경제학박사학위논문

The Effects of Technology Shocks on Real Exchange Rate and Net Exports: A Cross-Country Perspective

생산성 충격이 실질 환율과 순수출에

미치는 영향의 국별 비교

2021 년 2월

서울대학교 대학원

경제학부 경제학 전공

박미숙

The Effects of Technology Shocks on Real Exchange Rate and Net Exports: A Cross-Country Perspective

생산성 충격이 실질 환율과 순수출에 미치는 영향의 국별 비교

지도교수 김 소 영

이 논문을 경제학 박사 학위논문으로 제출함

2020년 12 월

서울대학교 대학원

경제학부 경제학 전공

박 미 숙

박미숙의 박사 학위논문을 인준함

2020년 12월

위 원 장 김 종 섭 (인)

부 위 원 장 김 소 영 (인)

위 원 안 재 빈 (인)

위 원 문 성 만 (인)

위 원 방 호 경 (인)

Abstract

The Effects of Technology Shocks on Real Exchange Rate and Net Exports: A Cross-Country Perspective

Misook Park

Department of Economics

The Graduate School

Seoul National University

International transmission of productivity shock, specifically the effects on the real exchange rate (RER), is a widely discussed issue, but a large share of the literature consists of theoretical modeling, and the predictions of the models are inconsistent. Empirical studies are limited to shocks in large economies, mainly the US, and the aggregate impact on the global economy is tested. In other words, previous studies investigate how the world economy as a whole is affected by productivity growth in large economies. This thesis, however, investigates the effects of US productivity shocks on 48 individual countries and finds that the responses can differ, depending on country characteristics. In addition, productivity shocks in small open economies are investigated and the responses are compared to the results found in a large economy, the US.

First, this study investigates the effects of US productivity shock on 48 countries. US productivity shock is identified via sign restrictions in the Vector

Autoregressive (VAR) model and the influence of country characteristics on the effects is tested with cross-country Ordinary Least Square (OLS). This study finds novel evidence that aggregate US RER appreciates but bilateral RER can appreciate or depreciate, depending on country characteristics. A country experiences appreciation in US RER if it has high consumption home bias, a strong trade relationship with the US, or its economy is more open to trade. Aggregate US net exports decline because of decreased exports and increased imports. In terms of bilateral trade, US exports to countries where the US RER appreciates more decline, and imports of intermediate goods to the US increases. US net exports increase to countries where the financial markets are more complete.

Second, this study investigates productivity shocks in 10 small open economies and documents the responses of aggregate RER and net exports. The 10 countries are Japan, South Africa, Canada, France, Norway, Finland, Germany, Ireland, Australia, and the UK. While the RER appreciates and net exports decrease in the US after productivity growth, there are varied responses in small open economies. An appreciation in the RER, similar to the effect in the US, is witnessed in a group of countries where strong wealth effect occurs and there is a high consumption home bias.

Keywords: productivity shocks, real exchange rate, net exports, country characteristics, small open economies, VAR, home bias, wealth effect

Student Number: 2012-30051

Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

This thesis analyzes productivity shock and its international transmission, specifically its effect on the real exchange rate (RER) and net exports. International transmission of productivity shock is a widely discussed issue but the predictions of models in the literature are diverse and poorly tested. A large share of the literature implemented theoretical models. Therefore, empirical evidence to support theoretical prediction is weak. Moreover, empirical studies examine shocks in large economies, such as the US and the EU, and they investigate the impacts of the shocks on the global economy. Consequently, the effects of the shock on individual countries are seldom reported, and studies on shocks in small economies are scarce.

Two popular models used in the literature to analyze the response of the RER to productivity shock are the international real business cycle (IRBC) model and the Harrod–Balassa–Samuelson (HBS) framework. The IRBC model is used to examine short–run RER movements while the HBS model predicts long–run equilibrium movements.

The standard IRBC view is widely accepted in the field of economics. Key studies are from Backus et al. (1994), Stockman and Tesar (1995), and Cole and Obstfeld (1991). The standard model asserts that productivity shock in a home country brings positive transmission effects to neighboring countries because the international relative price of products from home decreases due to increased output.[1] In other words, if a country experiences productivity growth, its RER depreciates and neighboring countries benefit from cheaper products from that country. However, recent IRBC studies produced contradicting theoretical and empirical evidence that indicate that appreciation in the RER is possible. While a depreciation in the RER caused by productivity growth is considered to have a positive impact on neighboring countries, an appreciation can cause a negative impact. If the RER of a country appreciates due to productivity growth, goods from that country become expensive to other countries. The rest of the world faces higher import price from the country where the productivity shock occurred. If US productivity grows, the international price of US goods increase due to the appreciation in the US RER, which means that the rest of the world will import US goods at a higher price even though the US output has increased. The rest of the world is considered to be negatively affected by a US productivity shock because of the higher price of US goods. Thus, the appreciation in the RER in response to a productivity shock is regarded to have a negative international spillover. A study by Corsetti et al. (2008) was the first to suggest that appreciation in the RER with the standard IRBC model, and a subsequent study by Corsetti et al. (2014) provides empirical support with US data. According to their studies, wealth effect and consumption home bias are key features to explain the RER appreciation. The appreciation mechanism in those studies is as follows. Productivity growth raises the relative wealth of the home country where the shock occurs. If the financial market in the home country is incomplete, household consumption

[1] Home country indicates the country where productivity shock occurs.

increases along with the increased wealth. In addition, if consumption in that country is biased toward domestically produced goods, consumption demand for domestic products rises excessively. Accordingly, the price of domestic goods increases and the RER appreciates. Empirical studies, such as those by Enders and Müller (2009) and Nam and Wang (2018), and the theoretical research of Hamano (2013), Akkoyun et al.(2017), and Kollmann(2016) also report RER appreciation. Those empirical studies investigated the productivity shock in the US as Corsetti et al. (2014) did, but different methods of shock identification were adopted in the Vector Autoregressive (VAR) model.[2] Theoretical models employ different assumptions, such as a complete financial market, cointegrated total factor productivity (TFP) shocks among countries, and recursive preference.[3] Those empirical studies analyzed shocks in large economies, mainly the US, and investigated the aggregate impacts on the world economy. Impacts on multiple individual countries have not yet been examined.

The traditional HBS framework predicts that the RER appreciates in the long-run. The basic idea was introduced and developed by Harrod (1933), Samuelson (1964), and Balassa(1964). The model was developed to be more mathematically rigorous in follow-up studies. The basic idea is that productivity growth in the tradable sector induces higher wages in not only that sector but also in non-tradable sectors. When assuming the law of one price, the price of tradable goods is identical across countries while the price of domestic non-

[2] Ender and Müller(2009) and Nam and Wang(2018) identifiy technology shocks with long-run restrictions.

[3] Kollmann(2016) assumes complete financial market and recursive preference, and Akkoyun et al.(2017) assume cointegrated shocks.

tradable goods increases due to higher wages. Accordingly, higher prices in domestic non−tradable goods makes domestic consumption more expensive and results in long−run RER appreciation. However, Berka et al. (2018) point out that there is little empirical evidence for the HBS effect, specifically with time series data of high−income and financially developed countries with floating exchange rates. Previous empirical studies only present significant evidence for a long−run relationship between RER and productivity.[4] Berka et al. (2018) state that the problem stems from a number of factors. First, while the HBS effects emphasize sectoral productivity, few studies use sectoral TFP data. Instead, many studies employ income level as a proxy for productivity. Second, even if sectoral TFP data is used, the data is in index and not applicable for cross−country comparison. Third, other factors that impact the RER, such as nominal exchange rate volatility and labor supply shocks, are not controlled. With these shortcomings, past empirical studies document meaningful results mainly for long−run cointegration, such as Chinn and Johnstone (1997) and Canzoneri et al. (1996). Berka et al. (2018) have overcome those drawbacks and have documented significant evidence with EU data that the RER can also appreciates in the short−run. Even though a recent study by Berka et al. (2018) report appreciation in the RER, there are many studies that report results that conflict with the HBS prediction. Gubler and Sax (2019) suggest that the HBS seems not to hold with the data of 23 OECD countries, Lee and Tang (2007) present opposite results to the HBS theory,[5] and Choudri and Schembri (2010,

---

[4] Berka et al. (2018) describe that many studies report evidence of cointegration of real exchange rate and productivity.

[5] Lee and Tang (2007) measure productivity either labor productivity or total factor

2014) and Bordo et al. (2017) have found that RER reaction to productivity shock can differ, depending on the parameter values of each economy, such as home bias and elasticity of substitution.[6]

To summarize the findings of two mainstream theories, theoretical modeling accounts for a large share of the studies, and the predictions of the models are inconsistent. Since empirical studies are limited and proper data was not used, the theories could not be confirmed empirically. Even though recent empirical works produced significant results to back each theory, they investigate shocks in large economies and analyze aggregate impacts on the world economy.

This study differs from the literature in two respects. First, this thesis invetigates productivity shock in the US and finds that the impacts can vary across countries, depending on country characteristics. Previous studies have investigated how the world economy as a whole is affected by the shocks. They did not address the effects on an individual country level. This thesis, however, investigates the effects of US productivity shock on 48 countries and reports novel evidence that the RER and net exports can respond in any direction, decrease or increase, depending on country characteristics. It finds that the possible factors that cause the responses to vary across countries. Second, this

productivity(TFP). Real exchange rate appreciates when productivity is measured using labor productivity, but it depreciates when it is measured using TFP. RER responses to TFP growth is contrary to the prediction of HBS theory.

[6] Choudri and Schembri (2010, 2014) propose that the response of RER differs depending on trade elasticity between domestic and foreign tradable goods. While low and high elasticity causes RER to appreciate, middle range of elasticity results in the depreciation of RER. Bordo et al.(2017) suggest that RER response to productivity growth varies depending on elasticity of substitution and home bias of consumption, and these parameters change over time.

study does not only investigate shocks in large economies but also in small open countries. Former empirical works focus on the productivity growth in large economies, namely the US and the EU. However, this thesis analyzes shocks in small countries, such as Japan, South Africa, Canada, France, Norway, Finland, Germany, Ireland, Australia, and the UK. It finds that the RER and net exports in small open economies can react contrary to the US and the parameter values of each economy can contribute to the varied responses.

Chapter 2 analyzes productivity shock in the US and its impacts on 48 countries. US productivity growth is identified via sign restrictions in the VAR model. The US aggregate RER appreciates and aggregate net exports decrease after productivity growth, where RER and net exports are measured between the US and the rest of the world. This is consistent with the study by Corsetti et al. (2014). However, the results from the bilateral relationship between the US and 48 individual countries vary, depending on country characteristics. The impact of country characteristics on the effect is tested with cross-sectional Ordinary Least Square (OLS). The results show that a country experiences strong negative effects, which means more appreciation in the US RER, if there is a high consumption home bias, if there is a strong trade relationship with the US, or if it is open to trade. The US aggregate net exports decline after productivity growth when the US RER appreciates. When decomposing net exports into exports and imports, US exports to partner countries where the US RER appreciates decrease and the US increases imports of intermediate goods. In addition, US net exports to countries with complete financial markets increase.

Chapter 3 documents the empirical results of productivity shocks in 10 small open economies. Productivity shocks are measured in two sectors: 1) the manufacturing sector and 2) the entire economy. While the RER in the US appreciates after productivity growth, it shows varied movement in each of the small open economies. An appreciation in the RER, similar to the case of the US, is witnessed where a strong wealth effect occurs and consumption home bias is high. Chapter 4 concludes the study.

