$*, and the real exchange rate is* $e = 1$*.*

Proof. *See the Appendix.* ■

Given the empirical finding in the next subsection that developed countries export relatively more goods with low elasticity of substitution, the more important message of Proposition 2 is Point 1, because given this fact, currency appreciation leads to a more similar export structure. Point 2 shows some conditions under which the above-mentioned fact can be generated from the model. The intuition behind Point 2(a) is that $e < 1$ creates an advantage for producers in the South, and this advantage is more pronounced for industry 1 because the price elasticity is larger. Although we do not model how the wages are determined, it is worthwhile noting that the price advantage of the South reflected by $e < 1$ is similar to the effect when the South's wages are lower than the North's, which is fitting to the U.S.-China scenario. Point 2(b) holds mainly because the home market effect is more pronounced for the good with larger price elasticity. It is easy to verify numerically that the same result holds in the convex combination of these two conditions, i.e., the case of $L_s \geq L_n$ and $e \leq 1$.[6]

2.4 Developed Countries Export Relatively More Goods with Low Elasticity of Substitution

Our theoretical analysis shows that when the South appreciates its currency, its exports become more skewed towards the industry with lower elasticity of substitution, and the

[6] It is also possible to explain the difference in export structure via technological differences. One can think of this as $\lambda_n = \frac{\lambda_{n2}}{\lambda_{n1}} > \frac{\lambda_{s2}}{\lambda_{s1}} = \lambda_s$, i.e., the North firm is more able and hence more likely to produce goods in industry 2, and there may be some natural association between technology and markups. When $\lambda_n > \lambda_s$, it is almost trivial that $\frac{X_{n2}}{X_{n1}} > \frac{X_{s2}}{X_{s1}}$, but since the effect of the exchange rate is mainly a price one, the result that the South's export structure moving closer to the North's should remain similar, at least in the short run.

export structure becomes more similar to developed countries. To connect our theoretical and empirical analyses, it is important to examine whether developed countries export relatively more goods with low elasticity of substitution. To this end, we examine the correlation between two relevant measures: an index developed by Hausmann, Hwang, and Rodrik (2007) called $PRODY$ that measures how heavily a good is exported by developed countries (see Section 3.1 for more details of this measurement) and a good's estimated elasticity of substitution by Broda and Weinstein (2006). Figure 1 shows a nonparametric relationship between the elasticity of substitution that we obtain from Broda and Weinstein (2006) and the export similarity index used in our empirical analysis. Clearly, there is a fairly strong negative correlation between these two.[7]

[Insert Figure 1 Here]

3 Estimation Strategy

3.1 Data and Variables

Our study draws on data from two sources. The first one is the China Customs data from 2000 (the earliest year of the data) to 2006 (the most recent year the authors have access to). The data set is at firm-product-destination-month level, covering a universe of all monthly import and export transactions by Chinese exporters and importers. Specifically, it includes product information (HS 8-digit-level classification), trade value, identity of Chinese importers and exporters, and import and export destinations.

The second data source is the International Financial Statistics (IFS) maintained by the International Monetary Fund (IMF), from which we obtain the monthly bilateral nominal exchange rates between China and the U.S. for the 2000-2006 period.

To characterize China's export structure to the U.S., we first construct an index that differentiates each export product. Specifically, we use the measurement developed by Hausmann, Hwang, and Rodrik (2007), i.e.,

$$PRODY_i = \frac{1}{N_i} \sum_j \frac{X_{ij}}{X_j} GDPPC_j,$$

[7]Both $PRODY$ and elasticity of substitution are at HS 3-digit level. The $PRODY$ at HS 3-digit level is the trade-weighted average of $PRODY$ at HS 6-digit level. The HS 3-digit elasticity of substitution is estimated based on U.S. trade data, and downloaded from http://www.columbia.edu/~dew35/TradeElasticities/TradeElasticities.html, see Broda, Greenfield, and Weinstein (2006). Moreover, the fitted curve excludes the top 5% sigma, i.e. 7 sigmas with a value greater than 10.

where X_{ij} is the export value of good i by country j; X_j is country j's total export value; $GDPPC_j$ is the real per capita GDP of country j; and N_i is a normalization term used to have the coefficients summed up to 1. The intuition behind this measurement is that a good with a higher value of $PRODY_i$ is exported more often by developed countries.

In the empirical analysis, we use COMTRADE data to compute $PRODY_i$ for each HS-6 product in 2000 (the initial year of our data),[8] and then use the China Customs data to obtain a measure of overall export structure Y_{cm} (denoted as *Export Similarity Index*) for each city c in each month m during the period of 2000-2006, i.e.,

$$Y_{cm} = \sum_i PRODY_i \frac{X_{icm}}{X_{cm}},$$

where X_{icm} is the export value of good i to the U.S. by city c at month m; and X_{cm} is the total export value to the U.S. by city c at month m.

By fixing $PRODY_i$ in the initial year, we attribute the change in the city-level measurement Y_{cm} to the change in the allocation of exports across different product categories (i.e., changes in $\frac{X_{icm}}{X_{cm}}$). In other words, this approach allows us to capture the change in the export structure, specifically, the similarity of export structure between China and developed countries.

To get a sense of $PRODY_i$, we list in Table 1 the five HS-6 product categories with the lowest values of $PRODY_i$ and the five HS-6 product categories with the highest values. Consistent with our intuition, goods with the lowest values of $PRODY_i$ are largely agricultural products, such as "Vegetable products nes", "Sisal and Agave (raw)", and "Cloves (whole fruit, cloves, and stems)". In the meantime, goods with the highest values of $PRODY_i$ are mostly metallic goods, such as "Cermets and articles thereof (waste or scrap)", "Sections H iron or non-alloy steel (nfw hot-roll/drawn/extruded $>$ 80m)", "Sheet piling of iron or steel", and "Flat-rolled iron or non-alloy steel (coated with aluminium, width $>$ 600mm)".

[Insert Table 1 Here]

An alternative measurement of export structure in the literature is the one proposed by Schott (2008), based on Finger and Kreinin (1979)'s export similarity index (ESI). Specifically, it calculates the similarity between China's export structure and those of some developed countries (such as OECD countries), and the higher values mean more similarity. To calculate this measure, we need export data from other developed countries, which are available to us at the yearly frequency (i.e., via UN's COMTRADE data). However, our iden-

[8] Results remain robust when we measure $PRODY_i$ in other years before currency appreciation.

tification requires a measure at the monthly level. Nonetheless, we find that the yearly correlation between the export similarity indices developed by Hausmann, Hwang, and Rodrik (2007) and by Schott (2008) is 0.859, suggesting a robustness of using the former measure.

3.2 China's Exchange-Rate Reform in July 2005

Timeline. Since the financial crackdown in 1994, China had adopted a decade-old fixed-exchange-rate regime, in which her currency (*Renminbi*) was pegged to the U.S. dollar at an exchange rate of 8.28. At 19:00 on July 21, 2005 (Beijing time), the People's Bank of China (PBOC, the central bank of China) suddenly announced a revaluation of Chinese currency against the U.S. dollar, which was set to be traded at an exchange rate of 8.11 immediately or about 2.1% appreciation. After that, Renminbi was allowed to trade flexibly with a *reference basket* of currencies with the target for Renminbi set by the PBOC every day. Figure 2 displays the monthly exchange rate between Chinese currency and the U.S. dollar during 2000-2006. It is clear that there was a sudden appreciation of Chinese currency against the U.S. dollar in July 2005, followed by steady and continuous appreciation. By the end of 2006, Renminbi had accumulated appreciation of about 5.5% against the U.S. dollar.

[Insert Figure 2 Here]

Exogeneity. The crucial part of our identification is to use the currency appreciation in China in mid-July 2005 as an exogenous shock; hence, it is important to establish the exogeneity of China's currency appreciation upfront. Note that the revaluation of Chinese currency in mid-July 2005 happened during a period of enormous international pressures on the Chinese government to appreciate her undervalued currency. However, the exact timing of the change has been widely considered as "unexpected". There is much anecdotal evidence as well as academic studies supporting this statement.

