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The impact of exchange rate volatility on the industry-level geographic diversification of global supply chain network

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Abstract: This study examines the net impact of exchange rate volatility on the industry-level geographic diversification of global supply chain network through trade data. The findings show that exchange rate volatility has an inverse yet nonlinear relationship regarding the choices of export destinations and import origins at the level of industries. This study suggests that firms consider potential exchange rate volatility in the design of supply chain network and develop resilient portfolios of customers and suppliers. The policy implications are discussed.

Keywords: exchange rate risk; global supply chain; global financial crisis.

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Jasmin Corona received her Bachelor of Science in Business Administration with a concentration in Finance from California State University, Dominguez Hills. During her college career, she worked as a STEM tutor and helped over a hundred students in subjects ranging from algebra to calculus and also, statistics, finance and accounting. She currently works as a Pricing Analyst for Henry LLC and is pursuing a Master of Science in Supply Chain Management.

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1 Introduction and motivation

Exchange rate is one of the most important factors that affect global supply chain decisions of firms. With offshore-outsourcing becoming a manufacturers' primary source of cost reduction since the early 2000s, the downside risk from exchange rate fluctuations has increased substantially. In a survey of 500 executives of global companies in 2009, the 'Economist' found that exchange rate uncertainty is the biggest threat to the resilience of supply chain (The Economist Intelligence Unit, 2009).

Christopher and Holweg (2011, 2017) argue that the conventional wisdom of supply chain management is based on long-term relative stability of business conditions. As the global business environment becomes more turbulent, 'supply chain 2.0', calls for building structural flexibility and resilience into the supply chain design. Thus, they develop the supply chain volatility index (SCVI) to measure supply chain turbulence and exchange rate volatility as one of eight primary parameters that may characterise a firm's global supply chain. Consequently, to design a 'supply chain 2.0' network, it is crucial to examine industry's behaviours in response to the volatility of currency exchange rate based on empirical data.

The impact of exchange rate uncertainty has been widely studied by economists and supply chain researchers. On the one hand, trade research argues that high exchange rate volatility can deter trade volume albeit its impact can be mitigated by the use of forward contracts (Clark, 1973; Ethier, 1973; Baron, 1976; Hooper and Kohlhagen, 1978; Viaene and de Vries, 1992; Broll, 1994). On the other hand, supply chain research found that exchange rate risk is an important factor affecting global sourcing strategies. It has been noted that, in general, a well-functioning global supply chain network can help firms mitigate the impact of exchange rate volatility (Kogut and Kulatilaka, 1994; Allen and Pantzalis, 1996; Tang and Tikoo, 1999; Tong and Reuer, 2007; Lee and Makhija, 2009; Qian et al., 2010; Christopher and Holweg, 2011, 2017). Further, Lee and Makhija (2009) found that operating flexibility of global supply chain network is relatively more valuable during a period of global financial crisis.

Even though the previous studies have investigated the relationship between exchange rate volatility, trade volume, and global location decisions, typically they either use relatively abstract, mathematical modeling approaches or estimate the relationship only at the single country level. Hence, the relevance of their policy implications for industry practitioners may be limited. In addition, Perée and Steinherr (1989) indicate that aggregate trade equations at the country level neglect industry structure and market structure, and time series estimation on an aggregate basis fails to fully capture the nature of the underlying structure. Clearly, in order to empirically more completely reveal the relatively micro-level impact of exchange rate volatility on global supply chain decisions, it is desirable to examine the relationship at the industry or the firm level. Thus, this study aims to estimate the impact of exchange rate volatility on geographic diversification of global supply chain network through export and import empirical data at the industry level.

Given distinct exchange rate volatility relevant for each economy, our study proposes the following research questions. First, to what extent, exchange rate volatility is a determinant of geographical diversification of sales destinations and sourcing origins in global supply chain? Second, given the degree of such impact, is the relationship between exchange rate uncertainty and global supply chain decisions linear or nonlinear? Third, does a 'global financial crisis' (of the kind experienced in 2008) moderate the above relationship? Using annual US trade statistics and manufacturing industry data for the years 2002–2015 between the US and its top 12 Asian trading partners, this study applies multiple regression methods to address these research questions.

2 Literature review and hypotheses development

When a firm gets involved in international trade, it starts to face several risks caused by volatility of currency exchange rate, including transaction exposure, accounting exposure (or translation exposure), and operating exposure. Transaction exposure occurs because the exchange rate is agreed on at the time of the trade contract negotiation, but payment is not made until the future delivery actually takes place. Accounting exposure is the risk that a firm's contractual items on balance sheet and income statement like stock, revenue, assets, or liabilities denominated in foreign currency will change in value as a result of nominal exchange rate changes. Transaction exposure and accounting exposure can be

hedged by a forward contract which locks in an exchange rate (Lessard and Lightstone, 1986). However, such risks may not be fully covered or mitigated unless the forward markets are complete, perfectly function and exist in all of the relevant foreign currency pairs – such pre-conditions are often not met. Operating exposure (or economic exposure)is the risk that the changes in real exchange rate affect a firm's production costs, selling prices, production and sales volume, and eventually the operating profits and cash flow. The degree of operating exposure is proportional to exchange rate volatility (Lessard and Lightstone, 1986).

Two research streams – the 'trade research' and the 'global supply chain research' – are relevant to examining the risk of exchange rate volatility. Firstly, the trade research examines the impact of exchange rate volatility on trade volume at the country level and finds mixed results. Some studies argued that higher exchange rate risk lowers risk-adjusted expected revenue from exports and thus reduces the incentive of risk-averse traders to export (Clark, 1973; Baron, 1976; Hooper and Kohlhagen, 1978; Broll, 1994). While other studies show that exchange rate volatility may not have any impact on trade volume if firms use forward contract to hedge the risk (Ethier, 1973; Baron, 1976). However, such forward or futures markets may be incomplete or imperfect as mentioned earlier. Thus, for instance, Ozturk (2006) indicates that exchange rate risk is generally not hedged for all countries since forward markets are not accessible to all traders. In general, even if hedging in the forward markets were possible, there are limitations and costs. Overall, while the trade literature results are mixed, there is significant evidence that higher exchange rate volatility of destination country reduces its export share at the country level. Hence, our study will test the hypothesis that an industry may shift the exporting destination from the economy with higher exchange rate volatility to other economies with lower volatility.