Chapter 2. Productivity Shock in the US and Its Effects on 48 Countries

2.1 Introduction

What impact does productivity shock have on the RER? Previous literature approaches this issue by using two models: IRBC model and HBS model. A large share of the previous studies centers on theoretical modeling, and the predictions of the two models are not supported with empirical evidence. Generally, the IRBC theory predicts short-run depreciation and the HBS forecasts long-run appreciation. However, predictions for the movement of RER are conflicting even under the same model, and some studies propose that the theories do not hold.[7] All these inconsistent results are as a result of a lack of empirical studies.

Recently, significant empirical works by Berka et al. (2018) and Corsetti et al. (2008, 2014), in both the IRBC and HBS fields, have been published. Traditional HBS theory predicts long-run appreciation in the RER but there was little empirical evidence due to the poor sectoral data regarding productivity. Berka et al. (2018) point out the problems with the data in previous studies and mention that reliable results with insufficient data were long-run cointegration between the RER and productivity. Berka et al. (2018), however, have overcome the previous problem with the data and

[7] Gubler and Sax(2019) show that RER depreciates in response to productivity growth since 1980s unlike HBS theory expects. They use annual data of 23 OECD countries and show that HBS effects are not valid for 1984-2008 while they are for 1970-1992.

document appreciation in the RER even in the short-run. The standard IRBC model asserts that productivity shock leads to depreciation in the RER. However, Corsetti et al. (2008, 2014) have found appreciation in the RER for the first time with the standard IRBC model and document empirical evidence with US data. Follow-up studies, such as by Enders and Muller (2009), Nam and Wang (2018), Hamano (2013), and Kolmann (2016), apply additional assumptions to the basic model or employ a new method to identify productivity shock. They also report appreciation in the RER. Recent empirical studies using both theories suggest that the RER can appreciate in response to productivity growth. However, they analyzed shocks in large economies, namely the US and the EU, and present aggregate impacts on the world economy. Even though aggregate US RER appreciates, bilateral RER of the US to individual neighboring countries can move in the opposite direction or the magnitude of appreciation can vary. However, there is no empirical study that examined the effect on multiple individual countries.

The contribution of this thesis is to investigate the effects of a US productivity shock on 48 individual countries and to discover what factors cause the reaction to vary across countries. The work done by Corsetti et al (2008, 2014) is a benchmark study and this thesis develops it further. The Corsetti et al (2008, 2014) studies have found aggregate impacts of a US productivity shock on the global economy, but this thesis extends the analysis to individual countries.

This analysis consists of two procedures. The first stage is to identify a US technology shock via sign restrictions of the VAR model and to establish the movement of the US RER and net exports from both aggregate and bilateral perspectives. The second stage is to run a cross-country regression of estimated responses from the first stage and to establish whether the responses can vary, depending on country characteristics.

The results indicate that a US technology shock leads to an appreciation in aggregate US RER and a decline in US aggregate net exports, which is consistent with the findings of Corsetti et al. (2014). However, the responses of individual countries to US technology shock can be diverse. To determine what country characteristics cause such differences, cross-country OLS was used. The characteristics are 1) consumption home bias, 2) trade intensity with the US, 3) completeness of financial markets, 4) trade openness, and 5) exports of intermediate goods to the US. Some of these factors appear as parameters in theoretical literature, but they have never been tested empirically.[8] In terms of RER responses, the regression results show that the US RER appreciates more in countries with high consumption home bias, strong trade relationship with the U.S, and more openness to trade. In terms of net exports, US exports decrease as the RER appreciates and imports of intermediate goods increase. Net exports from the US to countries with more complete financial markets increase.

The traditional view of the IRBC model, which states that a productivity growth in a country has positive spillover effects to its neighboring countries,

[8] Corsetti et al. (2008, 2014) assume that consumption bias for home goods exists and financial market is incomplete. Those parameters are included in the theoretical model and calibrated only for the US. But this paper measures them for 48 individual countries.

is widely accepted. According to this view, US productivity growth results in a depreciation in the US RER, which indicates lower international price of US goods. Other countries then benefit from cheaper US products. However, recent empirical studies suggest that a US productivity shock induces price increases in US goods, which means that US productivity growth can have a negative impact. These results are also confirmed in this study, which extends the knowledge of recent empirical studies and finds that negative transmission of a US productivity shock can be strong in countries with a high home bias of consumption, a strong trade relationship with the US, and high trade openness.

Chapter 2.2 describes the VAR model and reports the effects of a US productivity shock on the RER and net exports. Chapter 2.3 determines the country characteristics that induce different effects across countries. Chapter 2.4 describes extended experiments to check the robustness of the results, and Chapter 2.5 concludes the study.

2.2 Productivity Shock and Its Impact

A. Structural VAR Model with Sign Restrictions

I estimated the effects of US productivity shock on the RER and net exports with a structural VAR model. A US productivity shock was identified via sign restrictions proposed by Uhlig (2005). Signs imposed on key variables follow Corsetti et al. (2008).

Technology shock in this study is set as a standard TFP shock for all traded goods produced in the US. Technology shock was introduced as TFP by Kydland and Prescott (1982) and various measurement methods were developed later. Ramey (2016) reviewed the literature for macroeconomic shocks and synthesized the methods for the estimate. According to the study, three methods are mainly used in the VAR model to identify technology shock: (1) the long-run restriction of Gali (1999), (2) the sign restrictions from Uhlig (2005), and (3) the news shock from Barsky and Sims (2011). While news shock refers to an expectation that productivity will improve in the future, long-run and sign restrictions are used to identify already realized shocks. Identification with long-run restrictions assumes that only a technology shock can have a permanent effect on labor productivity. However, later studies suggest that other factors can induce a permanent change on labor productivity and long-run restrictions can cause distortions in the estimates.[9] Considering the shortcomings of long-run restrictions, this study selected sign restrictions to identify technology shock. The sign restrictions imposed on the variables were set similar to Corsetti et al. (2008).

I implemented a structural VAR model with six endogenous and six exogenous variables. The vector representation of the model follows Uhlig (2005). The VAR model assumes that all endogenous variables are dependent on their past values of order p. Thereafter, the model is set as equation (1).

Structural-form VAR model : $AY_t = C(L)Y_{t-1} + v_t$

[9] Uhlig (2004) argues that other shocks affect labor productivity in the long run such as dividend tax shocks and preference shocks. Juvenal (2011) describes that substantial distortions can arise from a small-sample bias (Faust and Leeper, 1997) or a lag-truncation bias (Chari et al., 2007).

$$E\left[v_t v_t^{'}\right] = I_m \quad \cdots\cdots\cdots (1)$$

where Y_t is a vector of 6x1 of endogenous variables. Y_t consists of 1) labor productivity of manufacturing sector, 2) manufacturing output, 3) consumption, 4) relative price of manufactured goods, 5) relative output of manufacturing sector, 6) RER or net exports. To avoid having too many variables in the model, the first five variables were fixed and the sixth variable set as RER or net exports. A is a square matrix of structural parameters, which represents the contemporaneous relationship among endogenous variables. C(L) is a lag polynomial of order p, where $C(L) = C_0 + C_1 L + C_2 L^2 + \cdots + C_p L^p$. v_t is a vector of exogenous variables, and the elements of v_t are mutually orthogonal and normalized to be of variance 1, thus, $E\left[v_t v_t^{'}\right] = I_m$. v_t is interpreted as structural shock. For instance, the first element of v_t refers to unexpected shocks to labor productivity, the second element indicates unexpected shocks to manufacturing output, and those two shocks are independent. Equation (1) is a structural model since it is derived from underlying economic theory, and the parameters and shocks can be interpreted with economic meaning.

The structural model cannot be estimated directly. Thus, it was modified by multiplying by A^{-1}, then the reduced-form model was derived. The reduced-form model was estimated by OLS and the parameters of the structural model were restored by implementing certain restrictions.

Reduced-form VAR model: $Y_t = A^{-1} C(L) Y_{t-1} + A^{-1} v_t$

$$= B(L) Y_{t-1} + u_t$$

$$E\left[u_t u_t^{'}\right] = \Sigma \quad \cdots\cdots\cdots (2)$$

where $\mathrm{B(L)} = A^{-1}C(L)$, and $\mathrm{u_t} = A^{-1}v_t$. Since $\mathrm{u_t} = A^{-1}v_t$, then $\mathrm{E}\left[\mathrm{u_t}u_t^{'}\right] = A^{-1}\mathrm{E}\left[v_t v_t^{'}\right]A^{-1'} = A^{-1}A^{-1'} = \Sigma$. The parameters of the reduced model, B(L) and Σ, were estimated by OLS. The purpose of the VAR model is to derive the responses of endogenous variables to structural shocks. In this study, its purpose is to find the responses of the RER and net exports to positive productivity shock. The responses of $\mathbf{Y}$ to structural shock up to k horizons is denoted as Ψ_{k}, and it can be computed using estimates of B(L) and A^{-1}.

$$\Psi_{\mathrm{k}} = \sum_{h=0}^{k} B_{k-h}\Psi_{\mathrm{h}} \;, \Psi_{0} = A^{-1}\mathrm{v}, \quad \mathrm{k} > 1, \mathrm{k} - \mathrm{h} \geq \mathrm{p} \quad \cdots\cdots\cdots (3)$$

Proposition 1 in the study by Uhlig (2005) shows that the structural parameter of A^{-1} can be represented as Pq, where P is a Cholesky decomposition of Σ and q belongs to the hypersphere of unitary radius. Since Σ is estimated, the A^{-1} can be computed from the Cholesky decomposition, q can be drawn from the unit sphere, and q can be interpreted as structural shock $\mathbf{v}$. Sign restrictions were imposed at this point to identify productivity shock and the Bayesian approach was adopted since Uhlig (2005) argues that the Bayesian approach is suitable for sign restrictions. Positive productivity shock drives prices up and output down. Numerous candidate vectors of q were drawn from the unit sphere while Σ and B(L) were drawn from a Normal-Wishart posterior. With the derived parameters, the impulse response, Ψ_{k}, was calculated. If a q vector induced restricted variables to react in accordance with the assumed signs, it was considered to be productivity shock and the results were retained. If the variables did not respond to the assumed signs, the q were discarded.

The endogenous variables of the VAR model and sign restrictions are demonstrated in Table 1. This study investigates the productivity shock in the tradable goods sector of the US, and the data of the manufacturing sector represents the tradable goods sector.

Table 1 Endogenous variables of VAR model and sign restrictions

	Variables		Sign restrictions
1	Log(Labor Productivity of US manufacturing sector)	$\log LP_{US}$	+
2	Log(Manufacturing production in the US)	$\log Y_{mf,US}$	+
3	Log(Private consumption in the US)	$\log C_{US}$	
4	Log(Relative price of manufactured goods in the US)[10]	$\log \frac{PPI_{mf,US}}{CPI_{service,US}}$	−
5	Log(manufacturing output relative to GDP in the US)	$\log \frac{Y_{mf,US}}{GDP_{US}}$	+
6[11]	Log(RER)	$\log RER$	
	Net exports of US to partner/GDP of partner,	$\frac{NE_i}{GDP_i}$[12]	

Positive productivity shock, or supply shock, raises output and lowers prices. Positive demand shock, such as monetary expansion, induces both output and prices to rise. While both positive demand shock and supply shock increase output, prices react in opposite directions in response to each shock. This study identified productivity shock imposing sign restrictions on prices and output variables, where price was set to decrease and output to increase. The effect

10 This relative price is a proxy for the relative price of US manufactured goods in terms of non-tradable goods. The price was measured as the log of relative US domestic producer price index of manufactured goods over the service consumer price index

11 The VAR model has 6 endogenous variables to avoid having too many variables, and the 6th variables are set as RER or net exports in turn.