First, foreign pressures on Renminbi appreciation had existed for more than two years, and the Chinese government regarded the exchange-rate policy as a matter of China's sovereignty and rejected any political pressures on this issue. For example, on June 26, 2005 (about a month before the currency revaluation), China's Premier Wen Jiabao said at the Sixth Asia-Europe Finance Ministers Meeting in Tianjin that China would "independently determine the modality, timing, and content of reforms" and rejected foreign pressures for an immediate shift in the nation's currency regime.[9] One day later, Zhou Xiaochuan, the governor of the PBOC, said that it was too soon to drop the decade-old fixed-exchange-rate

[9] See "Chinese Premier Warns against Yuan Reform Haste" by the *Wall Street Journal* (http://online.wsj.com/news/articles/SB111975074805069620) Access date: October 9, 2012.

regime and that he had no plans to discuss the currency issue at the weekend meeting of the global central bankers in Basel, Switzerland.[10] On July 19, two days before the reform, the PBOC still insisted that it would continue to keep the exchange rate stable and at a reasonable and balanced level in the second half of the year.[11]

Second, as elaborated by Yuan (2012), opinions were divergent among Chinese policy makers regarding whether Chinese currency should be appreciated during that period. Specifically, the Ministry of Commerce opposed the currency appreciation (so as to maintain the competitiveness of China's export sector), while the other three central governmental agencies: the PBOC, the National Development and Reform Commission, and the Ministry of Finance, all proposed to appreciate Chinese currency.

Third, after the reform, both domestic and international medias responded to the revaluation with complete surprise. For example, *CNN* reported the episode as "The surprise move by China...".[12] In the *Financial Times*' famous Lex Column on July 22, 2005 it was reported that "China likes to do things [in] its own way. After resisting pressure to revalue the Renminbi for so long, Beijing has moved sooner than even John Snow, the U.S. Treasury secretary, expected".[13] On July 22, 2005 the *BBC Worldwide Monitoring* said that "The People's Bank of China [PBOC] unexpectedly announced last night that the RMB [Renminbi] will appreciate by 2 per cent and will no longer be pegged to the U.S. dollar".[14]

Fourth, academic studies also imply that the change in the exchange-rate policy in July 2005 was unexpected. For example, Eichengreen and Tong (2011) study the impact of the Renminbi revaluation announcement on firm value in the 2005-2010 period. Using the change of stock prices before and after the announcement of the revaluation for 6,050 firms in 44 countries, they find that Renminbi appreciation significantly increases firm values for those exporting to China while significantly decreases firm values for those competing with Chinese firms in their home markets, suggesting the exogeneity of the policy change.

[10] See "China's Zhou Says 'Time Is Not Ripe' to Drop Yuan Peg to Dollar" by *Bloomberg* (http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aVAXsXEqKZcY&refer=home) Access date: October 9, 2012.

[11] See "China to Keep RMB Exchange Rate Basically Stable: Central Bank" by *People's Daily* (http://english.peopledaily.com.cn/200507/20/eng20050720_197148.html) Access date: October 9, 2012.

[12] See "World Events Rattle Futures" by *CNN* (http://money.cnn.com/2005/07/21/markets/stockswatch/index.htm) Access date: October 9, 2012.

[13] See "Renminimal THE LEX COLUMN" by *Financial Times* (http://www.lexisnexis.com.libproxy1.nus.edu.sg/ap/academic/) Access date: October 9, 2012.

[14] See "Hong Kong Daily Says Exchange Rate Reform Advantageous Overall" by *BBC Worldwide Monitoring* (http://www.lexisnexis.com.libproxy1.nus.edu.sg/ap/academic/) Access date: October 9, 2012.

3.3 Estimation Framework

To identify the effect of currency appreciation on export structure, we exploit the sudden and unexpected currency revaluation by the Chinese government on July 21, 2005. Specifically, the unexpectedness in the currency revaluation makes the export structure before the revaluation a good counterfactual to the one after the revaluation. In other words, the exogenous currency appreciation in China offers us a regression discontinuity (RD) setting, which is arguably closest in the observational data analysis to the experimental design (e.g., Lee and Lemieux, 2010).

Hahn, Todd, and Van der Klaauw (2001) show that the RD estimator (β) can be identified as

$$\beta = \lim_{m \downarrow m_0} E\left[y_{cm}|m\right] - \lim_{m \uparrow m_0} E\left[y_{cm}|m\right],$$

where $y_{cm} = \ln Y_{cm}$; and $m_0 = July$ 2005 is the cutoff month of the currency revaluation in China. Empirically, we focus on the data of the year 2005, use the local linear regression (as suggested by Hahn, Todd, and Van der Klaauw, 2001) with the triangle kernel function and the optimal bandwidth selected based on the procedure by Imbens and Kalyanaraman (2012), and obtain standard errors through the bootstrapping method.

However, there are two potential concerns about the above RD estimator. First, it may also capture the seasonal effect. For example, it could be that demand in the U.S. is different between July and August, causing the composition of Chinese exports to the U.S. to be different in these two months. In other words, $\hat{\beta}_{RD}$ becomes $\beta + \theta_{month}$, where θ_{month} is the monthly effect of exports. Second, the RD estimator essentially compares China's export structure to the U.S. in August 2005 with that in July 2005. Hence, one may be concerned whether the appreciation effect can be realized within such a short time window, especially given some pre-existing procurement contracts and the complexity of production.

To address these concerns, we include data of a year during which Chinese currency was fixed against the U.S. dollar, as a control group. Specifically, we choose the year 2003 as the month of Chinese New Year was the same for 2003 and 2005 (i.e., February), but different between 2004 and 2005 (i.e., January in 2004). Assuming the monthly effect is the same for these two years, we use a DD analysis to isolate the currency appreciation effect from the monthly effect, i.e.,

$$y_{cmt} = \alpha_t + \beta \cdot Aug_m \times Y2005_t + \psi_m + \varepsilon_{cmt}, \tag{4}$$

where $t \in \{2003, 2005\}$ represents year; α_t is the year fixed effect; $Aug_i = I\left[m \geq m_0\right]$ is an indicator of post-appreciation month;[15] $Y2005_t = I[t = 2005]$ is an indicator of the year 2005; and ψ_m captures the monthly effect. The standard errors are clustered at the month level, following Bertrand, Duflo, and Mullainathan (2004).

In addition to purging the monthly effect, the DD estimator, by comparing the five-month average export structure in the post-appreciation period with the seven-months average in the pre-appreciation period, reasonably captures the short-term effect of currency appreciation on export structure.

Note that Equation (4) uses an unbalanced city-level sample without inclusion of city fixed effects. Hence, we are estimating the overall effect of currency appreciation on export structure. Later, we will experiment with the regression with the inclusion of city fixed effects (which captures the within-city and across-firms effect of currency appreciation) and the regression using firm-level data with the inclusion of firm fixed effects (which captures the within-firm and across-products effect of currency appreciation).

4 Empirical Findings

4.1 Main Results

Table 2 reports our estimates of the currency-appreciation effect on the structure of Chinese exports to the U.S. Column 1 shows the RD estimate using data of the year 2005. It is found that currency appreciation has a negligible effect on export structure: the effect is -0.2% and statistically insignificant.

[Insert Table 2 Here]

However, such estimates may be biased due to some seasonal effects, e.g., U.S. demand difference between July and August. Column 2 presents the DD estimate by using data of the year 2003 as a control group. The DD estimate becomes positive and statistically significant, implying that currency appreciation makes the structure of Chinese exports to the U.S. more similar to those by developed countries.

Figure 3 presents graphically the results corresponding to Table 2: the dots and crosses represent the mean value of the similarity of Chinese export structure with developed countries' (in logarithm) for each month in 2003 and 2005, respectively; whereas the fitted curves are calculated using local linear regression with triangle kernel function. Clearly, the export similarity value dropped significantly from July 2003 to August 2003, suggesting a strong

[15] Empirically, we round m_0 to August as we only observe monthly trade data. Nonetheless, defining that the month of July has a value of 1/3 produces similar estimates (results available upon request).

monthly effect. Differencing out such monthly effects, there was a sizable increase in the similarity value between July 2005 and August 2005, consistent with our estimates in Table 2. Meanwhile, export similarity values from January to June in 2003 and 2005 followed quite parallel trends, lending support to the argument that currency revaluation in July 2005 was largely exogenous and data in 2003 constructs a good comparison group for data in 2005.