Hypothesis 1 *Ceteris paribus*, an industry's export share will be negatively correlated to exchange rate volatility.

Secondly, the global supply chain research, on the other hand, focuses on examining the functioning of global supply chain network in response to exchange rate volatility. Christopher and Holweg (2011, 2017) advocate the value of 'structural flexibility', which is the ability of the supply chain to adapt to fundamental changes in the business environment that are to be expected in a world with increased turbulences. For example, multinational companies (MNCs) with multiple operational locations can implement operational strategies such as dual sourcing to mitigate the impact of exchange rate volatility. Previous studies indicate that global supply chain network enables a firm to quickly respond to environmental variations such as foreign exchange rate movements. Their findings show that the diversification of MNCs' foreign locations contributes to a firm's market value and/or financial performances (Kogut and Kulatilaka, 1994; Allen and Pantzalis, 1996; Tang and Tikoo, 1999; Tong and Reuer, 2007; Lee and Makhija, 2009; Qian et al., 2010; Cho et al., 2017; Schwieterman et al., 2017). Specifically, Lee and Makhija (2009) and Cho et al. (2017) found that firms operating in more countries have better market value during a period of economic crisis.

Further, the global supply chain literature indicates that a firm reduces production activities in the country in response to increased exchange rate volatility (Kazaz et al., 2005; Liu and Nagurney, 2011). Kazaz et al. (2005) use analytical models to analyse the impact of exchange rate uncertainty on the choice of optimal production policies. They

propose two operational hedging strategies to mitigate the impact of unfavourable exchange rate. Production hedging produces less than total demand, while allocation hedging under serves some markets. Their study implies that a firm may reduce production from the countries with unfavourable exchange rate. Liu and Nagurney (2011) use simulations to examine the supply chain outsourcing decisions under exchange rate risk and competition. They argue that the risk-averse firm uses more in-house production and reduces the outsourcing quantity when exchange rate uncertainty is high, while the risk-neutral firm always uses the outsourcing strategy.

Accordingly, we hypothesise that an industry may shift the source of importing origins from the economy with higher exchange rate volatility to another economy with lower volatility.

Hypothesis 2 *Ceteris paribus*, an industry's import share will be negatively correlated to exchange rate volatility.

In light of its tests of Hypotheses 1 and 2, this study will further explore whether the relationship between exchange rate volatility and global supply chain decisions is nonlinear. Perée and Steinherr (1989) indicate that most empirical trade research about exchange rate uncertainty postulates a linear or log-linear relationship between risk and trade but most likely this relationship is intrinsically nonlinear. Some trade studies found higher exchange rate volatility actually stimulates trade (De Grauwe, 1988; Sercu, 1992). De Grauwe (1988) proposes that exchange rate uncertainty can lead to the substitution effect and the income effect. While the substitution effect is that increased exchange rate risk decreases the attractiveness of risky trades, the income effect indicates that increased exchange rate uncertainty reduces the expected utility of export revenue, leading to more export activities to offset the shortage (assuming a 'target' exchange rate revenue). The dominance of income effects over substitution effects can lead to a positive relationship between trade and exchange-rate volatility. Given a concave utility function, the relationship between exchange rate volatility and trade can be nonlinear. That is, exchange rate volatility leads to fewer trade when the extent of volatility is below certain level, and to more trade beyond that level. Still another study, Sercu (1992), argues that increased exchange rate volatility makes an exporting strategy more attractive than the direct investment, leading to positive correlation between exchange rate volatility and export. Besides, the above analytical reasons for postulating a nonlinear relationship, one could simply take a purely non-parametric point of view in this regard as it is easy to imagine many non-specifics effects of a 'global financial crisis' besides those encoded in the Hypotheses 1 and 2.

Accordingly, we hypothesise the relationship between exchange rate volatility and export and import share could be nonlinear.

Hypothesis 3 *Ceteris paribus*, an industry's export share has a nonlinear relationship with exchange rate volatility.

Hypothesis 4 *Ceteris paribus*, an industry's import share has a nonlinear relationship with exchange rate volatility.

Finally, this study will further test another two additional hypotheses regarding the moderating effect of a 'global financial crisis' like that of 2008. A few previous studies have found that the value of global supply chain network is mixed during the global

financial crisis (Lee and Makhija, 2009; Cho et al., 2017). Lee and Makhija (2009) find that firms with more diversified overseas locations have higher stock market value during a period of financial crisis. Cho et al. (2017) find that geographical diversification enhances an MNC's stock market performance while deteriorating its financial performance in the presence of a financial crisis. One of the significant effects of the 2008 global financial crisis was an overall dampening of the volume of international trade. As noted by Bernanke (2009), "international trade plunged about 20 percent in real terms from its pre-crisis peak to its trough in early 2009". Besides this structural deterioration in global environment, there were specific cost implications of the global financial crisis. More specifically, during global financial crisis, banks had to scale back credit limits thus leading to higher borrowing costs for firms. The cost of maintaining geographically diversified operations is higher due to high costs of transactions cross borders. Further, the crises-period exchange rates become more volatile than those during the 'calm' period without crisis (Mariano et al., 2003). The increased uncertainty and costs may have additional direct impact on firms' exporting and importing decisions in addition to the effect of higher exchange rate volatility indicated in Hypotheses 1, 2, 3, and 4. Hence, this study tests the differential relationships between the exchange rate volatility and the shares of export and import during a 'global financial crisis'.