12 i indicates trade partner of the US, and it can be a country or the rest of the world.

of demand shock was controlled, and the impulse responses were purely as a result of productivity shock. Four variables were employed to represent output and price, namely 1) labor productivity of the US manufacturing sector, 2) manufacturing production of the US, 3) manufacturing output relative to GDP in the US, and 4) the relative price of manufactured goods in the US. Positive signs restrictions were imposed on the output variable and negative signs restriction was imposed on the price variable. The detailed description and movement of variables followed Corsetti et al. (2008, 2014).[13] Productivity shock in the US tradable goods sector was set as an increase in labor productivity in US manufacturing relative to foreign labor productivity in the manufacturing sector in the model. When providing an impulse in productivity growth in the model, prices fall and output increases. This study imposed sign restrictions on four variables to identify productivity shock in the US tradable sector. The variables and corresponding signs are indicated in Table 1. Sign restrictions were placed for 20 quarters from the first quarter. For price, the restriction was imposed from the fifth quarter to consider nominal rigidities. I used the Bayesian approach suggested by Uhlig (2005) for estimation and inference. The reduced-form parameter, B(L) and Σ were drawn 1,000 times from the Normal-Wishart posterior of coefficients. For each draw of the parameters, impulse responses were simulated another 1,000 times, and only the responses that satisfied those sign restrictions were retained.

This study examines the effects of US productivity shock on individual countries and also reports the aggregate effects on the rest of the world to evaluate whether the results of this study are consistent with those in the

[13] Corsetti et al. (2008, 2014) set a standard open-economy DSGE model and derived the responses of price and output variables to productivity shock.

literature. Corsetti et al. (2014) set an aggregate of nine countries, where quarterly labor productivity data in the manufacturing sector is available, as the rest of the world (ROW). This study could obtain labor productivity data in the manufacturing sectors of seven countries from 1989 onwards and for five countries from 1981. Three different measures were used to build aggregate data for the rest of the world: 1) an aggregate of 5 countries (ROW1), 2) an aggregate of 7 countries (ROW2), and 3) an aggregate of all the countries in the world (ROW3). The aggregated variables, $\log LP_{ROW}$, $\log Y_{mf,ROW}$, $logC_{ROW}$, logRER, NE_{ROW}, and GDP_{ROW}, were average weighted by GDP shares at PPP values. The counterpart for the impact of US productivity shock is either ROW or individual countries. Table 2 shows how these counterparts are defined.

Table 2 Counterpart of US productivity shock

Counterpart	Sample periods	Countries	Notes
ROW1	1981–2017	Canada, Japan, Korea, Mexico, South Africa	An aggregate of 5 countries
ROW2	1989–2017	Canada, Japan, Korea, Mexico, South Africa, France, Norway	An aggregate of 7 countries
ROW3	1981–2017	All countries in the world	An aggregate of all countries
Individual country (i)	1993–2017	48 countries	48 individual countries

The impact of US productivity shock was examined in terms of individual countries (i) or the rest of the world (ROW). The variables of the VAR model were measured based on either US–i relation or US–ROW relation. The endogenous variables according to each counterpart are presented in Table 3.

Table 3 Endogenous variables of VAR model[14]

VAR variables	Counterpart of US productivity shock		
	ROW1, ROW2	ROW3	i (individual country)
1	$\log LP_{US} - \log LP_{ROW}$	$\log LP_{US}$	$\log LP_{US}$
2	$\log Y_{mf,US} - \log Y_{mf,ROW}$	$\log Y_{mf,US}$	$\log Y_{mf,US}$
3	$\log C_{US} - logC_{ROW}$	$\log C_{US}$	$\log C_{US}$
4	$\log \frac{PPI_{mf,US}}{CPI_{service,US}}$	$\log \frac{PPI_{mf,US}}{CPI_{service,US}}$	$\log \frac{PPI_{mf,US}}{CPI_{service,US}}$
5	$\log \frac{Y_{mf,US}}{GDP_{US}}$	$\log \frac{Y_{mf,US}}{GDP_{US}}$	$\log \frac{Y_{mf,US}}{GDP_{US}}$
6	$\log RER$[15]	$\log RER$[16]	$\log RER$[17]
	$\frac{NE_{ROW}}{GDP_{ROW}}$	$\frac{NE_{ROW}}{GDP_{US}}$	$\frac{NE_i}{GDP_i}$

[14] Labor productivity and manufacturing output variables are available for 5 and 7 countries. Those variables were input as the difference between the US and ROW where data was available, otherwise the US values were used.

[15] RER is an average of 5 or 7 countries, weighted by GDP shares at PPP value.

[16] RER is a real effective exchange rate of the US from Federal Reserve Economic Data.

[17] RER is a real exchange rate of US against individual country i.

B. Data

Quarterly data was used for the simulation. Labor productivity is real output per hour for all persons in the manufacturing sector, which was obtained from the Federal Reserve Economic Data (FRED). Manufacturing production is an index of real output with 2012 = 100, from FRED. Private consumption is household expenditure with real value, which was from the International Financial Statistics (IFS). The prices of US manufactured goods are measured by PPI for the total manufacturing sector, and the prices for non-tradable goods are measured by CPI for all urban consumers (services less energy services). Both of these were from FRED. Real GDP was obtained from FRED, and is in billions of chained 2012 dollars.

Bilateral US RER against i was calculated with the nominal exchange rate and price level of the two countries as follows:

$$\text{RER} = \text{E}\frac{P^{US}}{P^{i}} \cdots\cdots\cdots (4)$$

where E indicates nominal exchange rate, and P^{US} and P^{i} stand for price index of US and country i, respectively. The price index can be measured in various ways, such as CPI for all goods, CPI for manufactured goods, unit labor cost, PPI, and export deflator. Basically, I measured the RER with CPI for all goods, with the RER based on the CPI obtained from FRED. However, alternative prices indices were used to build the RER and the results are shown in the robustness check in Chapter 2.4, with 1) the US aggregate RER based on manufacturing CPI and 2) the manufacturing unit labor cost employed for the robustness test.

The RER in bilateral relationships was calculated based on CPI. The CPI of the US and of individual countries was obtained from the IFS. Aggregate real exchange rate, which was calculated with five or seven countries, were average weighted by GDP shares at PPP value. Corsetti et al. (2014) used this calculation. The US real effective exchange rate (REER) from FRED was used for aggregate US RER.

Net exports of the US were obtained from the US Census. Net exports were replaced by real exports or imports in the simulation to understand what drives the movement of net exports. Nominal exports and imports were downloaded from the US Census and converted into real value with the CPI of the US.

C. Responses of Real Exchange Rate and Net Exports to Productivity Shock

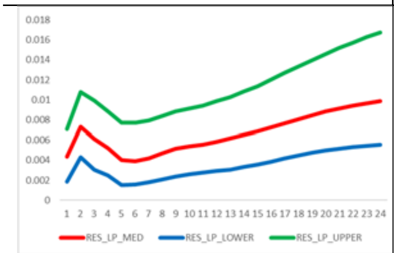
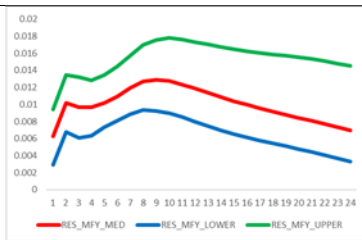
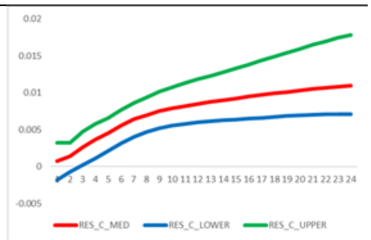
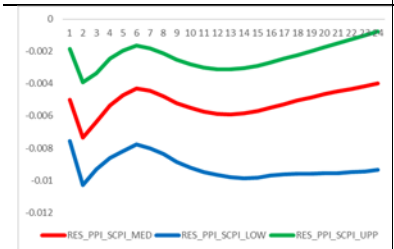
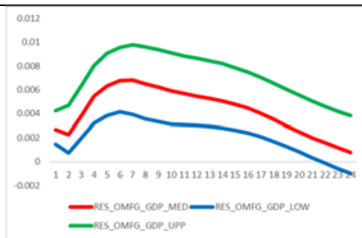
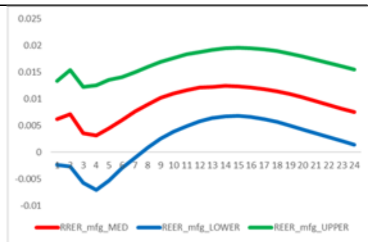
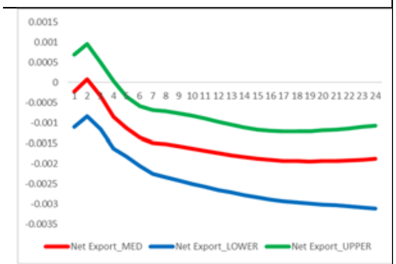
Figure 1 displays the impulse responses of US variables to a positive productivity shock in the US manufacturing sector vis-a-vis the rest of the world. Each figure presents the Bayesian credible intervals, which are the 16^{th} and 84^{th} percentiles of the posterior distribution of the responses. The median is presented in the middle. The four variables were restricted by signs, and they are labor productivity, manufacturing output, relative price of manufactured goods, and manufacturing output over GDP. Three other variables, private consumption, RER, and net exports, were not restricted. Labor productivity, manufacturing output, and relative manufacturing output to GDP increased for over 20 quarters, with the 16^{th} percentiles of responses remaining above zero. The relative price of manufactured goods decreased after productivity shock occurred, with the 84^{th} percentile response below zero beyond 20 quarters. The relative labor productivity of the US rose by 0.7% in median in response to productivity shock. The median manufacturing output and the median consumption increased by 1.1% and 0.16%, respectively. The relative price of manufactured goods decreased by a median of 0.7%. The 84th percentile of the RER rose above zero after 7 quarters. This indicates that the RER appreciates. The median RER appreciated by 0.7% initially and peaked at 1.2% appreciation after 12 quarters. The ratio of net exports to GDP decreased gradually, and the median trade deficit reached 0.1% of GDP after 4 quarters. The decrease in net exports can be derived from a decline in exports or an increase in imports. Real exports and real imports were entered in the model to check which one caused the decrease in net exports. Figure 3 demonstrates that it is not clear whether the change in exports is positive or negative, but documents a statistically significant increase in imports. Positive productivity shock causes US imports to increase and leads to a decline in net exports.

Variables of interest are the RER and net exports. Figure 2 depicts aggregate US RER and net exports, which were measured based on the US−ROW relationship. The US aggregate RER appreciates and aggregate net exports decrease after productivity improves. These results are consistent with the initial findings of Corsetti et al. (2014) and those in their follow−up studies, but are in contrast to the predictions of the traditional IRBC model. The interpretation of these results is that the US RER appreciates in relation to the rest of the world and US exports to the world decline after productivity growth in the US. However, the RER and net exports of the US in bilateral relationships with individual countries do not correspond to the movements of the aggregate ones. Figure 4 and Figure 5 show the US RER and net exports in bilateral relationships. While aggregate US RER appreciates in relation to the rest of the world, the US RER can appreciate or depreciate against individual countries (i).

Similarly, while US net exports to the world decrease, net exports of US to individual country i can increase or decrease. This finding implies that the impact of US productivity shock on individual countries can be diverse and country characteristics do play a role to cause such differences. Corsetti et al.'s (2014) studies investigate the impact of US productivity shock on the global economy. However, this study examines the impacts on individual countries and identifies the country characteristics that causes the impacts to vary across countries. The test to identify the role of country characteristics is described in the following section.