[Insert Figure 3 Here]

Note that our estimates of the appreciation effect on export structure could be underestimated due to at least two reasons. Firstly, despite the fact that the exact timing of currency revaluation (i.e., July 2005) was completely unexpected, there had been some expectation that the Chinese government might revalue her currency since mid-2004. Such an expectation may make some producers change their behavior (like product upgrading decisions) earlier than the occurence of currency appreciation, causing an underestimation of our effect of interest. Secondly, our DD estimator captures largely a short-term effect of currency appreciation. In the long run, producers can upgrade their technologies, acquire advanced management practices, and recruit intelligent employees, all of which make our estimate underestimated.

4.2 Robustness Checks

In this subsection, we present a battery of robustness checks on our aforementioned estimation results in Table 3.

Alternative way of controlling for the monthly effect. While the inclusion of the year 2003 data helps us control for the monthly effect arising from the U.S. market situation, one may be concerned that the economic environment in China changed from July 2005 to August 2005, which spuriously generates the positive relationship between currency appreciation and change in the export structure.[16] As a check on such concerns, we look at the structure of Chinese exports to Nigeria, a country whose currency remained stable against Chinese currency in 2003 and 2005 especially between July and August (see Appendix Figure 1 for details). Column 1 of Table 3 reports a DD estimate of equation (4) using Chinese export data to Nigeria. It is found that the estimated coefficient is highly insignificant and the magnitude is close to zero, indicating no significant changes in the Chinese market situation at the time of currency revaluation.

[16] Note that tariff reduction in China happened in the beginning instead of in the middle of the year; as a result, tariff reduction shall not contaminate our estimates.

[Insert Table 3 Here]

DDD estimation. In Column 2 of Table 3, we combine Chinese export data to the U.S. in 2003 and 2005 with Chinese export data to Nigeria in 2003 and 2005, and conduct a difference-in-difference-in-differences (DDD) estimation, which enables us to control for the monthly effect arising from changes in both Chinese and foreign markets. Clearly, we find a estimate of 0.017, similar to that in Column 2 of Table 2 (i.e., 0.018), suggesting the robustness of our previous findings.

Placebo test – pre-revaluation period. Given that Chinese currency was pegged to the U.S. dollar in 2002 and 2003, there was no break in the exchange rate between July and August in these years. Meanwhile, tariff reduction in China happened in the beginning instead of in the middle of the year; as a result, tariff reduction shall not contaminate our estimation. Hence, a DD estimation using data of the year 2002 and the year 2003 shall generate zero appreciation effect. Indeed, we find, in Column 3 of Table 3, the DD estimator is highly insignificant and its magnitude is close to zero.

U.S. exports to China. As the appreciation of Chinese currency against the U.S. dollar means the depreciation of the latter against the former, we shall expect a reversed sign using the U.S.'s export structure to China as the outcome variable. Column 4 of Table 3 reports the DD estimate using Chinese imports from the U.S. in 2003 and 2005. Consistently, we find a negative and statistically significant estimated coefficient, implying that the appreciation of Chinese currency against the U.S. dollar makes U.S. exports to China more similar to those exported by developing countries.

Exclusion of processing trade. A unique feature of the Chinese trade system is that China allows some firms to import intermediate inputs free of tariffs but to export all their output, the so-called processing trade regime (e.g., Yu, 2014). One may be concerned that our results are driven by this special trade regime, hence compromising the external validity of our findings. To address such concern, we, in Column 5 of Table 3, focus on the analysis of ordinary exports. Evidently, we still find a positive and statistically significant effect of appreciation on export similarity towards developed countries' export structures. Meanwhile, despite a slight drop, the estimated magnitude (0.014) is statistically indifferent from the estimate in our benchmark model (i.e., 0.018 in Column 2 of Table 2).

4.3 Decomposition of the Effect of Currency Appreciation

In this section, we use our data to decompose the resource reallocation at different margins (i.e., across cities, across firms within a city, and across products within a firm). Our previous analyses use an unbalanced city/firm sample; hence, the DD estimate in Column 2 of Table 2 is the overall effect of currency appreciation, including resource reallocation across cities, within city and across firms, and within firm and across products. To decompose the currency appreciation effect on export structure into these three different margins, we conduct two more regressions in Table 4. Specifically, in Column 1, we include city dummies and in Column 2, we use a sample of surviving multi-product exporters (i.e., those that existed before and after currency revaluation) with an inclusion of firm dummies.[17]

Both coefficients are found to be positive and statistically significant, consistent with our previous findings. Meanwhile, as the analysis with the inclusion of city dummies essentially calculates the effect of appreciation on the within-city change in export structure, the comparison of the coefficient with the one without city dummies (i.e., the one in Column 2 of Table 2) can give us the degree of across-cities resource reallocation effect of currency appreciation. Similarly, the comparison of coefficients between Column 1 and Column 2 can allow us to gauge the magnitude of within-city, across-firms resource reallocation effect of currency appreciation. Finally, the coefficient in Column 2 produces the within-firm, across-products resource reallocation effect of currency appreciation.

It is found that the majority of the currency appreciation effect on export structure comes from the resource reallocation within city and across firms, i.e., accounting for $(0.015 - 0.002)/0.018 = 72.22\%$. Meanwhile, the across-cities resource reallocation accounts for around $(0.018 - 0.015)/0.018 = 16.67\%$, while the within-firm, across-products resource reallocation accounts for 11.11%.

5 Conclusion

This paper investigates whether and how a country's export structure responds to its exchange-rate movement. Using China's sudden and unexpected revaluation of its currency against the U.S. dollar, we identify the effect of exchange rates on export structure through the combined regression discontinuity and difference-in-differences framework. We find that after its currency appreciation, China's exports to the U.S. became more similar to those by developed countries. Meanwhile, we find that the majority of the currency-appreciation effect on export structure comes from the resource reallocation within city and across firms.

The major implication of our empirical findings is that the depreciation strategy used by developed countries may reduce the import competition from developing countries, but not by much. Despite of the fact that our empirical results are necessarily short-term by the iden-

[17]Note that we put the change in export revenues for single-product firms in the category of the resource reallocation within city and across firms.

tification strategy, changes in export structure may have important long-run implications, especially with the resource reallocation and learning-by-doing effects.

References

[1] Amiti, Mary, Oleg Itskhoki, and Jozef Konings. 2014. "Importers, Exporters, and Exchange Rate Disconnect," *American Economic Review* 104, 1942–1978.

[2] Bacchetta, Philippe, and Eric van Wincoop. 2013. "On the Unstable Relationship between Exchange Rates and Macroeconomic Fundamentals," *Journal of International Economics* 91, 18–26.

[3] Berman, Nicolas, Philippe Martin, and Thierry Mayer. 2012. "How Do Different Exporters React to Exchange Rate Changes?," *Quarterly Journal of Economics* 127, 437–492.

[4] Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan. 2004. "How Much Should We Trust Differences-in-Differences Estimates?," *Quarterly Journal of Economics* 119, 249–275.

[5] Broda, Christian, Joshua Greenfield, and David Weinstein. 2006. "From Groundnuts to Globalization: A Structural Estimate of Trade and Growth," NBER Working Paper No. 12512.

[6] Broda, Christian, and David Weinstein. 2006. "Globalization and the Gains from Variety," *Quarterly Journal of Economics* 121, 541–585.

[7] Chatterjee, Arpita, Rafael Dix-Carneiro, and Jade Vichyanond. 2013. "Multi-Product Firms and Exchange Rate Fluctuations," *American Economic Journal: Economic Policy* 5, 77-101.

[8] Dekle, Robert, Hyeok Jeong, and Heajin Ryoo. 2010. "A Re-Examination of the Exchange Rate Disconnect Puzzle: Evidence from Firm Level Data," Working Paper, University of Southern California.

[9] Eichengreen, Barry, and Hui Tong. 2011. "The External Impact of China's Exchange Rate Policy: Evidence from Firm Level Data," NBER Working Paper No.17593.

[10] Finger, Joseph M., and Mordechai E. Kreinin. 1979. "A Measure of 'Export Similarity' and Its Possible Uses," *Economic Journal* 89, 905–912.

[11] Frankel, Jeffrey. 2006. "On the Yuan: The Choice between Adjustment under a Fixed Exchange Rate and Adjustment under a Flexible Rate," *CESifo Economic Studies* 52, 246–275.