Hypothesis 5 The relationship between exchange rate volatility and export share is different during a 'global financial crisis'.

Hypothesis 6 The relationship between exchange rate volatility and import share is different during a 'global financial crisis'.

3 Models and data collection

3.1 Model specification

This study adopts the concept of gravity model of trade to specify the models for export share (*XS*) and import share (*MS*). Using the analogy with the gravitational force in physics, the gravity model predicts that the volume of bilateral trade between two economies is determined by their relative sizes and distance. In the trade literature, the volume of trade is positively associated with the size of economies, measured by GDP, the growth of GDP, GDP per capita, and/or population, while it is negatively associated with the distance between them (Anderson, 1979; Frankel, 1997; Cheng and Wall, 2005). Because in this study, all the trade links are emanating from the US, we include GDP (*GDP*), the growth of GDP (*GGDP*), GDP per capita (*GDPPC*) of destination economies for export model and those of origin economies for import model as control variables. The distance (*DIST*) between two economies, measured by the direct distance of their capitals, is also included.

The exchange rate volatility is a major explanatory variable of interest in this study. Christopher and Holweg (2011) use the coefficient of variation as a normalised and scale-free measurement of volatility. In the spirit of this study, the present study uses the coefficient of variation (*CV)*, the ratio of standard deviation to the 12-month average to measure the exchange rate volatility. Given that the relationship between exchange rate volatility and import/export relative shares can be nonlinear, in an effort to capture this

possible nonlinearity, we include two variables, in turn. The first such variable is the deviation of CV (*CV_DEV*), measured by the difference between CV and the mean of CVs of one country over 13 years (excluding year 2008 which is the year of global financial crisis with extremely high exchange rate volatility). The second variable in this context is the squared term of CV (*CV_SQ*). In order to capture the effect of global financial crisis, we include a (0, 1) dummy variable *CRISIS*, where 1 represents year 2008 when there was a global financial crisis and 0 otherwise. To control for the time trend of currency values, we standardised the exchange rate of a given country over 14 years and used the estimated trend of currency in the 12 months of a year by including the slope of the time trend (*SLOPE*) in the export and import share models. In addition, we include the export unit value (*XPRICE*) and import unit value (*MPRICE*) of each industry relative to the cross-economy industry average to control for the differences of prices across economies. Besides, this study uses industry dummies, based on the three-digit NAICS industry codes, to capture varying factors that affect the choices of exporting destination and importing origins across different industries.

The estimation models for export share and import share are presented as follows. In order to capture the possible non-linear relationship between the exchange rate volatility and the relative export and import shares, the deviation of CV (*CV_DEV*) and the squared term of CV (*CV_SQ*) are included in turn in each of the models for export share and import share.

- Export share model – 1

$$\begin{aligned} XS_{ijt} &= \alpha_0 + \alpha_1 CV_{jt} + \alpha_2 CV\_DEV_{jt} + \alpha_3 CRISIS_t + \alpha_4 SLOPE_{jt} \\ &\quad + \alpha_5 DIST_j + \alpha_6 GDP_{jt} + \alpha_7 GGDP_{jt} + \alpha_8 GDPPC_{jt} \\ &\quad + \alpha_9 Xprice_{ijt} + Industry\ dummies + \tau_{ijt} \end{aligned} \tag{1}$$

where *i* is the three-digit NAICS industry in implicit home country, the USA; *j* is the destination country *j*; *t* is the year *t*.

τ_{ijt} is assumed to be iid ~ (0, finite).

- Export share model – 2

$$\begin{aligned} XS_{ijt} &= \beta_0 + \beta_1 CV_{jt} + \beta_2 CV\_SQ_{jt} + \beta_3 CRISIS_t + \beta_4 SLOPE_{jt} \\ &\quad + \beta_5 DIST_j + \beta_6 GDP_{jt} + \beta_7 GGDP_{jt} + \beta_8 GDPPC_{jt} \\ &\quad + \beta_9 Xprice_{ijt} + Industry\ dummies + \tau_{ijt} \end{aligned} \tag{2}$$

- Import share model – 1

$$\begin{aligned} MS_{ijt} &= \gamma_0 + \gamma_1 CV_{jt} + \gamma_2 CV\_DEV_{jt} + \gamma_3 CRISIS_t + \gamma_4 SLOPE_{jt} \\ &\quad + \gamma_5 DIST_j + \gamma_6 GDP_{jt} + \gamma_7 GGDP_{jt} + \gamma_8 GDPPC_{jt} \\ &\quad + \gamma_9 MPrice_{ijt} + Industry\ dummies + \varepsilon_{ijt} \end{aligned} \tag{3}$$

where *i* is the three-digit NAICS industry in implicit home country, the USA; *j* is the source country *j*; *t* is the year *t*.

ε_{ijt} is assumed to be iid ~ (0, finite).

- Import share model – 2

$$MS_{ijt} = \delta_0 + \delta_1 CV_{jt} + \delta_2 CV\_SQ_{jt} + \delta_3 CRISIS_t + \delta_4 SLOPE_{jt} + \delta_5 DIST_j + \delta_6 GDP_{jt} + \delta_7 GGDP_{jt} + \delta_8 GDPPC_{jt} + \delta_9 MPrice_{ijt} + Industry\ dummies + \varepsilon_{ijt} \quad (4)$$

3.2 Data collection

This study focuses on relative export and import shares for manufacturing industries of the US and its top 12 trading partners in Asia, namely, China, Hong Kong, India, Indonesia, Japan, South Korea, Malaysia, The Philippines, Singapore, Taiwan, Thailand, and Vietnam, which together accounted for 88% of the Asian GDP in 2010 (International Monetary Fund, 2012).