Figure 1 Responses of US variables to a positive productivity shock[18]

(US vs ROW)

Labor Productivity (US-ROW)	Manufacturing Output (US-ROW)	Consumption (US-ROW)
		
Relative price of manufactured goods (US)	Manufacturing output/GDP, (US)	US RER (+ indicates appreciation)
		
US net exports		
		

[18] The data for the rest of the world(ROW) is an aggregate of 5 countries from 1981 to 2017 to compare the results of this paper with Corsetti et al.(2014) which measured ROW by similar way.

Figure 2 Responses of aggregate US RER and net exports[19]

(US vs ROW)

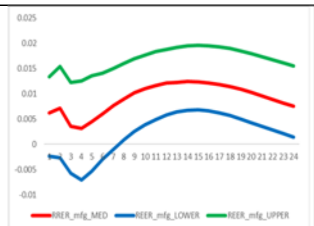
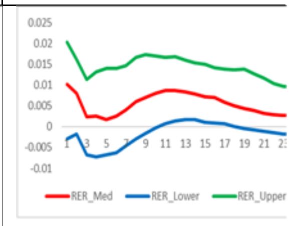
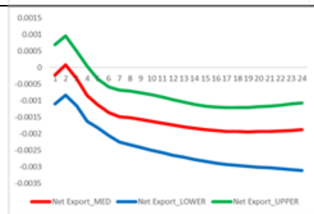
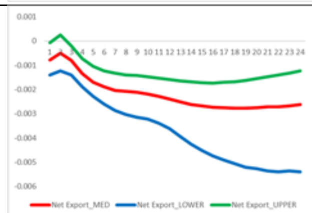
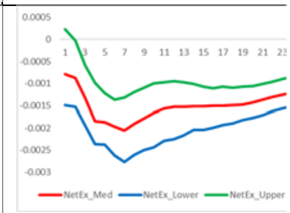
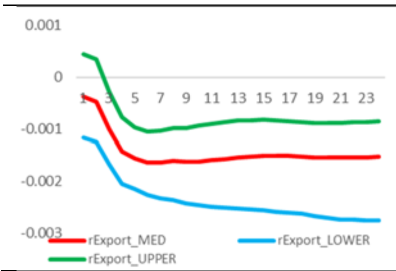
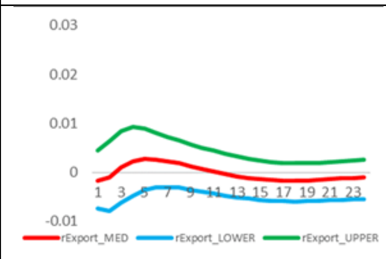
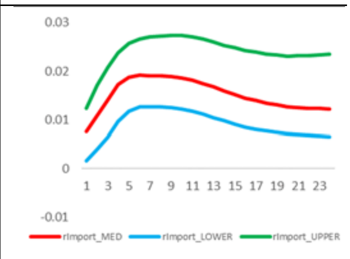
	US vs ROW1 (1981–2017)	US vs ROW2 (1989–2017)	US vs ROW3 (1981–2017)
RER (+ indicates appreciation)			
Net exports (− indicates decrease)			

Figure 3 Responses of aggregate US net exports, exports and imports[20]

(US vs ROW3)

Net Exports	Exports	Imports
		

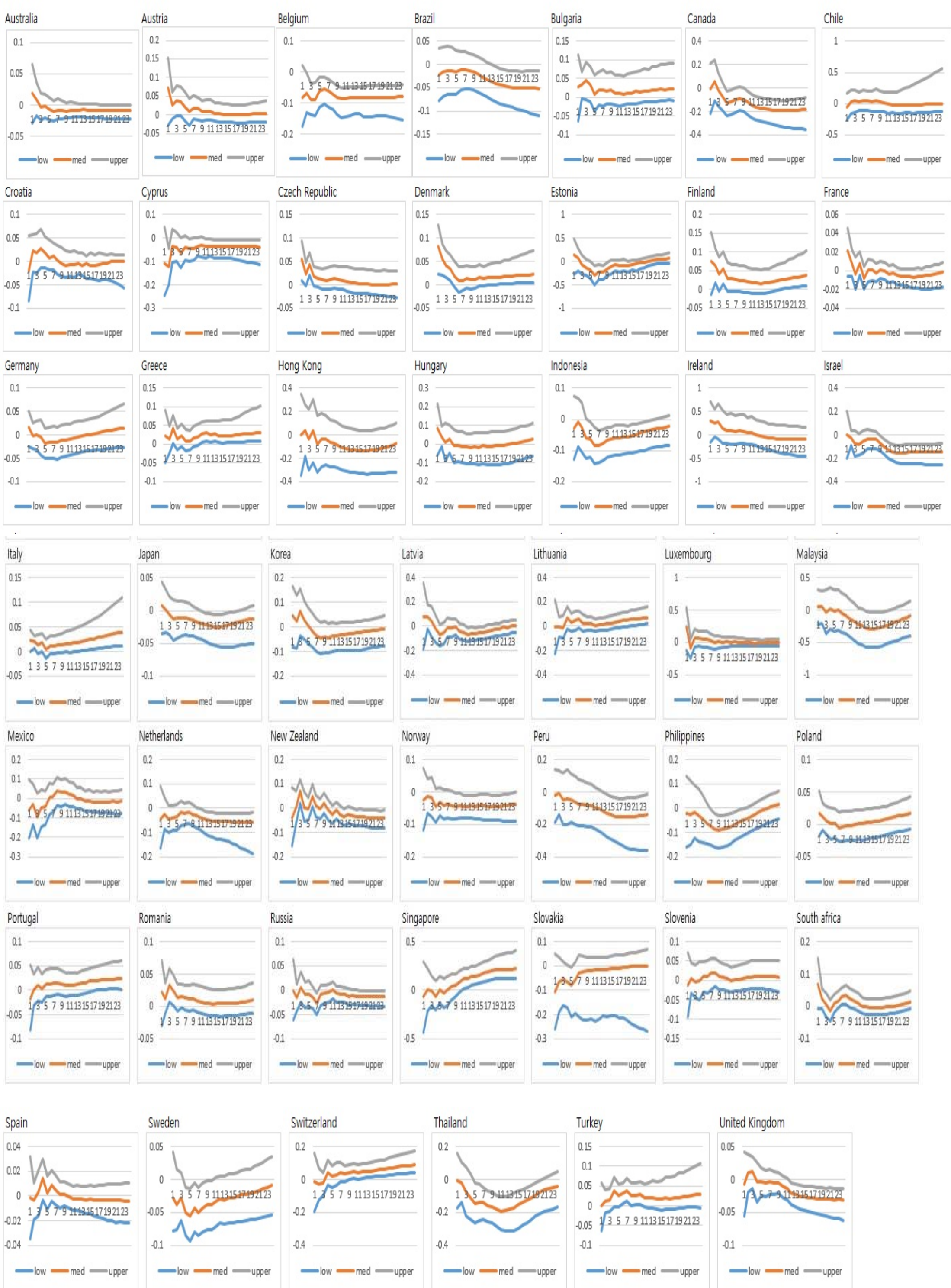
---

[19] The data for the rest of the world(ROW) is an aggregate of 5 countries from 1981 to 2017 or an aggregate of 7 countries to compare the results of this paper with Corsetti et al.(2014), where ROW was measured by similar way.

[20] Net exports in the VAR model is the ratio of $\frac{Net\ exports}{GDP}$. Exports and imports in the VAR model are real values of billions of chained 2012 US dollars.

Figure 4 Responses of bilateral US RER

Figure 5 Responses of bilateral US net export[21]



[21] Net exports in the VAR model was measured as the ratio of $\frac{Net\ exports}{GDP}x100$.

2.3 Different Impact Across Countries and the Role of Country Characteristics

A. Factors that Cause Varied Responses to Productivity Shock

The results in the previous chapter indicate that US productivity shock leads to the appreciation in US aggregate RER relative to the rest of the world and a decline in US net exports to the world. However, the responses of the RER and net exports in bilateral relationships between the US and individual countries are not uniform. The varied responses of bilateral RER and net exports can result from country characteristics. This chapter investigates the role of country characteristics on the varied responses with the OLS estimate.

There are several studies that investigate the impacts that US productivity shock causes in the global economy. Occasionally, some studies examine the effect of US productivity shock on individual countries, such as Canada (Miyamoto & Nguyen, 2017; Choudri & Schembri, 2014). However, there are few empirical studies that examine the impacts of US productivity shock on multiple individual countries or show that the impacts can vary across countries.

This study differs from previous research on some points. First, this study investigates the impact of US productivity shock on 48 individual countries while previous studies investigate the aggregate effects on the world or the effects on a few neighboring countries. Second, this study finds that US productivity shock can have different impacts on neighboring countries, depending on the countries' characteristics. There are cross-country empirical studies, but they examine the characteristics of the countries where productivity shocks happened while this study analyzes the characteristics of shock−recipient countries.[22] Third, productivity shock is identified and measured in a more accurate way in this study, while many of the cross−sectional studies use GDP per capita as a proxy for productivity of the tradable sector.

This study uses the country characteristics described in previous studies as independent variables for the OLS model. The majority of cross−sectional empirical studies that examine the appreciation in aggregate RER in response to productivity shock use simple models with one explanatory variable and regress the relative productivity of tradable goods on the RER. However, some studies employ additional independent variables. According to Tica and Druzic (2006), additional explanatory variables frequently used in the literature are openness of economy and government spending. Government spending is added since it can affect the demand for non−tradable goods. Government spending is used to control the effect of government demand shock on the RER. The dependent variable in this study is the RER responses of the VAR model described in the previous section. In the VAR model, sign restrictions were imposed on price and productivity variables to identify productivity shock. The sign restrictions rule out the impacts of government demand shocks and identify productivity shock only. Since the demand shock was already controlled in the VAR model, there is no need to include government spending as independent variable in this study. Instead, other independent variables found in previous

[22] Tica and Druzic(2006) surveyed cross−country empirical studies to test HBS theory. Country characteristics were used as explanatory variables of OLS but they were characteristics of shock−occurrence countries. Yet this study analyzed that the impact of US shock can differ across countries depending on the characteristics of shock−recipient countries.

empirical studies, such as openness of economy and exchange rate regime, are used.

Furthermore, this study includes other country characteristics that have not yet been investigated in the literature. Newly added explanatory variables that represent country characteristics are 1) consumption home bias, 2) trade with the US, 3) completeness of financial market, and 4) exports of intermediate goods to the US.

1) Consumption home bias

The US RER in relation to a country i is the real price of a US consumption basket relative to that of country i. The RER (Q) can be calculated with the nominal exchange rate (E), price level in the US (P^{US}), and price level in i (P^{i}).

$$Q = \frac{EP^{US}}{P^{i}} \quad \cdots\cdots\cdots\cdots \ (5)$$

The RER can be decomposed to tradable−based and non−tradable−based RER.

$$Q = Q_T Q_N \quad \cdots\cdots\cdots\cdots \ (6)$$

where Q_T and Q_N indicate tradable−based and non−tradable−based RER, respectively. Q_T and Q_N can be expressed with the price of tradables (P_T) and non−tradables (P_N), as done by Lee and Tang (2007).

$$Q_N = \frac{\left(\frac{P_N^{US}}{P_T^{US}}\right)^{1-\alpha^{US}}}{\left(\frac{P_N^{i}}{P_T^{i}}\right)^{1-\alpha^{i}}} \quad \cdots\cdots\cdots\cdots \ (7)$$

$$\mathrm{Q_T} = \frac{EP_T^{US}}{P_T^i} = \left(\frac{EP_T^{US*}}{P_T^{US}}\right)^{1-\beta_i} \left(\frac{EP_T^{i*}}{P_T^i}\right)^{\beta_i} \left(\frac{P_T^{i*}}{P_T^{US*}}\right)^{\beta_{US}-\beta_i} \quad \cdots\cdots\cdots\cdots \ (8)$$

where $\mathrm{P_T^{US}}$ is the price of tradable goods produced in the US and $\mathrm{P_T^i}$ is the price of tradable goods produced in country i, β_i and β_{US} are weights of home-produced tradables in total consumption, namely consumption home bias. The asterisk (*) indicates the price in the US, and no asterisk denotes the price in country i.