[12] Hahn, Jinyong, Petra Todd, and Wilbert Van Der Klaauw. 2001. "Identification and Estimation of Treatment Effects with a Regression-discontinuity Design," *Econometrica* 69, 201–209.

[13] Hausmann, Ricardo, Jason Hwang, and Dani Rodrik. 2007. "What You Export Matters," *Journal of Economic Growth* 12, 1–25.

[14] Helpman, E., and P. Krugman. 1985. *Market Structure and International Trade.* MIT Press.

[15] Imbens, Guido, and Karthik Kalyanaraman. 2012. "Optimal Bandwidth Choice for the Regression Discontinuity Estimator," *The Review of Economic Studies* 79, 933–959.

[16] Jarreau, Joachim, and Sandra Poncet. 2012. "Export Sophistication and Economic Growth: Evidence from China," *Journal of Development Ecnomics* 97, 281–292.

[17] Krugman, Paul R. 1980. "Scale Economies, Product Differentiation, and the Pattern of Trade," *American Economic Review* 70, 950–959.

[18] Lee, David S., and Thomas Lemieux. 2010. "Regression Discontinuity Designs in Economics," *Journal of Economic Literature* 48, 281–355.

[19] Li, Hongbin, Hong Ma, and Yuan Xu. 2013. "How Do Exchange Rate Movements Affect Chinese Exports? A Firm-level Investigation," Working Paper.

[20] Rodrik, Dani. 2008. "The Real Exchange Rate and Economic Growth," *Brookings Papers on Economic Activity*, 39(2), 365–439.

[21] Rodrik, Dani. 2010. "Making Room for China in the World Economy," *American Economic Review: Papers & Proceedings.*

[22] Schott, Peter K. 2008. "The Relative Sophistication of Chinese Exports," *Economic Policy* 53, 5–49.

[23] Yu, Miaojie. 2014. "Processing Trade, Tariff Reductions, and Firm Productivity: Evidence from Chinese Firms," the *Economic Journal*, forthcoming.

[24] Yuan, Wen Jin. 2012. "China's Export Lobbying Groups and the Politics of the Renminbi," A Freeman Briefing Report.

Appendix

Proof of Proposition 1

Using (1), we can define the equilibrium entry ratio m^* to be the solution to $F(m, e, \sigma_1, \sigma_2, \alpha_1, \alpha_2) = 0$, where

$$\begin{aligned} F(m, e, \sigma_1, \sigma_2, \alpha_1, \alpha_2) \equiv\ & \frac{\alpha_1}{\sigma_1}\left[\frac{L_n\left(1-e^{-\sigma_1}\tau^{1-\sigma_1}\right)}{m+(e\tau)^{1-\sigma_1}}+\frac{L_s\left(e^{\sigma_1}\tau^{1-\sigma_1}-1\right)}{1+m\left(e^{-1}\tau\right)^{1-\sigma_1}}\right] \\ & +\frac{\alpha_2}{\sigma_2}\left[\frac{L_n\left(1-e^{-\sigma_2}\tau^{1-\sigma_2}\right)}{m+(e\tau)^{1-\sigma_2}}+\frac{L_s\left(e^{\sigma_2}\tau^{1-\sigma_2}-1\right)}{1+m\left(e^{-1}\tau\right)^{1-\sigma_2}}\right] \\ \equiv\ & H(m, e, \sigma_1, \alpha_1) + H(m, e, \sigma_2, \alpha_2), \end{aligned}$$

where

$$H(m, e, \sigma, \alpha) = \frac{\alpha}{\sigma}\left[\frac{L_n\left(1-e^{-\sigma}\tau^{1-\sigma}\right)}{m+(e\tau)^{1-\sigma}}+\frac{L_s\left(e^{\sigma}\tau^{1-\sigma}-1\right)}{1+m\left(e^{-1}\tau\right)^{1-\sigma}}\right]. \tag{5}$$

Note that $H(0, e, \sigma, \alpha) > 0$ if and only if

$$e^{\sigma-1}\ell\tau^{2\sigma-2} - \left(e^{-1}\ell+1\right)\tau^{\sigma-1} + e^{\sigma} > 0. \tag{6}$$

Let $x = \tau^{\sigma-1}$, and $\Gamma_a(x) \equiv e^{\sigma-1}\ell x^2 - \left(e^{-1}\ell+1\right)x + e^{\sigma}$. Hence, (6) holds if and only if $\Gamma_a(x) > 0$. $\Gamma_a(x)$ is a parabola opening upward with $\Gamma_a(1) = -e^{-1}\ell + e^{\sigma} - 1 < 0$. Hence, there are two positive roots to $\Gamma_a(x) = 0$, and one is less than 1 and one is greater than 1. Since $\tau > 1$, there is only one τ satisfying $e^{\sigma}\left[\tau^{\sigma-1}\left(e^{-1}\ell\right)+\tau^{1-\sigma}\right] = e^{-1}\ell + 1$. Denote this value of τ as τ_a. So, $H(0, e, \sigma, \alpha) > 0$ holds if and only if $\tau > \tau_a$.

We now show that there exists a unique positive number $\hat{m}$ defined as the solution to $\frac{1+m\left(e^{-1}\tau\right)^{1-\sigma}}{m+(e\tau)^{1-\sigma}} = \frac{1-e^{\sigma}\tau^{1-\sigma}}{1-e^{-\sigma}\tau^{1-\sigma}}\frac{L_s}{L_n}$ such that $H > 0$ for $m < \hat{m}$, and $H < 0$ for $m > \hat{m}$. Observe from (5) that $H > 0$ if and only if

$$\frac{1+m\left(e^{-1}\tau\right)^{1-\sigma}}{m+(e\tau)^{1-\sigma}} > \frac{1-e^{\sigma}\tau^{1-\sigma}}{1-e^{-\sigma}\tau^{1-\sigma}}\frac{L_s}{L_n} \equiv G, \tag{7}$$

the right-hand side of which is positive because $e^{\sigma}\tau^{1-\sigma} < e^{-\sigma}\tau^{1-\sigma} < 1$. The second inequality holds because $\tau > \tau_a$ implies that $\tau > e^{-\frac{\sigma}{\sigma-1}}$, because $H(0, e, \sigma, \alpha) < 0$ when $\tau = e^{-\frac{\sigma}{\sigma-1}}$. The left-hand side of (7) strictly decreases in m from $e^{\sigma-1}\tau^{\sigma-1}$ at $m = 0$ to $e^{\sigma-1}\tau^{1-\sigma}$ when $m \to \infty$. If $G \geq e^{\sigma-1}\tau^{\sigma-1}$, then $H \leq 0$ for all $m \geq 0$, which contradicts that $H > 0$ at $m = 0$. So, $\tau > \tau_a$ guarantees that $G < e^{\sigma-1}\tau^{\sigma-1}$. If $G \leq e^{\sigma-1}\tau^{1-\sigma}$, then $H > 0$ for all $m \geq 0$, and we also have $F > 0$ for all $m \geq 0$. In this case, equilibrium is such that $M_s = 0$ so that all firms are located in the North. To rule out this scenario, we must also impose that $G > e^{\sigma-1}\tau^{1-\sigma}$, which is equivalent to

$$\tau^{2\sigma-2} - \left(e^{\sigma} + \ell e^{\sigma-1}\right)\tau^{\sigma-1} + \ell e^{-1} > 0.$$

Again, let $x = \tau^{\sigma-1}$ and $\Gamma_b(x) \equiv x^2 - \left(e^{\sigma} + \ell e^{\sigma-1}\right)x + \ell e^{-1}$. $\Gamma_b(x)$ is a parabola opening upward with its minimum at $\left(e^{\sigma} + \ell e^{\sigma-1}\right)/2$.

$$\Gamma_b\left(\frac{e^{\sigma} + \ell e^{\sigma-1}}{2}\right) = \ell e^{-1} - \frac{\left(e^{\sigma} + \ell e^{\sigma-1}\right)^2}{4}.$$