Data of this study were collected from several sources. Regarding the relative shares of export from the US and of import to the US, the yearly trade data at the level of three-digit NAICS industry code were retrieved from the USA Trade Online usatrade.census.gov) maintained by the US Census Bureau. Only the trade data related to the manufacturing industries, whose NAICS industry codes start with 3, are included in this study. The export share is calculated as the export value of a specific industry from the US to a given destination economy relative to the total export value of the entire manufacturing industry from the US to the 12 selected Asian economies in a year. Correspondingly, similar method is applied to the calculation of the relative import share. The USA Trade Online database also provides the average unit value at the levels of industry and economy pair.

The data about the monthly exchange rate during 2002–2015 was collected from http://www.usforex.com which yielded data on *CV*, *CV_DEV*, *CV_SQ*, and *SLOPE* variables. The country macroeconomic statistics such as *GDP*, *GGDP*, and *GDPPC* were collected from the World Bank. The distance is based on the natural logarithm of air distance between the capitals of a given pair of economies. Excluding the observations without trade data at the industry level, our panel dataset consists of 3,360 observations for exports specification and 3,515 observations for imports specification.

4 Results

The following section presents summary statistics whereas the multiple regression results are presented in Section 4.2.

4.1 Summary statistics

Figure 1 and Table 1 report the trend of exchange rate volatility in terms of the CVs of the local currencies of 12 economies against the US dollar during 2002–2015. It shows that Chinese Yuan and Hong Kong Dollar have the lowest CV on average. China had been adopting the currency policy of fixed exchange rate from 1994, and the Chinese Yuan was pegged to the US dollar at 8.28. In July 2005, the Chinese government permitted the Chinese Yuan to appreciate by 2.1% against the dollar, moving the Yuan to a ‘managed float’ system. Indonesian Rupiah, South Korea Won, and India Rupee have

the highest volatility. In addition, during the period of global financial crisis in 2008, the exchange rates of all economies became much more volatile than the periods without crisis. The cross-economy average of CV during the global financial crisis period was 0.053, nearly a double of the level of non-crisis period.

Figure 1 Coefficient of variations of exchange rates – by economy (see online version for colours)

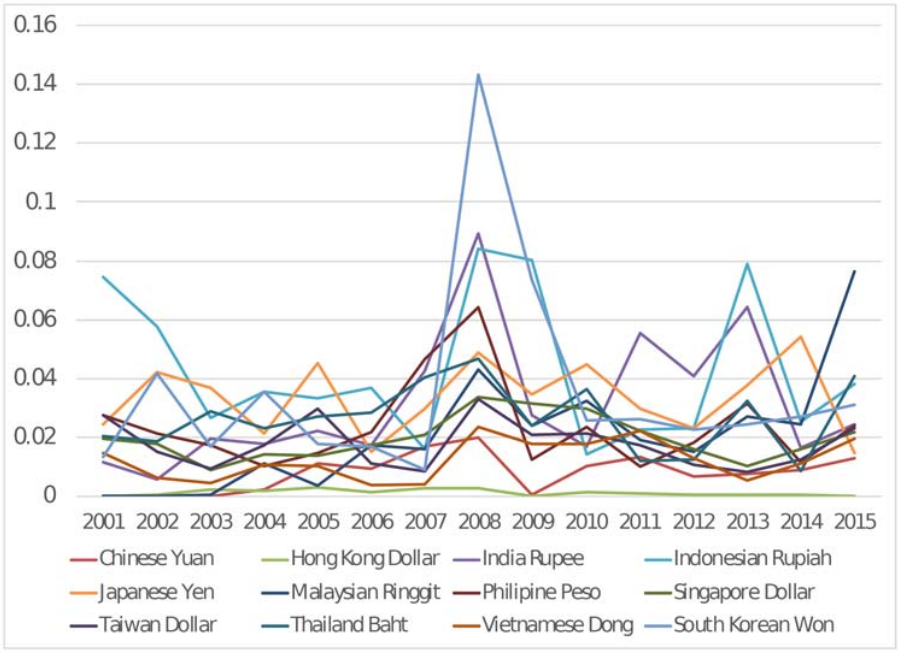

Table 2 presents the descriptive statistics of the variables used in this study. The export share represents the share of the export value of a US industry to an economy over the total export value of that industry to 12 selected Asian economies. The export share and import share at the industry level are both 0.4% on average. The CV of exchange rate is 0.0230 on average with the range between 0 and 0.1433. The relative export price is the ratio of the unit value of an industry to an Asian economy over the average unit value of that industry to 12 Asian economies, and thus the mean for the relative export price is 1. The relative import price is calculated in similar method. The distance is converted to the logarithm term because of the skewness of data distribution.

Table 3 reports the correlation among the variables used in this study. It shows that the export share is positively correlated with *GDP* and *GDPPC* and negatively with distance, supporting the assumptions of the gravity model. The import share is positively correlated to GDP and negatively to distance. The exchange rate volatility appears to be negatively correlated to export and import shares, and the relationships need to be examined in the regression models by controlling for other variables. In addition, it is found that higher GDP per capita of origin economy is associated with higher relative import price of that economy.