Home bias (β_i) is a component of tradable-based RER ($\mathrm{Q_T}$). The equation (8) was modified to see the role of β_i more clearly.

$$\mathrm{Q_T} = \left(\frac{P_T^{US}}{P_T^i}\right)^{\beta_\mathrm{i}} \left(\frac{P_T^{i*}}{P_T^{US*}}\right)^{\beta_{US}} \frac{EP_T^{US*}}{P_T^{US}} = \left(\frac{P_T^{US}}{P_T^i}\right)^{\beta_\mathrm{i}} Q_{T,Rest} \quad \cdots\cdots\cdots\cdots \ (9)$$

$$\text{where } Q_{T,Rest} = \left(\frac{P_T^{i*}}{P_T^{US*}}\right)^{\beta_{US}} \frac{EP_T^{US*}}{P_T^{US}}$$

$$\mathrm{Q} = \mathrm{Q_T} Q_N = \left(\frac{P_T^{US}}{P_T^i}\right)^{\beta_\mathrm{i}} Q_{T,Rest} Q_N \quad \cdots\cdots\cdots\cdots \ (10)$$

According to Corsetti et al. (2008), the price of US goods is expected to rise after productivity shock, if consumption home bias exists in the US and the US financial market is incomplete. Then $\frac{P_T^{US}}{P_T^i}$ can be assumed to be greater than 1 after productivity growth in the US. Since $\frac{P_T^{US}}{P_T^i}$ is greater than 1, $\left(\frac{P_T^{US}}{P_T^i}\right)^{\beta_\mathrm{i}}$ increases as the consumption home bias of country i (β_i) rises. A higher Q indicates an appreciation in the US RER against country i, according to the setting in equation (5). Assuming all else remains the same, the US bilateral

RER against country i appreciates if country i has a higher consumption home bias.

Home bias is measured as the ratio of consumption of domestically produced tradable goods to the consumption of total tradable goods. The Inter-Country Input-Output Table of OECD provides relevant consumption data for each country. Home bias was calculated as an average for the period from 1995 to 2015, where the data is available.

$$\textbf{HomeBias} = \frac{\textit{Consumption of domestically produced tradable goods}}{\textit{Consumption of total tradable goods}} \cdots\cdots\cdots (11)$$

2) Trade with the US

Miyamoto and Nguyen (2017) investigated the US permanent technology shock and its impacts on Canada and Mexico. The results show that the US technology shock raises output in both countries and the output increases sharply after they joined NAFTA. This suggests that strong trade ties with the US can be an important transmission channel for US shock. The simulation of the VAR model previously described indicates that the US aggregate RER appreciates after productivity growth. Therefore, it can be expected that the US bilateral RER will appreciate more in a country with strong trade ties with the US.

This study measured the trade relations between the US and individual countries with both conventional trade data and value-added trade data. Due to the growing global supply chain, various countries join in the process of production. However, conventional trade statistics do not reflect the complex international production process. Production inputs are sourced globally, but the traditional trade data do not account for the contribution of all countries involved in the production. Thus, this study used OECD TiVA statistics, which measures the value added by all countries involved in the production process. Trade relations between the US and a country i was measured as the trade between two countries over the total trade of country i. The trade was measured by either traditional gross trade flow or by the value−added trade between two countries. Value−added trade between the US and a country captures their trade relation in the global supply chain.

$$\mathbf{Trade\_with\_US} = \frac{\textit{Gross Exports and Imports with the US}}{\textit{Gross Exports and Imports with the World}} \times \mathbf{100} \quad \cdots\cdots\cdots(12)$$

$$\mathbf{VA\_Trade\_with\_US} =$$

$$\frac{\textit{Value added imports from US} + \textit{Domestic Value added exports to the US}}{\textit{Foreign Value added imports} + \textit{Domestic value added exports}} \mathbf{x100}$$

$$\cdots\cdots\cdots(13)$$

Value−added export and import data are available for the period between 2005 to 2015 on the OECD TiVA database. Gross trade data were obtained from UN Comtrade. Since the value−added data is available for the period 2005−2015, both indices were calculated as the average for those years.

3) Completeness of financial market

An economy is exposed to various shocks that cause fluctuation in income. The level of consumption in an economy is driven by income. If an economy experiences a negative shock, consumption shrinks as income decreases. According to the theory of international consumption risk sharing, such consumption risk can be insured through the financial market. If the financial market is complete (developed), agents of an economy can hold productive assets of other countries and cover the risk of income fluctuation from country-specific shocks. Optimal consumption levels can then be achieved and consumption does not react to income fluctuations. Full consumption risk sharing is possible with complete financial markets. If a financial market is incomplete, consumption risk is not fully covered. In other words, consumption changes along with income. If the financial market is complete, consumption risk is fully hedged and consumption is optimal with consumers' utility maximized, and consumption level changes only by price, not by wealth. However, agents in incomplete financial markets are exposed to country-specific consumption risk, where consumption changes with changes in wealth. Consumption rises as wealth increases or the other way around. Therefore, consumption is sensitive to wealth change in countries with incomplete financial markets while it does not respond to wealth in countries with complete financial markets. When the US aggregate RER appreciates after productivity growth, the RERs of other countries depreciate relatively, and their relative wealth decreases. If a country has a more complete financial market, its consumption is not sensitive to a decline in wealth. In trade between the US and country i, i may not decrease imports from the US even if its wealth decreases since consumption is not affected by wealth. Therefore, it follows that US exports to countries with more complete financial markets may not decrease even when US aggregate net exports to the world decrease after productivity growth.

The completeness of financial markets was measured as a level of the development of the stock market. I measured it dividing the sum of asset and liability of portfolio investment by the GDP of a country. Portfolio investment data is available from the International Financial Statistics of the IMF and the

GDP was obtained from the World Economic Outlook database of the World Bank. Since the data is available since 1993, the index is an average of the period from 1993 to 2017.

$$\boldsymbol{FinancialComplete} = \frac{\boldsymbol{Portfolio\ \ Investment}}{\boldsymbol{GDP}} \times \mathbf{100} \quad \cdots\cdots\cdots (14)$$

4) Exports of intermedia goods to the US

This study makes the same two assumptions as Corsetti et al. (2008, 2014), namely that the financial market is incomplete and consumption home bias exists. Since the financial market is incomplete, consumption risk is not fully covered and US consumption increases due to positive productivity shock. Since consumption is biased for domestic goods, demand for domestic goods rises strongly. Since supply rises gradually, demand exceeds supply in the short-run. Excess demand for domestic goods drives prices up, and the US RER appreciates. If US consumption rises in response to a positive productivity shock, it leads to a decrease in net exports, as the VAR results indicate. The decrease in net exports is as a result of either a decline in exports or an increase in imports. Imports can be divided into the imports of final goods and imports of intermediate goods. Since home bias causes the demand for domestic goods to strongly rise, it can undermine demand for imported foreign final goods. Simultaneously, US imports of intermediate goods can increase due to increased domestic production. Accordingly, I deduce that the decline in net exports is partly induced by an increase in intermediate imports. Thus, the US will increase imports of intermediate goods.

I measured the share of intermediate goods exports to the US in the total exports of a country to the US. Exports to the US from a country with a higher index are expected to rise. In other words, US imports from a country with a higher index are expected to rise. The export of intermediate goods to the US from individual countries can be calculated from OECD TiVA data. Since the data is available for the period between 2005−2015, the index was calculated as an average of this period.

$$\mathbf{ExportsInterm\_to\_US} = \frac{\textbf{exports of intermediate goods to the US}}{\textbf{total exports to the US}} \times \mathbf{100} \quad \cdots\cdots\cdots (15)$$

5) Imports of intermediate goods from the US

Lian et al. (2020) showed that information technology has advanced significantly since the 1990s, and this caused a decrease in the price of investment goods. The exports of input[23] accounts for approximately 62% of the total exports of goods from the US as of the second quarter of 2020. Since US exports include a large share of intermediate goods, the price of which has declined due to productivity shock, the US is expected to increase the export of intermediate goods. This means that US exports to countries that have been importing intermediate goods from the US is expected to rise.

I measured the share of intermediate goods imports from the US in the total imports of a country. If a country has a higher index, it imports more intermediate goods from the US, and an increase in imports from the US can be experienced after productivity growth in the US. The index was computed from OECD TiVA data and is an average for the period 2005–2015.

[23] It includes industrial supplies and materials, and capital goods except automotive.

$$\textbf{ImportsInterm\_from\_US} = \frac{\textbf{imports of intermediate goods from the US}}{\textbf{total imports from the US}} \times \textbf{100} \quad \cdots\cdots\cdots (16)$$

6) Openness

De Broeck and Sloke (2006) measured the openness of an economy as trade openness, exports plus imports divided by the GDP. They suggest that the response of the RER is expected to be more pronounced in more closed economies. This study measured openness as financial openness or trade openness. Chinn and Ito (2006) measured the openness of the capital account of a country and provided the annual index for the period 1996-2017. This study employed the Chinn-Ito index to represent financial openness. Trade openness is a measure of the ratio of trade over GDP of a country. While there is trade data available for most countries from 1993, the data is available from 2000 for a few countries, such as South Africa. Thus, trade openness was calculated as an average for the period 2000-2017 for all countries.

$$\textbf{FinancialOpenness} = \textbf{Chinn\&Ito index} \quad \cdots\cdots\cdots (17)$$

$$\textbf{TradeOpenness} = \frac{\textbf{Exports+Imports}}{\textbf{GDP}} \times \textbf{100} \quad \cdots\cdots\cdots (18)$$

7) Other variables

The aggregate US RER appreciates as US productivity grows, as shown in the VAR estimates in the previous chapter. The appreciation is expected to be clear when the exchange rate is not controlled. Ilzetzki et al. (2018) formulated an index to represent the exchange rate system of each country. A higher index reflects a floating exchange rate system. This study used an average of the index for the period 1993−2016 ($ExchangeRegime$) to capture the exchange rate system of each country. Certain countries displayed drastic changes in the exchange rate systems, mostly when joining the Eurozone. In those cases, entire periods were divided into before and after the drastic change in the system and the average was calculated for the longer period.

The RER changes in response to US productivity growth, and then net exports between the US and other countries can be affected by the changes. Consequently, changes in the RER (R_RER) after productivity growth was included as an independent variable where net exports were used as a dependent variable.