Note that $\Gamma_b(1) = (1 - e^{\sigma})\left(1 + \ell e^{-1}\right) > 0$. We distinguish the following cases. If $\frac{e^{\sigma}+\ell e^{\sigma-1}}{2} \leq 1$, then $\tau \geq 1$ is at the strictly increasing portion of the parabola. Since $\Gamma_b(1) > 0$, $\Gamma_b(x) > 0$ for all $\tau > 1$. So, we don't need any extra restriction in this case. If $\frac{e^{\sigma}+\ell e^{\sigma-1}}{2} > 1$ and $\Gamma_b\left(\frac{e^{\sigma}+\ell e^{\sigma-1}}{2}\right) > 0$, then $\Gamma_b(x) > 0$ for all $\tau > 1$. But if $\frac{e^{\sigma}+\ell e^{\sigma-1}}{2} > 1$ and $\Gamma_b\left(\frac{e^{\sigma}+\ell e^{\sigma-1}}{2}\right) \leq 0$, then $\Gamma_b(x) > 0$ for all $\tau > 2^{-\frac{1}{\sigma-1}}\left[e^{\sigma} + \ell e^{\sigma-1} + \sqrt{\left(e^{\sigma} + \ell e^{\sigma-1}\right)^2 - 4\ell e^{-1}}\right]^{\frac{1}{\sigma-1}}$. In sum, we can define

$$\tau_b = \begin{cases} \max\left\{1, 2^{-\frac{1}{\sigma-1}}\left[e^{\sigma} + \ell e^{\sigma-1} + \sqrt{\left(e^{\sigma} + \ell e^{\sigma-1}\right)^2 - 4\ell e^{-1}}\right]^{\frac{1}{\sigma-1}}\right\} & \text{if} \quad 4\ell e^{-1} \leq \left(e^{\sigma} + \ell e^{\sigma-1}\right)^2 \\ 1 & \text{if} \quad 4\ell e^{-1} > \left(e^{\sigma} + \ell e^{\sigma-1}\right)^2 \end{cases}.$$

Thus, $G > e^{\sigma-1}\tau^{1-\sigma}$ for all $\tau > \tau_b$. Let $\hat{\tau}_i = \max\{\tau_{ai}, \tau_{bi}\}$, where τ_{ai} and τ_{bi} are the values of τ_a and τ_b when $\sigma = \sigma_i$. Also let $\hat{\tau} = \max\{\hat{\tau}_1, \hat{\tau}_2\}$. Hence, when $\tau > \hat{\tau}$,

$$e^{\sigma_i-1}\tau^{\sigma_i-1} > G_i > e^{\sigma_i-1}\tau^{1-\sigma_i}, \tag{8}$$

and a finite $\hat{m}_i > 0$ is the unique solution to $\frac{1+m_i\left(e^{-1}\tau\right)^{1-\sigma_i}}{m_i+(e\tau)^{1-\sigma_i}} = G_i$. Then, $H_i \equiv H(m, e, \sigma_i, \alpha_i) > 0$ for $m < \hat{m}_i$, and $H_i < 0$ for $m > \hat{m}_i$.

Now, denote $\hat{m}_{\max} = \max\{\hat{m}_1, \hat{m}_2\}$ and $\hat{m}_{\min} = \min\{\hat{m}_1, \hat{m}_2\}$. Since $F = H_1 + H_2$, $F > 0$ for $m \in [0, \hat{m}_{\min}]$, and $F > 0$ for $m \in [\hat{m}_{\max}, \infty)$. By continuity, any equilibrium m^* such that $F(m^*, ...) = 0$ must be in $(\hat{m}_{\min}, \hat{m}_{\max})$. Moreover, if m^* is unique, then we have $\partial F/\partial m < 0$ at m^*. Since $\partial F/\partial e > 0$ (because $\partial H/\partial e > 0$) and $\partial F/\partial m < 0$, we have, at m^*,

$$\frac{dm}{de} = -\frac{\frac{\partial F}{\partial e}}{\frac{\partial F}{\partial m}} > 0.$$

The rest of the proof proves the uniqueness of m^*, and for this purpose, we use the Descartes' rule of signs to show that there is exactly one positive root of $F = 0$. Observe that

$$F = \frac{Am^3 + Bm^2 + Cm + D}{\left[m + (e\tau)^{1-\sigma_1}\right]\left[1 + m\left(e^{-1}\tau\right)^{1-\sigma_1}\right]\left[m + (e\tau)^{1-\sigma_2}\right]\left[1 + m\left(e^{-1}\tau\right)^{1-\sigma_2}\right]},$$

where

$$\begin{aligned}
A &= K_1\left(e^{-1}\tau\right)^{1-\sigma_2} + K_2\left(e^{-1}\tau\right)^{1-\sigma_1} \\
B &= P_1\left(e^{-1}\tau\right)^{1-\sigma_2} + P_2\left(e^{-1}\tau\right)^{1-\sigma_1} + K_1\left(1+\tau^{2-2\sigma_2}\right) + K_2\left(1+\tau^{2-2\sigma_1}\right) \\
C &= P_1\left(1+\tau^{2-2\sigma_2}\right) + P_2\left(1+\tau^{2-2\sigma_1}\right) + K_1(e\tau)^{1-\sigma_2} + K_2(e\tau)^{1-\sigma_1} \\
D &= P_1(e\tau)^{1-\sigma_2} + P_2(e\tau)^{1-\sigma_1},
\end{aligned}$$

where

$$\begin{aligned}
K_i &= \frac{\alpha_i}{\sigma_i}\left[L_n\left(1 - e^{-\sigma_i}\tau^{1-\sigma_i}\right)\left(e^{-1}\tau\right)^{1-\sigma_i} + L_s\left(e^{\sigma_i}\tau^{1-\sigma_i} - 1\right)\right] \\
P_i &= \frac{\alpha_i}{\sigma_i}\left[L_n\left(1 - e^{-\sigma_i}\tau^{1-\sigma_i}\right) + (e\tau)^{1-\sigma_i} L_s\left(e^{\sigma_i}\tau^{1-\sigma_i} - 1\right)\right].
\end{aligned}$$

Since $F = 0$ if and only if $Am^3 + Bm^2 + Cm + D = 0$, it suffices to show that there is exactly one positive root to this polynomial. By (8), we know that

$$\begin{aligned}
K_i &= \frac{\alpha_i L_n\left(1 - e^{-\sigma_i}\tau^{1-\sigma_i}\right)}{\sigma_i}\left[e^{\sigma_i - 1}\tau^{1-\sigma_i} - G\right] < 0, \\
P_i &= \frac{\alpha_i L_n\left(1 - e^{-\sigma_i}\tau^{1-\sigma_i}\right)(e\tau)^{1-\sigma_i}}{\sigma_i}\left[e^{\sigma_i - 1}\tau^{\sigma_i - 1} - G\right] > 0.
\end{aligned}$$

Hence, $A < 0$, $D > 0$, and

$$\begin{aligned}
B &= \left[\left(e^{-1}\tau\right)^{1-\sigma_2} + \left(1+\tau^{2-2\sigma_2}\right)\frac{e^{\sigma_1-1}\tau^{1-\sigma_1} - \frac{1-e^{\sigma_1}\tau^{1-\sigma_1}}{1-e^{-\sigma_1}\tau^{1-\sigma_1}}\frac{L_s}{L_n}}{e^{\sigma_1-1}\tau^{\sigma_1-1} - \frac{1-e^{\sigma_1}\tau^{1-\sigma_1}}{1-e^{-\sigma_1}\tau^{1-\sigma_1}}\frac{L_s}{L_n}}(e\tau)^{\sigma_1-1}\right]P_1 \\
&\quad + \left[\left(e^{-1}\tau\right)^{1-\sigma_1} + \left(1+\tau^{2-2\sigma_1}\right)\frac{e^{\sigma_2-1}\tau^{1-\sigma_2} - \frac{1-e^{\sigma_2}\tau^{1-\sigma_2}}{1-e^{-\sigma_2}\tau^{1-\sigma_2}}\frac{L_s}{L_n}}{e^{\sigma_2-1}\tau^{\sigma_2-1} - \frac{1-e^{\sigma_2}\tau^{1-\sigma_2}}{1-e^{-\sigma_2}\tau^{1-\sigma_2}}\frac{L_s}{L_n}}(e\tau)^{\sigma_2-1}\right]P_2 \\
C &= \left[1+\tau^{2-2\sigma_2} + (e\tau)^{1-\sigma_2}\frac{e^{\sigma_1-1}\tau^{1-\sigma_1} - \frac{1-e^{\sigma_1}\tau^{1-\sigma_1}}{1-e^{-\sigma_1}\tau^{1-\sigma_1}}\frac{L_s}{L_n}}{e^{\sigma_1-1}\tau^{\sigma_1-1} - \frac{1-e^{\sigma_1}\tau^{1-\sigma_1}}{1-e^{-\sigma_1}\tau^{1-\sigma_1}}\frac{L_s}{L_n}}(e\tau)^{\sigma_1-1}\right]P_1 \\
&\quad + \left[1+\tau^{2-2\sigma_1} + (e\tau)^{1-\sigma_1}\frac{e^{\sigma_2-1}\tau^{1-\sigma_2} - \frac{1-e^{\sigma_2}\tau^{1-\sigma_2}}{1-e^{-\sigma_2}\tau^{1-\sigma_2}}\frac{L_s}{L_n}}{e^{\sigma_2-1}\tau^{\sigma_2-1} - \frac{1-e^{\sigma_2}\tau^{1-\sigma_2}}{1-e^{-\sigma_2}\tau^{1-\sigma_2}}\frac{L_s}{L_n}}(e\tau)^{\sigma_2-1}\right]P_2
\end{aligned}$$