Table 1 Coefficient of variations of exchange rates – by economy

Year	*CN*	*HK*	*IN*	*ID*	*JP*	*MY*	*PH*	*SG*	*TW*	*TH*	*VN*	*KR*	*AVG*
2002	0.000	0.000	0.006	0.058	0.042	0.000	0.021	0.018	0.015	0.019	0.006	0.042	0.019
2003	0.000	0.002	0.020	0.027	0.037	0.001	0.017	0.009	0.009	0.029	0.005	0.017	0.014
2004	0.002	0.002	0.018	0.035	0.021	0.011	0.010	0.014	0.018	0.023	0.011	0.035	0.017
2005	0.011	0.003	0.022	0.033	0.045	0.004	0.015	0.014	0.030	0.027	0.010	0.018	0.019
2006	0.009	0.001	0.017	0.037	0.015	0.017	0.022	0.017	0.011	0.028	0.004	0.017	0.016
2007	0.017	0.003	0.043	0.016	0.030	0.016	0.046	0.021	0.009	0.040	0.004	0.009	0.021
2008	0.020	0.003	0.089	0.084	0.049	0.043	0.064	0.034	0.033	0.047	0.024	0.143	0.053
2009	0.001	0.000	0.028	0.080	0.035	0.024	0.013	0.032	0.021	0.024	0.018	0.074	0.029
2010	0.010	0.001	0.017	0.014	0.045	0.032	0.024	0.030	0.022	0.037	0.018	0.026	0.023
2011	0.013	0.001	0.055	0.023	0.030	0.019	0.010	0.022	0.017	0.012	0.022	0.026	0.021
2012	0.007	0.001	0.041	0.023	0.023	0.015	0.018	0.016	0.011	0.013	0.013	0.023	0.017
2013	0.008	0.000	0.064	0.079	0.038	0.027	0.031	0.010	0.008	0.032	0.005	0.024	0.027
2014	0.009	0.000	0.017	0.025	0.054	0.024	0.012	0.016	0.013	0.009	0.011	0.027	0.018
2015	0.013	0.000	0.025	0.038	0.015	0.076	0.024	0.022	0.023	0.041	0.020	0.031	0.027
AVG	0.009	0.001	0.033	0.041	0.034	0.022	0.023	0.020	0.017	0.027	0.012	0.037	

Notes: The abbreviations of currencies are summarised as follows:
CN: Chinese Yuan; HK: Hong Kong Dollar; IN: India Rupee;
ID: Indonesian Rupiah; JP: Japanese Yen; MY: Malaysian Ringgit;
PH: Philippine Peso; SG: Singapore Dollar; TW: Taiwan Dollar;
TH: Thailand Baht; VN: Vietnamese Dong; KR: South Korean Won;
AVG: average.

Table 2 Summary statistics

Variable	*Unit*	*Obs*	*Mean*	*Std. dev.*	*Min*	*Max*
XS	Percent	3.528	0.0040	0.0086	0.0000	0.0819
MS	Percent	3.515	0.0040	0.0138	0.0000	0.1957
CV	Ratio	3.528	0.0230	0.0199	0.0000	0.1433
CV_DEV	Ratio	3.528	0.0023	0.0164	–0.02	0.11
CV_SQ	Ratio	3.528	0.0009	0.0020	0.0000	0.0205
CRISIS	Dummy	3.528	0.0714	0.2576	0.0000	1.0000
SLOPE	Z value	3.528	0.0001	0.0687	–0.2136	0.3570
DIST	Log of miles	3.528	9.0179	0.1398	6.5191	9.2276
GDP	Trillion USD	3.528	1.2351	2.0233	0.0379	10.8664
GGDP	Percent	3.528	0.0904	0.0915	–0.1760	0.3994
GDPPC	Million USD	3.528	0.0144	0.0151	0.0005	0.0560
XPRICE	Ratio	3.360	1.0000	0.7824	0.0281	11.3024
MPRICE	Ratio	3.515	1.0000	1.0840	0.0008	10.4406

Table 3 Correlation table

		(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(9)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*
1	XS	1.00												
2	MS	0.61	1.00											
3	CV	–0.02	–0.05	1.00										
4	CV_DEV	0.00	–0.01	0.86	1.00									
5	CV_SQ	–0.01	–0.03	0.89	0.88	1.00								
6	CRISIS	0.00	0.00	0.41	0.50	0.44	1.00							
7	SLOPE	–0.06	–0.03	0.40	0.39	0.47	0.29	1.00						
8	DIST	–0.26	–0.26	0.00	–0.03	–0.03	0.00	0.07	1.00					
9	GDP	0.31	0.39	0.03	0.01	0.00	–0.01	–0.01	–0.59	1.00				
10	GGDP	–0.04	0.05	–0.17	–0.18	–0.22	0.06	–0.25	0.15	–0.05	1.00			
11	GDPPC	0.19	–0.01	–0.06	–0.01	–0.04	0.00	–0.14	–0.18	0.15	–0.33	1.00		
12	XPRICE	0.04	0.02	0.07	0.01	0.05	0.00	0.04	0.04	–0.02	0.00	–0.01	1.00	
13	MPRICE	0.10	–0.01	0.07	0.00	0.02	0.00	–0.04	0.00	0.07	–0.12	0.41	0.03	1.00

4.2 Regression results

Table 4 reports the regression results of the export share model,which is used to test Hypotheses 1, 3, and 5. Table 5 reports the results of the import share model for Hypotheses 2, 4, and 6. To examine the impact of each explanatory variable on the dependent variable, the base model which includes only the control variables was estimated first, and the explanatory variable is added to the model one by one. As mentioned in Section 4.1, we introduce two variables, *CV_DEV* and *CV_SQ*, in two separate models to capture this possible nonlinearity. In Tables 4, column 5 shows the results of fixed-effect OLS regression including *CV_DEV* as an explanatory variable, while column 6 reports the beta coefficients, which measure the standardised impact of each independent variable. Column 7 shows the results of fixed-effect OLS regression including *CV_SQ* as an explanatory variable, and column 8 shows the beta coefficients of the model. Table 5 is presented in similar approach. Given that the results of the models with different nonlinear variables are highly consistent, the following discussion primarily focus on the result of the models with *CV_SQ*, or columns 7 and 8.

In Table 4, the R square is 0.431, implying that this model can explain 43.1% of variances in US export share among Asian countries at the industry level. More specifically, the result shows that the exchange rate volatility (CV) has a negative impact on export share at the significance level of 0.05, lending support to Hypothesis 1. As the exchange rate of an economy becomes more volatile, it results in a redirection of exporting shipments from this economy to other economies. Also, both measures of nonlinearity show significant results. In column 5 of Table 4, the results show that as the deviation of CV is higher than the average level, the impact of CV on export share is diminishing. In column 7, the coefficient of squared term of CV is significant at a 0.05 level, implying a U-shape relationship between CV and export share, providing support to Hypothesis 3. It may be noted that interestingly, the financial crisis variable, *CRISIS*, is statistically not significant, failing to support Hypothesis 5.