B. Cross−country OLS

Cross−country OLS was used to examine the effects of country characteristics on the US RER in relation to country i and US net exports to i. The basic models are as follows;

$$R\_RER_{\mathrm{i}} = \beta_0 + \beta_1 Trade\_with\_US_i + \beta_2 HomeBias_i + \beta_3 FinancialComplete_i + \beta_4 Openness_i + \beta_5 ExchangeRegime_i + \varepsilon_{1i} \qquad \cdots\cdots\cdots\cdots(19)$$

$$R\_NetExp_i = \beta_0 + \beta_1 Trade\_with\_US_i + \beta_2 HomeBias_i + \beta_3 FinancialComplete_i + \beta_4 Openness_i + \beta_5 ExchangeRegime_i + \beta_6 R\_RER_i + \beta_7 ExporttInterm\_to\_US_i + \beta_8 ImporttInterm\_from\_US_i + \varepsilon_{2i} \qquad \cdots\cdots\cdots\cdots(20)$$

The dependent variables are US RER in relation to country i (R_RER) or US net exports to i (R_NetExp). These were measured from the VAR results in Section 2.2.

$$\text{R\_RER} \equiv \frac{\sum_{k=1}^{K} RER_k}{\sum_{k=1}^{K} LP_k} \quad \cdots\cdots\cdots\cdots \quad (21)$$

$$\text{R\_NetExp} \equiv \frac{\sum_{k=1}^{K} NE_k}{\sum_{k=1}^{K} LP_k} \quad \cdots\cdots\cdots\cdots \quad (22)$$

where RER_k, LP_k and NE_k are the responses of RER, labor productivity, and net exports, respectively, in the k-th quarter after a productivity shock. R_RER and R_NetExp are cumulative responses of bilateral US RER and net exports in relation to the country i. The periods of accumulation (K) are 4, 8, 12, and 16 quarters. Responses of the RER and net exports were divided by the responses of labor productivity to account for the different size of productivity shocks in each country.

The VAR model with variable RER discussed in the previous section was simulated 630 times and the model with net exports 650 times, which are the number of cases that satisfy sign restrictions. Thus, the OLS was simulated 630 and 650 times for R_RER and R_NetExp, respectively. The results of the regression are presented with the 5th, 16th, 84th, and 95th percentiles of empirical distribution of the regression coefficients. A similar method was used by Kim (2015) and Berka et al. (2018).

Seven independent variables were included to consider country characteristics: 1) trade with the US, measured by gross trade ($Trade\_with\_US_i$) or value-added trade (VA $Trade\_with\_US_i$), 2) consumption home bias (HomeBias_i), 3) financial market completeness ($FinancialComplete_i$), 4) openness of an economy ($Openness_i$), measured by financial openness ($FinancialOpenness_i$)

or trade openness($TradeOpenness_i$), 5) exchange rate regime (ExchangeRegime_i), 6) responses of RER for k quarters (R_RER_i), 7) the exports of intermediate goods from country i to the US ($ExportInterm\_to\_US_i$), and 8) the imports of intermediate goods to country i from the US ($\text{ImportsInterm\_from\_US}_i$)

The dependent variables RER and net exports were obtained from the VAR model discussed in the previous section. The sample period for the VAR model is 1993–2017, and the country characteristics of the seven variables should be an average for the same periods. However, some data is not available for 1990s and those variables were averaged for the periods where data is available.

C. Results

The regressions were conducted with 48 individual countries. Dependent variables are the US RER against country i; net exports from the US to country i; real exports from the US to country i; and real imports to the US from country i.[24] The median estimates are described with 68% probability bands in parentheses, and *, **, and *** indicate that the estimates deviate from zero with a greater than 84%, 90%, and 95% probability, respectively.

Table 4 displays the results of the regression with the dependent variable RER at one-year, two-year, three-year, and four-year horizons. When a country has a high consumption home bias, the US RER relative to that country is expected to appreciate, as noted in the previous section. The

[24] Net exports is the results of the VAR model, and it was measured as the ratio of $\frac{Net\ exports}{GDP}x100$. Real exports and real imports are not ratios but level.

estimates of home bias present expected positive signs and deviate from zero with a probability greater than 84% for a four−year horizon. The estimates of trade with the US show expected positive signs. Trade with the US was measured by gross trade or value−added trade. Both deviate from zero with a probability greater than 84% in one−year and two−year horizons. Trade openness presents significant positive value for all horizons and deviate from zero with a probability greater than 84% or 90%. This suggests that the RER tends to appreciate when an economy is more open to trade.[25] When trade relations with the US are strong, the RER also appreciates. These two results suggest that trade is an important channel to transmit US productivity shock. The regression results for RER reveal that the US bilateral RER appreciates in a country where home bias is high, trade relations with the US are strong, and the economy is more open to trade.

Table 5 documents the regression results for net exports from the US to individual countries. Aggregate US net exports to the world appeared to decrease after productivity increases. However, net exports to individual countries can be diverse. This difference is likely caused by two country characteristics. If a country has a more complete financial market, US net exports to that country may not decrease since the consumption demand of that country is less sensitive to US productivity shock. The estimates of "financial completeness" present significant positive values, and a higher index means a more complete financial market. The results are consistent with the expectation. Net exports from the US will be affected by the RER, thus, "RER responses" after productivity shock were included as independent variables. The results

[25] Financial openness does not produce significant results, and it is not presented in the table.

show that US net exports decrease to countries where the US bilateral RER appreciates more.

Net exports are composed of exports and imports. To better understand the movement of net exports, this dependent variable was replaced by real exports or real imports. If aggregate US net exports decrease, it can be as a result of either a decrease in exports or an increase in imports. If the real exports are used as a dependent variable, the estimates of "RER responses" are negative and statistically significant. This indicates that real US exports decrease as the RER appreciates. With the real imports as the dependent variable, an increase in imports can be seen in the countries that export intermediate goods to the US. This means that the US increases imports of intermediate goods after productivity growth. To summarize, US exports decrease due to RER appreciation and imports of intermediate goods increase due to increased production, which results in a decrease in net exports. US exports of intermediate goods is expected to increase, but the coefficients is not significant. US productivity growth lowers the price of US intermediate goods, but the lower price does not boost exports.

In summary, US productivity shock causes US goods to become expensive as aggregate US RER appreciates. Moreover, US aggregate net exports decrease as demand in domestic consumption increases. However, the impacts on the RER and net exports are not uniform across countries. In terms of the RER, US RER appreciates more in a country with a high consumption home bias, strong trade ties with the US, and more openness to trade. In terms of trade, US net exports decreases. When net exports are decomposed into exports and imports, it becomes clear that US exports decrease due to RER appreciation and imports increase due to high demand for intermediate goods.

Table 4 Regression results for US RER in relation to country i

	Dependent variable: RER of one−year horizon			Dependent variable: RER of two−year horizon		
Constant	−3.8 (−7.5, 0.8)	−3.8 (−7.5,0.7)	−3.3 (−7.3.0.9)	**−3.5*** **(−6.7,−0.3)**	−3.8 (−7.5, 0.7)	−3.2 (−6.3, 0.1)
Trade with US	**0.04*** **(0.01, 0.1)**			0.03 (−0.004, 0.1)		
VA Trade with US		**0.05*** **(0.005, 0.1)**	0.04 (−0.001,0.1)		**0.1*** **(0.05, 0.1)**	0.02 (−0.01, 0.1)
Home Bias	2.1 (−3.9, 8.1)	2.1 (−4.1, 8.0)	0.8 (−5.0, 7.1)	2.5 (−2.2, 7.0)	2.1 (−4.1, 8.0)	1.2 (−3.7, 5.7)
Financial Completeness	0.01 (−0.02, 0.04)	0.002 (−0.03, 0.03)	0.01 (−0.02, 0.04)	0.01 (−0.02, 0.04)	0.002 (−0.03, 0.03)	0.01 (−0.02, 0.04)
Trade openness	**0.01*** **(0.001, 0.01)**	**0.01*** **(0.001, 0.01)**	**0.01*** **(0.001, 0.01)**	0.01* (0.001, 0.01)	**0.01*** **(0.001, 0.01)**	**0.01*** **(0.001, 0.01)**
Exchange Regime			0.1 (−0.1, 0.2)			0.1 (−0.04, 0.2)

	Dependent variable: RER of three-year horizon			Dependent variable: RER of four-year horizon		
Constant	**−3.7*** (−6.4, −0.8)**	**−3.7** (−6.4, −0.8)**	**−3.3* (−6.1, −0.6)**	**−3.7*** (−5.8, −1.4)**	**−3.7*** (−5.8, −1.4)**	**−3.4** (−5.5, −1.1)**
Trade with US	0.01 (−0.01, 0.04)			0.005 (−0.02, 0.03)		
VA Trade with US		0.02 (−0.02, 0.04)	0.01 (−0.02, 0.04)		0.01 (−0.02, 0.03)	−0.001 (−0.03, 0.02)
Home Bias	3.5 (−0.7, 7.5)	3.5 (−0.8, 7.4)	2.1 (−2.1, 6.2)	**3.9* (0.5, 7.1)**	**3.9* (0.4, 7.1)**	2.5 (−0.8, 5.9)
Financial Completeness	0.01 (−0.01, 0.04)	0.01 (−0.02, 0.04)	0.01 (−0.01, 0.04)	0.01 (−0.01, 0.03)	0.01 (−0.01, 0.03)	0.01 (−0.01, 0.03)
Trade openness	**0.01* (0.001, 0.01)**	**0.01* (0.001, 0.01)**	**0.01* (0.001, 0.01)**	**0.01** (0.001, 0.01)**	**0.01** (0.001, 0.01)**	**0.01** (0.001, 0.01)**
Exchange Regime			0.1 (−0.02, 0.2)			0.1 (−0.01, 0.2)

The median estimates are reported, and 68% probability bands are reported in parentheses.

*, **, and *** indicate that the estimates deviate from zero with greater than 84%, 90% and 95% probability, respectively.

The increase in the dependent variable US RER means that it appreciates.

Table 5 Regression results for net exports of US

	one−year horizon				two−year horizon			
Dependent / Independent	Net Export		Real Export	Real Import	Net Export		Real Export	Real Import
Constant	−26.3 (−77.0, 29.1)	12.2 (−29.1, 53.3)	−5.0 (−21.5, 11.2)	−6.5 (−16.0, 2.5)	−24.3 (−68.7, 19.7)	5.4 (−24.9, 40.1)	−0.4 (−11.9, 9.3)	−1.3 (−8.3, 6.0)
VA Trade with US	−0.1 (−0.5, 0.4)	−0.1 (−0.5, 0.4)	0.002 (−0.1, 0.1)	−0.03 (−0.1, 0.03)	−0.1 (−0.4, 0.2)	−0.1 (−0.4, 0.3)	0.02 (−0.04, 0.1)	−0.03 (−0.1, 0.01)
Home Bias	3.3 (−36.5, 41.8)	0.7 (−43.0, 39.5)	8,1 (−5.1, 19.9)	−0.6 (−8.9, 8.1)	3.8 (−25.1, 32.0)	1.9 (−28.5, 30.6)	4.4 (−4.4, 11.9)	−3.2 (−9.1, 2.3)
Financial Completeness	0.0 (−0.4, 0.5)	0.2 (−0.0, 0.5)	0.1 (−0.04, 0.2)	−0.01 (−0.1, 0.1)	0.1 (−0.2, 0.4)	**0.2*** **(0.1, 0.4)**	0.1 (−0.02, 0.1)	−0.01 (−0.05, 0.04)
Trade Openness	−0.0 (−0.2, 0.1)	−0.0 (−0.1, 0.1)	0.002 (−0.02, 0.03)	−0.003 (−0.02, 0.01)	−0.0 (−0.1, 0.1)	−0.0 (−0.1, 0.1)	0.002 (−0.02, 0.02)	−0.002 (−0.01, 001)
Intermediate goods exports to US from i		−0.2 (−0.6, 0.2)		**0.2**** **(0.1, 0.3)**		−0.1 (−0.5, 0.2)		**0.1**** **(0.05, 0.2)**
Intermediate goods imports from US to i	0.5 (−0.4, 1.4)		0.005 (−0.2, 0.2)		0.4 (−0.3, 1.2)		−0.01 (−0.2, 0.1)	
RER responses	−67.4 (−198.3, 89.5)	−73.4 (−200, 83.2)	−15.5 (−58, 29.3)	1.7 (−24.3, 30.9)	−43.4 (−89.5, 1.5)	−42.9 (−88.4, 3.1)	**−30.5*** **(−60, −1.6)**	1.1 (−19.0, 20.3)