So, because $1+\tau^{2-2\sigma_i} > 1 > \left(e^{-1}\tau\right)^{1-\sigma_i}$ and $1+\tau^{2-2\sigma_i} > 1 > (e\tau)^{1-\sigma_i}$, $B < C$. To apply the rule of signs, distinguish three cases, $C > B > 0$, $0 > C > B$, and $C > 0 > B$. Combined with the facts that $A < 0$ and $D > 0$, there is exactly one positive root in each case. Hence, m^* is unique.

Proof of Proposition 2

Observe that $\frac{d}{de}\left(\frac{X_{s2}}{X_{s1}}\right) > 0$ if and only if

$$\frac{d}{de}\left(\frac{P_{n1}^{1-\sigma_1}}{P_{n2}^{1-\sigma_2}}e^{\sigma_1-\sigma_2}\right) = \frac{d}{de}\left(\frac{\lambda_1\left(\mu_1 c\right)^{1-\sigma_1}\left[m+\left(e\tau\right)^{1-\sigma_1}\right]}{\lambda_2\left(\mu_2 c\right)^{1-\sigma_2}\left[m+\left(e\tau\right)^{1-\sigma_2}\right]}e^{\sigma_1-\sigma_2}\right) > 0,$$

which is positive if and only if

$$\frac{d}{de}\left(\frac{m+\left(e\tau\right)^{1-\sigma_1}}{m+\left(e\tau\right)^{1-\sigma_2}}e^{\sigma_1-\sigma_2}\right) > 0.$$

In the short run when m is kept fixed, we have

$$\begin{aligned}&\frac{\partial}{\partial e}\left(\frac{m+\left(e\tau\right)^{1-\sigma_1}}{m+\left(e\tau\right)^{1-\sigma_2}}e^{\sigma_1-\sigma_2}\right)\\ = &\frac{e^{-1}\tau^{\sigma_2-\sigma_1}\left[m^2(e\tau)^{\sigma_1+\sigma_2}(\sigma_1-\sigma_2)+m(e\tau)^{\sigma_1+1}(\sigma_1-1)-m(e\tau)^{\sigma_2+1}(\sigma_2-1)\right]}{\left[e\tau+m(e\tau)^{\sigma_2}\right]^2}.\end{aligned}$$

It is easy to verify that $\hat{\tau} > e^{-1}$ by checking (6) and so $e\tau > 1$. Hence, the above derivative is positive. Next, in the long run when m is not fixed, we must examine

$$\frac{\partial}{\partial m}\left(\frac{m+\left(e\tau\right)^{1-\sigma_1}}{m+\left(e\tau\right)^{1-\sigma_2}}e^{\sigma_1-\sigma_2}\right) = \frac{e\tau^{1-\sigma_1+\sigma_2}\left[(e\tau)^{\sigma_1}-(e\tau)^{\sigma_2}\right]}{\left[e\tau+m(e\tau)^{\sigma_2}\right]^2},$$

which is positive since $e\tau > 1$. From Proposition 1, $\frac{dm}{de} > 0$, and hence at m^*,

$$\frac{d}{de}\left(\frac{m+\left(e\tau\right)^{1-\sigma_1}}{m+\left(e\tau\right)^{1-\sigma_2}}e^{\sigma_1-\sigma_2}\right) = \frac{\partial}{\partial e}\left(\frac{m+\left(e\tau\right)^{1-\sigma_1}}{m+\left(e\tau\right)^{1-\sigma_2}}e^{\sigma_1-\sigma_2}\right)+\frac{\partial}{\partial m}\left(\frac{m+\left(e\tau\right)^{1-\sigma_1}}{m+\left(e\tau\right)^{1-\sigma_2}}e^{\sigma_1-\sigma_2}\right)\frac{dm}{de} > 0.$$

Hence, $\frac{d}{de}\left(\frac{X_{s2}}{X_{s1}}\right) > 0$. The proof for $\frac{d}{de}\left(\frac{X_{n2}}{X_{n1}}\right) < 0$ is similar.

For Point 2, first observe from (2) and (3), $\frac{X_{n2}}{X_{n1}} > \frac{X_{s2}}{X_{s1}}$ if and only if

$$\frac{P_{s1}^{1-\sigma_1}}{P_{s2}^{1-\sigma_2}}\left(e^{-1}\right)^{\sigma_1-\sigma_2} > \frac{P_{n1}^{1-\sigma_1}}{P_{n2}^{1-\sigma_2}}e^{\sigma_1-\sigma_2},$$

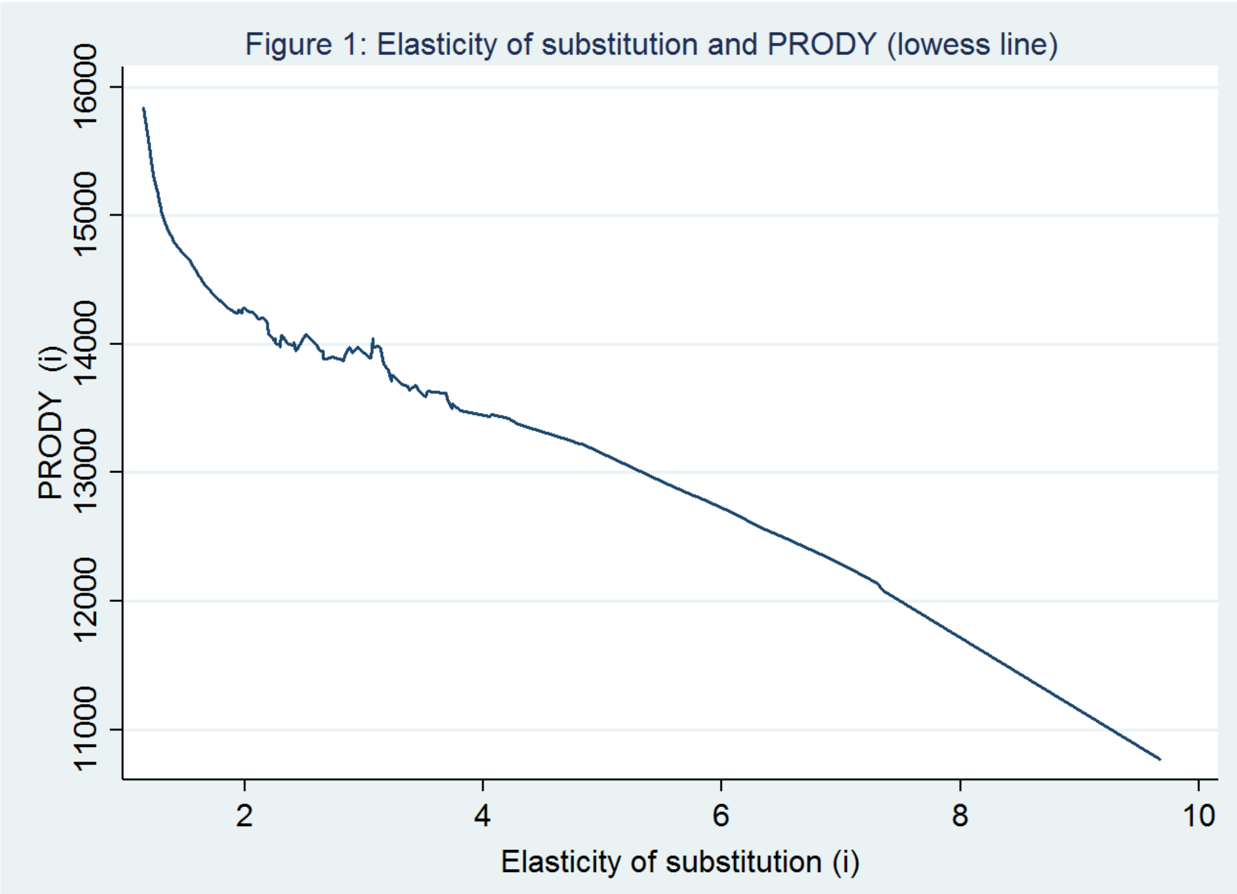
Figure 1: Elasticity of substitution and PRODY (lowess line)
PRODY (i)
11000
12000
13000
14000
15000
16000
2
4
6
8
10
Elasticity of substitution (i)