The control variables of the export share model show the signs as expected. In column 7 of Table 4, the one-year trend of exchange rate, *SLOPE*, has a marginally negative impact on the export share at the significance level of 0.01. When the currency is depreciating (i. e. more local currency is needed to exchange for one US dollar), the product made in the US becomes more expensive, discouraging the demand in the destination economy to import goods from the US The GDP and GDP per capita of the destination economy have a positive impact on the export share, implying that a bigger economy and a 'richer customer' will buy more. In addition, longer distance between the US and the destination economy has a negative impact on the export share because of higher transport costs and less familiarity. The growth of GDP is statistically insignificant even though the positive sign of the estimated cost is fairly intuitive in the case of the export share specification. Quite importantly, consistent with basic economics, the results show that if the unit value of a product is higher in the destination economy, the higher export prices will encourage the US manufacturers to export more shipments to that economy. Based on the beta coefficient in column 8, the GDP has the highest impact on the export share. Next to the GDP, GDP per capita, distance, exchange rate volatility, and export prices are ranked among the top five factors that affect the export share.

Table 4 Regression result – export share model

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
	DV: XS	*DV: XS*	*DV: XS*	*DV: XS*	*DV: XS*	*Beta*	*DV: XS*	*Beta*
CV				–0.00901	–0.0345***	–0.0783	–0.0325**	–0.0739
				(0.00679)	(0.0116)		(0.0130)	
CV_DEV					0.0398***	0.0746		
					(0.0146)			
CV_SQ							0.286**	0.0659
							(0.135)	
CRISIS			0.000337	0.000582	0.000137	0.0040	0.000418	0.0123
			(0.000473)	(0.000508)	(0.000533)		(0.000513)	
SLOPE		–0.00294*	–0.00339*	–0.00273	–0.00300	–0.0235	–0.00368*	–0.0288
		(0.00179)	(0.00189)	(0.00196)	(0.00196)		(0.00201)	
DIST	–0.00675***	–0.00656***	–0.00653***	–0.00651***	–0.00629***	–0.1004	–0.00624***	–0.0996
	(0.00103)	(0.00103)	(0.00103)	(0.00103)	(0.00104)		(0.00104)	

Notes: Standard errors in parentheses: ***p < 0.01, **p < 0.05, *p < 0.1.

Table 4 Regression result – export share model (continued)

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
	DV: XS	*DV: XS*	*DV: XS*	*DV: XS*	*DV: XS*	*Beta*	*DV: XS*	*Beta*
GDP	0.00101***	0.00102***	0.00102***	0.00102***	0.00104***	0.2391	0.00104***	0.2399
	(7.04e-05)	(7.05e-05)	(7.06e-05)	(7.06e-05)	(7.08e-05)		(7.11e-05)	
GGDP	0.00311**	0.00235*	0.00217	0.00186	0.00212	0.0221	0.00223	0.0232
	(0.00134)	(0.00141)	(0.00144)	(0.00146)	(0.00146)		(0.00147)	
GDPPC	0.0836***	0.0805***	0.0798***	0.0789***	0.0779***	0.1344	0.0789***	0.1361
	(0.00814)	(0.00836)	(0.00841)	(0.00844)	(0.00844)		(0.00843)	
XPRICE	0.000552***	0.000561***	0.000562***	0.000575***	0.000613***	0.0547	0.000583***	0.0520
	(0.000147)	(0.000147)	(0.000147)	(0.000147)	(0.000148)		(0.000147)	
Industry dummies	Included	Included	Included	Included	Included		Included	
Constant	0.0701***	0.0685***	0.0682***	0.0682***	0.0667***		0.0660***	
	(0.00931)	(0.00936)	(0.00937)	(0.00937)	(0.00938)		(0.00943)	
Observations	3,360	3,360	3,360	3,360	3,360		3,360	
R-squared	0.430	0.430	0.430	0.431	0.432		0.431	

Notes: Standard errors in parentheses: ***p < 0.01, **p < 0.05, *p < 0.1.

Table 5 Regression result – import share model

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
	DV: MS	*DV: MS*	*DV: MS*	*DV: MS*	*DV: MS*	*Beta*	*DV: MS*	*Beta*
CV				–0.0452***	–0.137***	–0.1974	–0.110***	–0.1592
				(0.0123)	(0.0209)		(0.0236)	
CV_DEV					0.142***	0.1692		
					(0.0264)			
CV_SQ							0.790***	0.1154
							(0.244)	
CRISIS			0.000335	0.00156*	–0.00000534	–0.0001	0.00112	0.0208
			(0.000854)	(0.000916)	(0.000957)		(0.000925)	
SLOPE		–0.00353	–0.00397	–0.000657	–0.00154	–0.0076	–0.00327	–0.0162
		(0.00322)	(0.00341)	(0.00352)	(0.00351)		(0.00361)	
DIST	–0.00614***	–0.00592***	–0.00588***	–0.00585***	–0.00517***	–0.0523	–0.00514***	–0.0520
	(0.00186)	(0.00188)	(0.00188)	(0.00188)	(0.00187)		(0.00189)	

Note: Standard errors in parentheses: ***p < 0.01, **p < 0.05, *p < 0.1.