Dependent / Independent	three−year horizon				four−year horizon			
	Net Export		Real Export	Real Import	Net Export		Real Export	Real Import
Constant	−15.3 (−51.9, 21.7)	3.4 (−21.5, 33.0	0.5 (−7.8, 8.7)	−1.9 (−7.4, 4.1)	−4.2 (−33.7, 24.3)	3,1 (−17.5, 26.6)	1.5 (−5.4, 8.0)	−2.6 (−6.8, 2.6)
VA Trade with US	−0.1 (−0.4, 0.2)	−0.1 (−0.4, 0.2)	0.03 (−0.01, 0.1)	−0.02 (−0.1, 0.01)	−0.1 (−0.4, 0.1)	−0.1 (−0.4, 0.1)	0.03 (−0.002, 0.1)	−0.02 (−0.05, 0.01)
Home Bias	0.5 (−22.9, 21.7)	−0.9 (−26.0, 21.7)	1.9 (−5.5, 7.3)	−2.9 (−7.6, 1.3)	−1.2 (−19.3, 15.9)	−1.3 (−21.6, 15.9)	0.2 (−5.9, 4.6)	−2.5 (−6.4, 0.9)
Financial Completeness	0.1 (−0.2, 0.3)	0.2** (0.0, 0.3)	0.03 (−0.03, 0.1)	−0.01 (−0.05, 0.03)	0.1 (−0.1, 0.3)	0.1** (0.0, 0.2)	0.02 (−0.03, 0.1)	−0.02 (−0.04, 0.02)
Trade Openness	−0.0 (−0.1, 0.1)	−0.0 (−0.1, 0.1)	−0.001 (−0.02, 0.01)	−0.003 (−0.01, 0.01)	−0.0 (−0.1, 0.1)	−0.0 (−0.1, 0.1)	−0.001 (−0.01, 0.01)	−0.004 (−0.01, 0.003)
Intermediate goods exports to US from i		−0.1 (−0.4, 0.2)		0.1** (0.1, 0.2)		−0.1 (−0.3, 0.2)		0.1*** (0.1, 0.2)
Intermediate goods imports from US to i	0.2 (−0.4, 1.0)		−0.01 (−0.1, 0.1)		0.0 (−0.4, 0.6)		−0.03 (−0.1, 0.1)	
RER responses	−31.0** (−51.5, −10.0)	−30.6** (−52, −9.3)	−33.9** (−59, −10.7)	0.7 (−16.5, 17.9)	−19.3*** (−31.3, −9.0)	−19.1** (−31.6, −8.6)	−33.7** (−54.1, −14.2)	−1.4 (−14.0, 14.0)

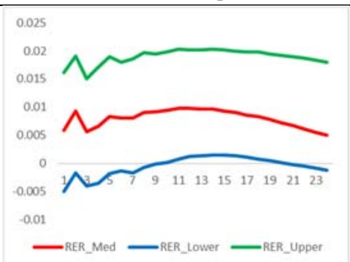
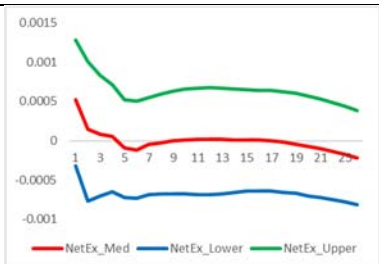
The median estimates are reported, and 68% probability bands are reported in the parentheses.

*, **, and *** indicate that the estimates are different from zero with greater than 84%, 90% and 95% probability, respectively.

2.4 Robustness

The baseline model was extended to check the robustness of the results. First, I changed the sample period of the VAR model in line with the literature. The previous studies, such as Corsetti et al. (2014) and Nam and Wang (2018), selected a sample before 2007 to avoid the effects of the 2008 global financial crisis. Corsetti et al. (2014) used a sample of 1973:1–2004:4 and Nam and Wang (2018) examined the period of 1975:1–2007:4. Since this study set Corsetti et al. (2008, 2014) as a benchmark, the same period, 1973:1–2004:4, was examined. In the baseline model in the previous section, three different measures were used to establish the aggregate US variable. These differed in how many countries were included in the rest of the world, where five countries, seven countries, or all countries were considered, respectively. In this robustness test, I used US data that include all countries as the rest of the world. Figure 6 demonstrates the responses of US aggregate RER and net exports in response to productivity shock for the sample period of 1973:1–2004:4. The results indicate that the RER appreciates and deviates from zero with a probability of 84% for nine quarters after productivity shock. The appreciation in the RER is consistent with the literature and the results of the baseline model of this study. Net exports decrease in the literature and in the baseline model of this study, but the direction of the movement is not clear in the robustness test.

Figure 6 Responses of US aggregate data to productivity shock

Real exchange rate	Net export
	

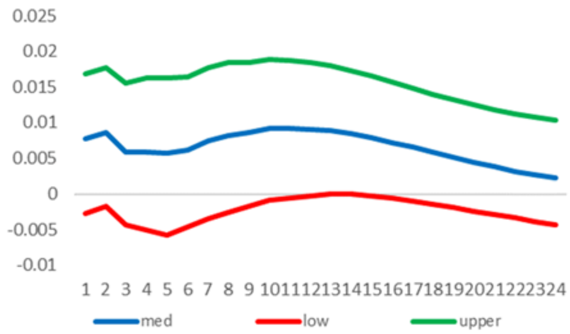
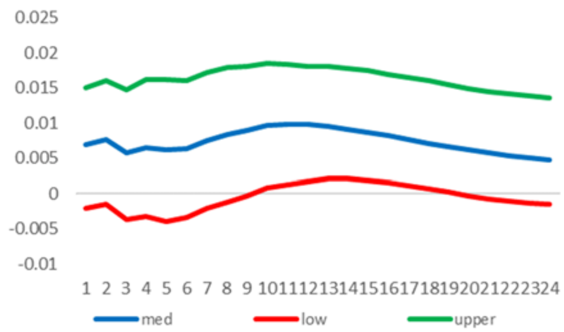
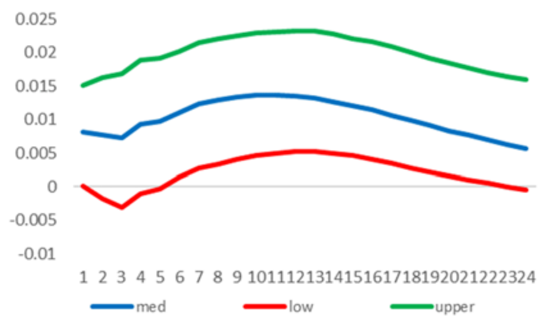
Second, the RER was calculated with two alternative price indices, which are 1) manufacturing CPI and 2) manufacturing ULC. The baseline model used REER measured with the CPI for all goods. The aggregate RER of the US in the VAR model was represented by the REER. The REER is the real value of a currency against those of its trading partners, which is calculated as a trade−weighted average of RER. The US REER can be measured as follows:

$$\mathrm{REER_{US}} = \sum_{i=1}^{N} \frac{P_{US}}{P_i} \times TradeWeight_i \cdots\cdots\cdots (23)$$

P = CPI, manufacturing CPI, or manufacturing ULC

where P_{US} and P_i are the price indices of the US and country i in dollars, respectively, $TradeWeight_i$ is the trade weight of country i in the total trade of the US, and i is a trade partner of the US. The REER can be measured with various price indices, P_{US} and P_i. This study adopted three different indices, 1) CPI, 2) manufacturing CPI, and 3) manufacturing ULC. The baseline model used the REER based on CPI. This study assumed that goods consist of tradables and non−tradables. The CPI is composed of the price of tradable and non−tradable goods. Manufacturing CPI is close to the price of tradable goods. Manufacturing ULC is the price of non−tradable goods since the ULC is the average cost of labor per unit of output produced. Productivity shock in the tradable goods sector lowers the relative price of tradable goods in relation to non−tradable goods, and then the price index of the US, P_{US}, in the above equation is higher when measured with the price of non−tradable goods. Since manufacturing ULC is the price of non−tradable goods, the US REER is expected to be higher when measured with ULC. Since higher REER means appreciation, the US REER is expected to appreciate strongly when measured with manufacturing ULC. The VAR model was simulated with three different indices, REER based on 1) CPI, 2) manufacturing CPI, and 3) manufacturing ULC. In all cases, the REER appreciate in response to productivity growth in the tradable sector, and the appreciation is strong when the REER is measured with manufacturing ULC, as shown in Figure 7. This is consistent with expectations.

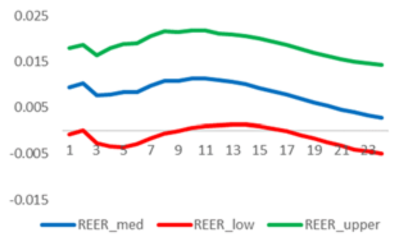
Figure 7 Responses of aggregate US REER to productivity shock

<table>
<tr><td>REER based on CPI (Baseline model)</td><td>
</td></tr>
<tr><td>REER based on manufacturing CPI</td><td>
</td></tr>
<tr><td>REER based on manufacturing Unit Labor Cost</td><td>
</td></tr>
</table>

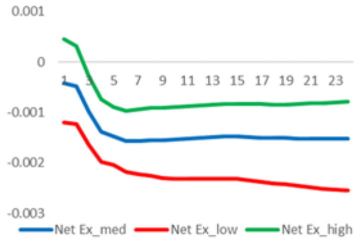
Third, the PPI of manufactured goods which was used to measure the relative price of tradable goods in the baseline model, $\log \frac{PPI_{mf}}{CPI_{service}}$, was replaced by the price of investment goods. This study investigated productivity growth in the US manufacturing sector, accordingly, the relative price of manufactured goods is included as a variable. I narrowed down the manufacturing sector into an investment goods sector since there has been significant productivity progress in the US in the production of investment goods. The relative price of manufactured goods can then be replaced by the relative price of investment goods. The advances in information technology has been significant since the 1990s, and it has led to a dramatic decrease in the price of investment goods, according to Lian et al. (2020). The study documents that the relative price of overall investment goods fell by approximately 40% and the relative price of machinery and equipment decreased by approximately 55% relative to 1990. To be precise, the price of computing equipment decreased by 90% and of communication equipment by 60% during the same periods. The study explains that the fall in the prices are mainly due to productivity growth in the relevant sectors. Since the production of investment goods in the manufacturing sector experienced strong productivity growth, I conducted the robustness check in the investment goods sector. The relative price of manufactured goods, $\log\frac{PPI_{mf}}{CPI_{service}}$, was replaced by the relative price of investment goods, and it was represented by four indices 1) the relative price of investment goods, $\log RelP_{invst}$, 2) the PPI of investment goods over service CPI, $\log\frac{PPI_{invt}}{CPI_{service}}$, 3) the PPI of industrial commodities over service CPI, $\log\frac{PPI_{indst}}{CPI_{service}}$, and 4) the PPI of intermediate goods over service CPI, $\log\frac{PPI_{interm}}{CPI_{service}}$. All indices, $RelP_{invst}$, PPI_{invt}, PPI_{indst}, PPI_{interm}, and $CPI_{service}$, were downloaded from FRED. The simulation of the VAR model with the new indices depicts that the RER appreciates and net exports decrease in response to productivity shock. The results are shown in Figure 8.