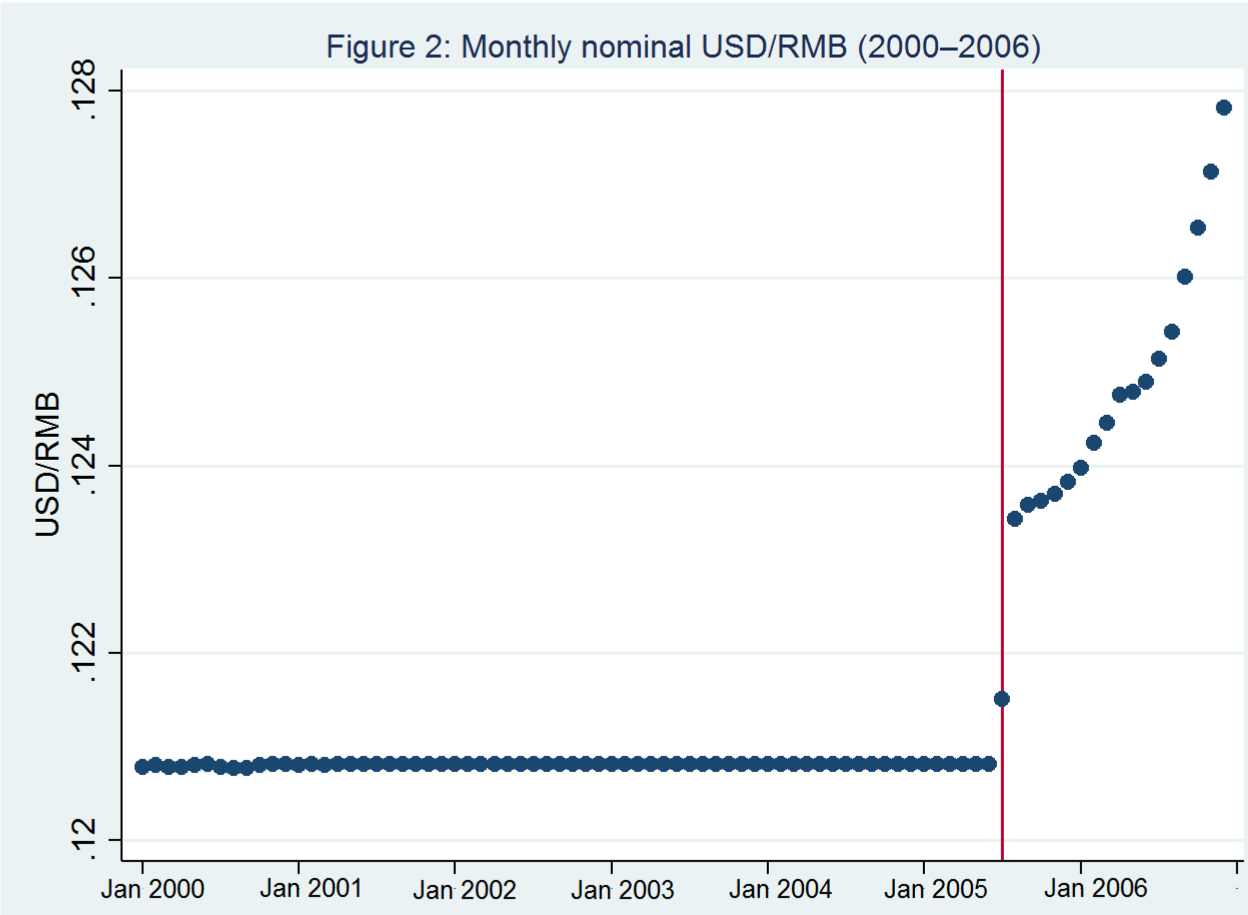
Figure 2: Monthly nominal USD/RMB (2000–2006)
USD/RMB
.12
.122
.124
.126
.128
Jan 2000
Jan 2001
Jan 2002
Jan 2003
Jan 2004
Jan 2005
Jan 2006

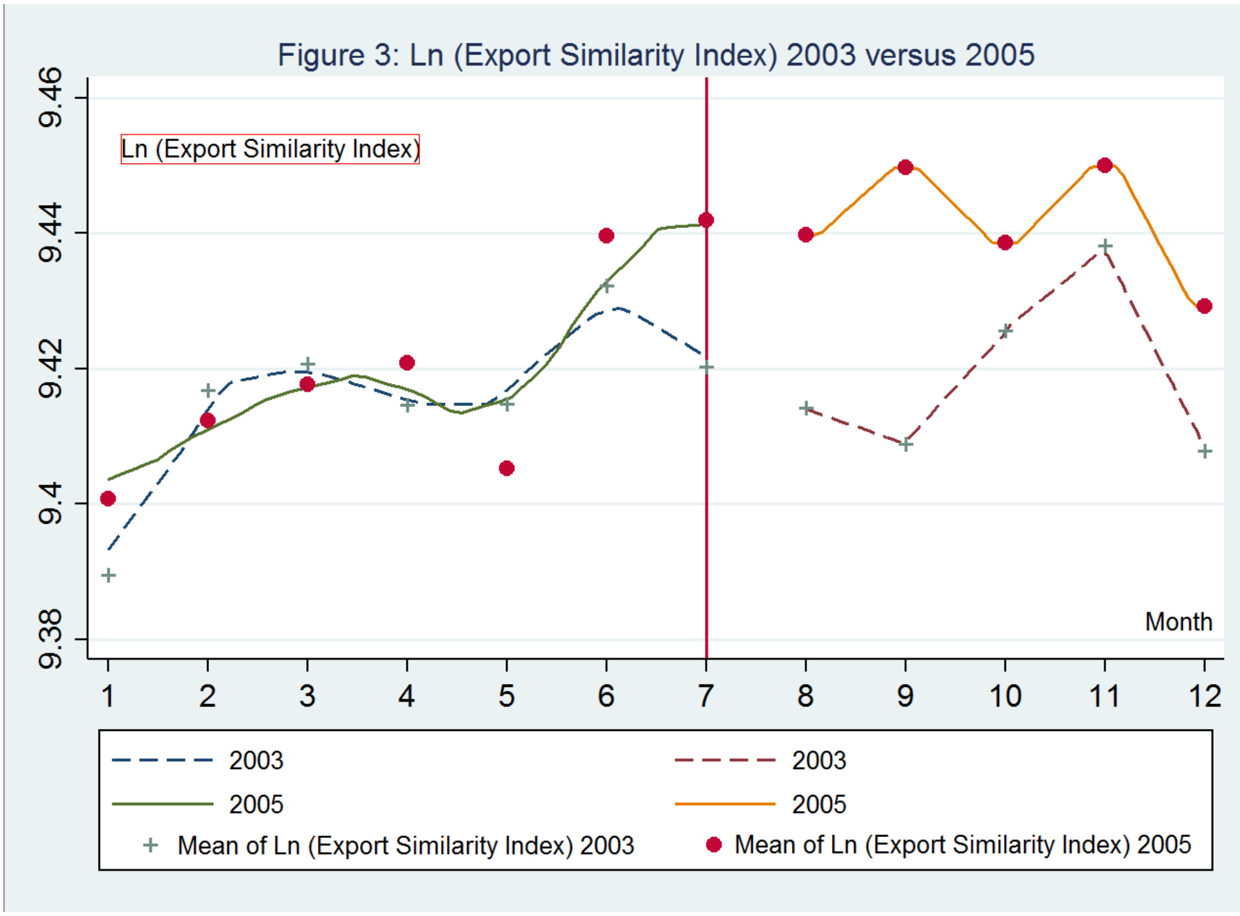
Figure 3: Ln (Export Similarity Index) 2003 versus 2005
Ln (Export Similarity Index)
9.38
9.4
9.42
9.44
9.46
1
2
3
4
5
6
7
8
9
10
11
12
Month
2003
2005
Mean of Ln (Export Similarity Index) 2003
2003
2005
Mean of Ln (Export Similarity Index) 2005