Table 5 Regression result – import share model (continued)

Variables	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*
	DV: MS	*DV: MS*	*DV: MS*	*DV: MS*	*DV: MS*	*Beta*	*DV: MS*	*Beta*
GDP	0.00240***	0.00241***	0.00241***	0.00243***	0.00248***	0.3626	0.00248***	0.3629
	(0.000127)	(0.000127)	(0.000128)	(0.000127)	(0.000127)		(0.000128)	
GGDP	0.00937***	0.00845***	0.00827***	0.00673**	0.00761***	0.0503	0.00770***	0.0510
	(0.00241)	(0.00255)	(0.00260)	(0.00262)	(0.00262)		(0.00264)	
GDPPC	–0.0439***	–0.0478***	–0.0484***	–0.0558***	–0.0641***	–0.0702	–0.0576***	–0.0630
	(0.0158)	(0.0162)	(0.0163)	(0.0164)	(0.0164)		(0.0164)	
MPRICE	–0.0000999	–0000958	–0.0000954	–0.0000959	0.000157	0.0123	0.0000544	0.0043
	(0.000208)	(0.000208)	(0.000208)	(0.000209)	(0.000210)		(0.000210)	
Industry dummies	Included	Included	Included	Included	Included		Included	
Constant	0.0625***	0.0606***	0.0603***	0.0611***	0.0567***		0.0553***	
	(0.0169)	(0.0170)	(0.0170)	(0.0170)	(0.0169)		(0.0171)	
Observations	3,515	3,515	3,515	3,515	3,515		3,515	
R-squared	0.219	0.220	0.220	0.223	0.229		0.225	

Note: Standard errors in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

In Table 5, the result in column 7 shows that the exchange rate volatility has a negative impact on import share at the significance level of 0.01, providing strong support to Hypothesis 2. This finding substantiates that an industry shifts the source of importing from the economy with high exchange rate volatility to other economies with stable exchange rate. Further, we test the possible nonlinear relationship between exchange rate volatility and import share. The result in column 7 shows that CV has a diminishing impact on the import share when the CV is higher than the average level. The squared term of CV shows a positive impact on the import share at a 0.01 significance level, implying a U-shape and lending support to Hypothesis 4. About the moderating effect of global financial crisis, the global financial crisis is not found to have any direct impact besides its effect via higher exchange rate volatility. Hence, Hypothesis 6 is not supported.

Table 6 Regression result – the impact of forward market

Variables	*(1)*	*(2)*
	DV: XS	*DV:MS*
CV	–0.0357**	–0.112***
	(0.0139)	(0.0252)
CV_SQ	0.252*	0.773***
	(0.145)	(0.261)
X_CV_Forward	0.00718	0.00356
	(0.0107)	(0.0194)
CRISIS	0.000452	0.00113
	(0.000516)	(0.000930)
SLOPE	–0.00369*	–0.00327
	(0.00201)	(0.00361)
DIST	–0.00615***	–0.00510***
	(0.00105)	(0.00190)
GDP	0.00105***	0.00248***
	(0.0000723)	(0.000130)
GGDP	0.00218	0.00767***
	(0.00147)	(0.00264)
GDPPC	0.0813***	–0.0565***
	(0.00915)	(0.0174)
XPRICE	0.000585***	
	(0.000147)	
MPRICE		0.000058
		(0.000211)
Constant	0.0652***	0.0549***
	(0.00951)	(0.0172)
Observations	3,360	3,515
R–squared	0.432	0.225

Notes: Standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Most control variables of the import share model show the signs as expected. The trend of one-year exchange rate of the origin economy has no impact on the import share. The GDP and the growth of GDP of the origin economy have a positive impact on the import share. The distance has a negative impact on import share. However, the GDP per capita appears a negative impact on the import share. A possible explanation is that higher income level of origin economy leads to more demand for domestic market, leading to less capacity allocated for export. The relative import price does not have significant impact on import share when other variables are controlled. This finding can be explained by the high correlation between the GDP per capita and relative import price. As the income level of the origin economy goes up, the price of product made in that economy becomes higher, leading to less competitive price in the global market. The negative impact was already reflected by the negative coefficient of GDP per capita and the impact of relative import price becomes insignificant. Based on the beta coefficient in column 8, the GDP is still the most important factor that affects the import share. Note that the exchange rate volatility is the second important factor, followed by GDP per capita, distance, and the growth of GDP.

5 Discussion

As globalisation has firmly taken hold in all parts of the globe, exchange rate volatility inevitably has a significant role in firms' global supply chain decisions and governments' trade policy. This study has revealed the relationships between exchange rate volatility and export and import shares at the industry level. First, this study finds such relationships are inversely related but are nonlinear. The impact of exchange rate volatility on trade share is diminishing as the variability grows. Further, we can estimate the tipping point when such relationship becomes positive. Based on the result in column 7 of Table 4, when CV is lower than 0.056 (= 0.0325/(0.286*2)), higher CV of exchange rate leads to lower export rate. Given that the CV is 0.023 on average with standard deviation of 0.02 (see Table 2), it is estimated 95% of CV is below the tipping point of 0.056 based on the z-value of 1.65 (= (0.056-0.023)/0.02). Note that the average CV is higher than the tipping point during global financial crisis. It means that an industry does reduces its export share to an economy with higher exchange rate volatility for most situations, except for the period of excessively high CV like the global financial crisis in 2008.

This finding provides evidence that exchange rate uncertainty has an important role in an industry's export decisions. When all the demand factors are the same, the economies with more stable exchange rate are more attractive to exporters. Furthermore, such relationship becomes less prominent when the exchange rate volatility becomes extremely high. History has shown that the CV of four countries, including Indonesia, South Korea, India, and Philippine, surged higher than 0.06 during the period of global financial crisis in 2008 (see Figure 1). The diminishing effect of exchange rate volatility can be explained by the trade-off between the substitution effect and the income as mentioned in Section 2 literature review and hypotheses development**.**

Given that previous literature indicates that a forward contract may reduce the negative impact of exchange volatility on trade (Ethier, 1973; Baron, 1976; Viaene and de Vries, 1992), this study further tests whether the existence of forward contract can reduce the impact of exchange rate volatility on trade. Ma et al. (2004) indicate that

non-deliverable forward (NDF) markets are available for six Asian currencies: Chinese Yuan, Indian Rupee, Indonesian Rupiah, South Korean Won, Philippine Peso, and New Taiwan Dollar. To examine whether the existence of forward market affects the impact of exchange rate volatility, an interaction term between CV and the dummy variable of forward market (1 for the existence of forward contract and 0 for non-existence) was included in the export share model. The results presented in Table 6 show that the coefficient of the interaction term is insignificant, implying that the existence of forward contracts does not affect the impact of exchange rate volatility on export share. This finding echoes the argument of Ozturk (2006), which indicates that exchange rate risk is generallynot hedged because forward markets are not accessible to all traders and come with costs and limitations and that such markets may be incomplete or imperfect.

In addition, this study also finds a U-shape relationship between exchange rate volatility and import share. Based on the result of Column 7 of Table 5, when CV is lower than 0.07 (= 0.11/(0.79*2)), higher CV of exchange rate leads to lower import rate. Based on the average and standard deviation of CV in Table 2, it is estimated that 99.06% of CV is below the tipping point of 0.07 based on the z-value of 2.35 (= (0.07 – 0.023)/0.02). It means that an industry imports fewer items from an economy with higher exchange rate volatility for most situations. Following similar procedure above, this study tests whether the existence of forward contract can reduce the impact of exchange rate volatility on import share (see Table 6). The coefficient of the interaction term between CV and the dummy variable of forward market remain insignificant. It shows that even when forward market is available, the exchange rate volatility still has a strongly negative impact on the import share.

This finding has important managerial implications to practitioners. As mentioned above, ‘supply chain 2.0’ calls for building structural flexibility into the supply chain design. Facing supply chain turbulences such as a surge in currency exchange rate, firms with geographically diverse customer bases can easily shift their sales among customers. Firms with geographically diverse sourcing bases can procure materials from or outsource production to alternative suppliers. However, geographic diversification has both pros and cons. Cho et al. (2017) find that high geographic diversification leads to lower financial performance during a stable period but higher market performance during a financial crisis. Christopher and Holweg (2017) argue that firms need to find balance between internal and external recovery costs and resilience cost. Therefore, firms need to consider potential exchange rate volatility in the design of supply chain network and develop resilient portfolios of customers and suppliers (Schwieterman et al., 2017).

In addition, when firms are selecting production locations for supply chain network, the stability of exchange rate can be an important factor. The beta coefficients in Column 8 indicate that the exchange rate volatility is the second most important factor that affects their sourcing decisions. Facing increased exchange rate volatility of an economy, firms may choose to reduce the percentage of raw materials from the suppliers in that economy or relocate their production activities to another economy with lower exchange rate volatility. Liu and Nagurney (2011) argue that when exchange rate becomes more volatile generally, firms may tend to reduce the percentage of offshore production and simultaneously increase the percentage of domestic in-house production. Our finding is consistent with their argument.

Furthermore, the finding of this study has important implications for government policymakers. Government can play an important role in managing the exchange rate volatility. Emerging economies such as China, Vietnam, and India cannot overlook the

importance of exchange rate stability when they are competing for foreign direct investments (FDIs). The result shows that the economy with lower exchange rate volatility attracts more export and import, implying that more FDIs will flow to that economy. Hence, to attract more investments from MNCs, policymakers of emerging economies could consider a managed floating policy to keep exchange rate more stable. Recently, there has been a strong push for 'bringing jobs back to the US' from an increasing number of multinational manufacturers as well as the US politicians. With increasing turbulences in the world affecting the stability of exchange rate, domestic production seems to become an appealing option to US manufacturers. All else being equal, a reduced exchange rate risk could support a policy for the US manufacturers to choose to produce in their home country. However, since this argument can be used by all other countries which would lead to reduction in global trade, the 'First Best' solution remains for the policymakers especially the Central Banks and Monetary Authorities around the World to strive for a relatively stable exchange rate regimes.

6 Conclusions

Exchange rate volatility is considered one of the most important factors that affect global supply chain decisions and also one of the biggest threats to the resilience of supply chain (The Economist Intelligence Unit, 2009). Using annual US trade statistics and manufacturing industry data for the years 2002–2015 between the US and its top 12 Asian trading partners, this study aims to estimate the impact of exchange rate volatility on firms' global supply chain decisions through export and import empirical data at the industry level. The findings show that exchange rate volatility has a negative and essentially nonlinear impact on the on the choices of export destinations and import origins. When the exchange rate volatility is excessively high, higher volatility leads to more export and import.

This study has both analytical as well as managerial significance. It fills a gap left by the existing studies of trade shares/volume and global supply chain research which have limited policy usefulness as they either use mathematical modeling approaches or estimate the relationship at the country level. To our knowledge, this paper is among the first empirical studies that use archival data to examine the impact of exchange rate volatility on the industry-level geographic diversification of global supply chain network and draws strong and practical policy implications. The findings provide evidence about how practitioners make global supply chain decisions in response to the exchange rate uncertainty. Specifically, this study highlights the importance of exchange rate volatility in the global supply chain decisions at the micro level of industries.

As a part of these concluding records, some caveats are in order. There are a few of limitations in this study which as such also represent opportunities for future research. First, this study uses aggregate industry level data to estimate the global supply chain decisions in response to exchange rate volatility. Given that firms are the actual decision makers, firm level data may provide even richer information to understand the decision maker's behaviour. Second, not all important US trade partners are included in the sample. This study includes the trade links between the US and 12 Asian trade partners, and most of them are developing economies. The behaviours of the firms in the developed countries like European countries can be different from those in the sampled countries.

In conclusion, given the above caveats, this study breaks new empirical ground by specifying, estimating and analysing for various manufacturing industries of the US, the impact of exchange rate volatility (net of other control factors) on the US trading partner's share of imports and exports in global supply chain. The findings show that exchange rate volatility has an inverse yet nonlinear relationship regarding the choices of export destinations and import origins at the level of industries. These findings have strong and very significant managerial policy implications.

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