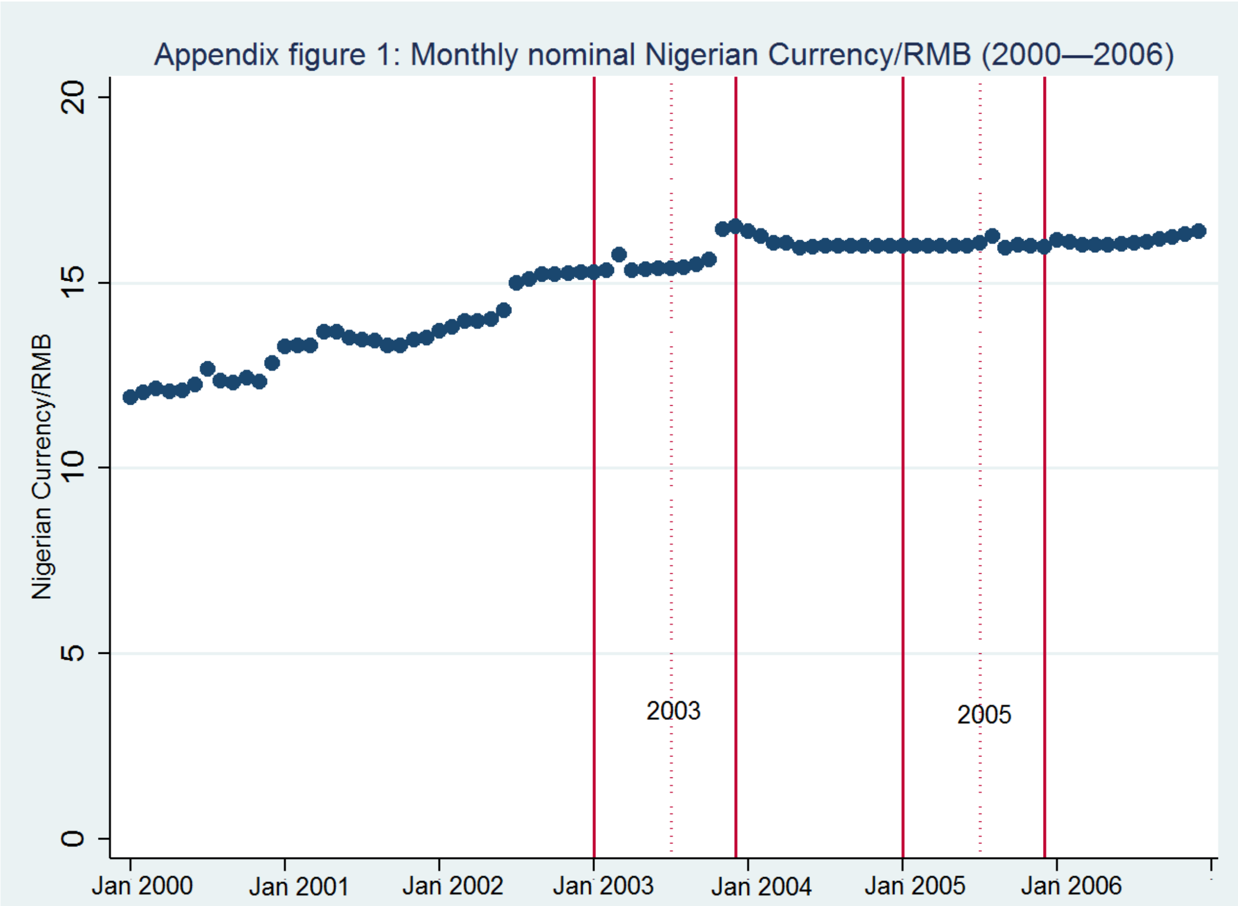
Appendix figure 1: Monthly nominal Nigerian Currency/RMB (2000—2006)
Nigerian Currency/RMB
0
5
10
15
20
2003
2005
Jan 2000
Jan 2001
Jan 2002
Jan 2003
Jan 2004
Jan 2005
Jan 2006

Table 1: Top 5 sophisticated goods and the bottom 5 sophisticated goods (U.S.$2000)

	Product name	PRODY 2000
Bottom 5	Vegetable products nes	739.67145
	Asses, mules, and hinnies, live	803.94128
	Sisal and agave, raw	822.37665
	Cloves (whole fruit, cloves, and stems)	866.57587
	Hand-made lace, in the piece, in strips or in motifs	901.80627
Top 5	Flat-rolled iron or non-alloy steel, coated with aluminium, width > 600mm	50699.391
	Sheet piling of iron or steel	46986.039
	Sections H iron or non-alloy steel, nfw hot-roll/drawn/extruded > 80m	46242.609
	Tyre cord fabric of viscose rayon	46077.578
	Cermets and articles thereof, waste or scrap	46058.699

Table 2: Main results

	1	2
	RD	DD
Dependent variable	Ln (Export Similarity Index)	
August	-0.002**	
	(0.023)	
August* Year 2005		0.018**
		(0.006)
Month fixed effect		X
Year fixed effect		X
NOB	4404	8525

Notes: Standard errors in Column 1 are bootstrapped; standard errors in Column 2 are clustered at the month level. Standard errors are reported in the parentheses.
** p<0.05.

Table 3: Robustness checks

	1 Nigeria DD	2 DDD	3 Placebo test, 2003 vs 2002	4 U.S. exports to China	5 Exclusion of processing trade
Dependent variable			Ln (Export Similarity Index)		
August*Year2005	0.001	0.017	-0.001	-0.049**	0.014*
	(0.015)	(0.011)	(0.009)	(0.022)	(0.008)
Month fixed effect	X		X	X	X
Year fixed effect	X		X	X	X
Group-month fixed effect		X			
Group-year fixed effect		X			
Month-year fixed effect		X			
NOB	3972	12497	8262	7015	8435

Notes: Standard errors in Column 1, 3, 4, 5, are clustered at the month level; standard errors in Column 2 are clustered at country-month level; standard errors are reported in the parentheses. ** $p<0.05$, * $p<0.1$.

Table 4: Decomposition of the effect of currency appreciation

	1	2
	Across firms within a city	Across products within a firm
Dependent variable	Ln (Export Similarity Index)	
August* Year 2005	0.015***	0.002***
	(0.005)	(0.001)
Month fixed effect	X	X
Year fixed effect	X	X
City fixed effect	X	
Firm fixed effect		X
NOB	8516	120672

Notes: Standard are clustered at the month level. Standard errors are reported in the parentheses. *** p<0.01.

if and only if

$$\frac{1+m\left(e^{-1}\tau\right)^{1-\sigma_1}}{1+m\left(e^{-1}\tau\right)^{1-\sigma_2}}\left(e^{-1}\right)^{\sigma_1-\sigma_2} > \frac{m+\left(e\tau\right)^{1-\sigma_1}}{m+\left(e\tau\right)^{1-\sigma_2}}e^{\sigma_1-\sigma_2}. \tag{9}$$

We can first look at a special case where $e = 1$. The only difference between two countries in this case is the scenario when $L_n \neq L_s$. When $L_s > L_n$, $m = \frac{M_n}{M_s} < 1$. With $e = 1$ and $m < 1$, it is easy to verify that (9) holds. This proves Point 2(b). For Point 2(a), let $L_n = L_s$. When $e = 1$, $m = 1$ and (9) holds in equality, i.e., $\frac{X_{s2}}{X_{s1}} = \frac{X_{n2}}{X_{n1}}$. By Point 1, when $e < 1$, $\frac{X_{s2}}{X_{s1}} < \frac{X_{n2}}{X_{n1}}$ holds.