Figure 8 Responses of US REER and net exports to productivity shock

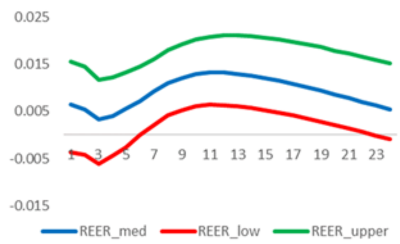
<table>
<tr><th>Relative Price of investment goods</th><th>Response of REER</th><th>Response of net exports</th></tr>
<tr><td>$\log\frac{PPI_{mf}}{CPI_{service}}$
(baseline model)</td><td>



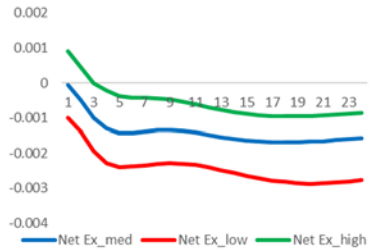
</td><td>



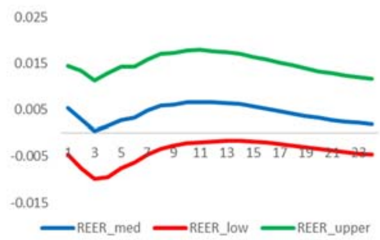
</td></tr>
<tr><td>$\log RelP_{invst}$</td><td>



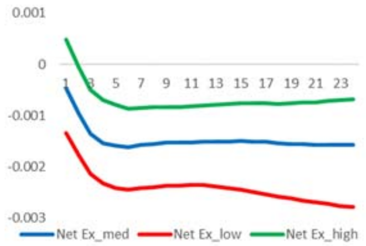
</td><td>



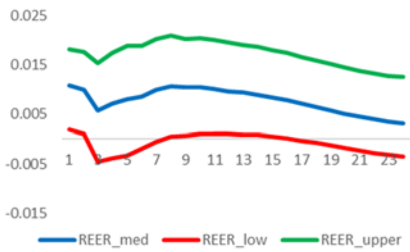
</td></tr>
<tr><td>$\log\frac{PPI_{invt}}{CPI_{service}}$</td><td>



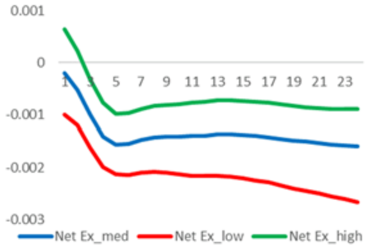
</td><td>



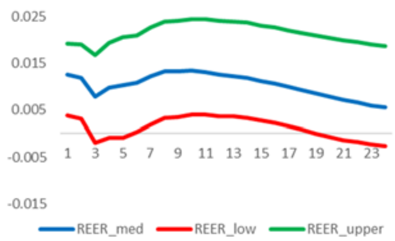
</td></tr>
<tr><td>$\log\frac{PPI_{indst}}{CPI_{service}}$</td><td>



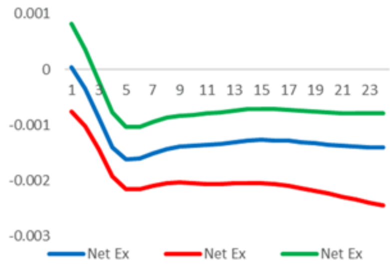
</td><td>



</td></tr>
<tr><td>$\log\frac{PPI_{interm}}{CPI_{service}}$</td><td>



</td><td>



</td></tr>
</table>

The REER appreciates in all cases. The 16th percentiles of responses remain above zero, except the results with $\log\frac{PPI_{invt}}{CPI_{service}}$, which means that the REER appreciates more than 84% of probability. In the case of $\log\frac{PPI_{invt}}{CPI_{service}}$, the 16th percentile remains below zero, and then the appreciation is not statistically significant. Net exports decline in response to productivity shock and the results are statistically significant for all cases.

2.5 Conclusion

The impact of productivity shock on the RER has been widely studied, but previous literature is centered on theoretical modeling. Two models are mainly used in the literature: IRBC and HBS framework. Generally, traditional IRBC theory predicts short-run depreciation and the conventional HBS model anticipates long-run appreciation. However, the predictions for the movement of the RER are conflicting, even with the same model, and some studies propose that the theories do not hold. Since empirical studies are limited, the predictions of the models are not fully confirmed. Recent empirical studies document that the RER can appreciate in both the short-run and the long-run. However, these studies analyze shocks in large economies, such as US and EU, and examine aggregate impacts on the world economy.

This thesis investigated the effects of US productivity shock on 48 individual countries and found that the effects can differ across countries. This study estimated the responses of the RER and net exports with the VAR model, and found that the responses can vary across countries, depending on country characteristics with cross-country OLS. US productivity shock causes US aggregate RER to appreciate and aggregate net exports to decrease. However, bilateral movement of the RER and net exports are not uniform. In terms of the RER, US RER relative to a country appreciates if the country has high consumption home bias, strong trade ties with the US, or an economy more open to trade. In terms of trade, the decline in net exports results from the decrease in exports and the increase in imports. Exports decrease due to the appreciation in the US RER, and imports of intermediate goods increase. Nevertheless, US net exports increase to countries where the financial markets are more complete.

The widely accepted view of the traditional IRBC model is that productivity growth in a home country will benefit other countries since the relative price of home goods decreases, which results in depreciation in the home RER. Accordingly, net exports of the home country increase due to the depreciation in the home RER. However, this positive transmission was not witnessed in the data. The empirical results of this study show that aggregate US RER appreciates and net exports decrease. The rest of the world faces an increase in the price of US goods after productivity growth, and they have to import US products at higher price. In this respect, US productivity shock can have a negative transmission to the rest of the world. A country is likely to experience more appreciation in the US RER, namely depreciation in the RER of that country, from a US productivity shock if its consumption home bias is high, trade ties with the US is strong, or the economy is more open to trade.

Chapter 3. Productivity Shocks in Small Open Economies and International Transmission

3.1 Introduction

International transmission of productivity shock, specifically its impact on the RER, is a contentious issue. Previous literate concentrated on theoretical modeling; consequently, the predictions of the models are not fully supported by empirical studies. Two popular models are used in the literature, the IRBC model and the HBS framework. Traditional IRBC literature suggests that RER depreciates in the short-run while the traditional HBS model anticipates that RER appreciates in the long-run. However, new outcomes published recently under each model show results that contradict the prediction of the original models. Standard IRBC views by Backus et al. (1994), Stockman and Tesar (1995), and Cole and Obstfeld (1991) explain that RER depreciates after productivity growth. However, a 2008 study of Corsetti et al. (2008) and some follow-up studies, assert that the RER can appreciate under the standard model and document empirical evidence with data from the US. The key factors that cause the appreciation in the RER in their model is the assumption of wealth effect from incomplete financial markets and consumption home bias. Traditional HBS theory, such as Harrod (1933) and Samuelson (1964), predicts that the RER appreciates in the long-run. However, Berka et al. (2018) overcome the drawbacks of the data in the previous literature and document significant evidence with data from the EU that the RER can even appreciate in the short-run.

Recently, meaningful empirical studies have found that the RER can appreciate, contrary to the predictions of the traditional theoretical models. However, empirical evidence is still insufficient, and the studies are restricted to large economies, mainly the US and EU. Corsetti et al. (2008, 2014), Ender and Muller (2009), Enders et al. (2011), Nam and Wang (2018), and Miyamoto and Nguyen (2017) investigated productivity shock in the US. Recent studies suggest that the RER can appreciate after productivity growth, and Corsetti et al. (2008) suggested that appreciation is possible if financial markets are incomplete and consumption home bias exists. Financial market conditions and home bias are included as parameter values in their model but, the role of those parameters have not been investigated.

This study investigates productivity shocks in various small open economies and compares the movement of the RER and net exports to the results of the US. Productivity shocks in 10 small open economies are examined, namely 1) Japan, 2) Germany, 3) Canada, 4) France, 5) Ireland, 6) Australia, 7) the UK, 8) South Africa, 9) Norway, and 10) Finland. Shocks are identified via sign restrictions in the VAR model, and shock identification methods are different to those used for large economies. Small open economies are affected by productivity shocks in large economies, while the small open economies play no role in explaining the economic variables of the large economies. Therefore, this study controls the variables in large economy, the US, to identify productivity shocks in small open economies. The results reveal that the RER in small open economies responds in both direction, appreciation or depreciation, while it appreciates in the US. This study measures the wealth effect and consumption home bias of each country. The RER tends to appreciate where a strong wealth effect is witnessed and consumption home bias is high.

3.2 Structural VAR with Sign Restrictions

The structural VAR model with sign restrictions was used to identify productivity shock and to examine its effects. The US is assumed to be a large and closed economy. Small open economies play no role in explaining the US variables while the US variables impact on small open economies. Thus, US productivity growth is included as an exogenous variable in the model.

A reduced form of the VAR model is as follows:

$$\mathrm{Y_t} = B_1(L)Y_{t-1} + B_2(L)US_t + U_t \quad \cdots\cdots\cdots\cdots \ (24)$$

where $\mathrm{Y_t}$ is a vector of the mx1 endogenous variables of each small open economy. US_t is a vector 2x1 of exogenous variables, where US variables are components. $\mathrm{B}(L)$ is a lag polynomial of the order p, which is set at four in the model. U_t is a vector of reduced−form residuals, and the covariance matrix of U_t is denoted by Σ. The Bayesian approach by Uhlig (2005) was used to estimate the parameters of the above reduced−form VAR model, namely B(L) and Σ that are considered random variables. The reduced−form parameter, B(L) and Σ were drawn 1,000 times from the Normal−Wishart posterior of coefficients. For each draw of the parameters, impulse responses were simulated another 1,000 times and only the responses that satisfied those assumed restrictions were kept.

Productivity shock was measured in either the manufacturing sector or in the entire economy. Productivity was measured as quarterly labor productivity. Manufacturing productivity data is available for Japan, South Africa, Canada, France, and Norway. Productivity data in the entire economic sectors is available for Japan, Canada, France, Finland, Germany, Ireland, Australia, and the UK. Components of $\mathrm{Y_t}$ of equation (24) is different for manufacturing data and for entire economy data.

They are described in the following equations, (25) and (26). Sign restrictions to identify productivity shock were imposed to lower the price and to raise the output. These restrictions are based on the study by Corsetti et al. (2008). Sign restrictions were placed for 20 quarters from the first quarter. For the price variable, the restriction was imposed from the fifth quarter to consider nominal rigidities.

Case 1. Productivity shock in the manufacturing sector

$$\mathrm{Y_t} = B_1(L)Y_{t-1} + B_2(L)US_t + U_t$$

$$\mathrm{Y_t} = \begin{bmatrix} logLP\_Manuf_i \\ logY\_Manuf_i \\ logC_i \\ log\frac{PPI_i}{CPI\ Service_i} \\ log\frac{Y\_Manuf_i}{GDP_i} \\ logREER_i\ or\ \frac{NetExports_i}{GDP_i} \end{bmatrix},\ US_\mathrm{t} = \begin{bmatrix} logLP\_Manuf_{US} \\ logY\_Manuf_{US} \end{bmatrix} \cdots\cdots\ (25)$$

Table 6 Endogenous variables for productivity shock in the manufacturing sector

Y_t	Description	Sign restrictions
$\boldsymbol{LP\_Manuf_i}$	Quarterly labor productivity in manufacturing sector of country i	+
$\boldsymbol{Y\_Manuf_i}$	Index of manufacturing production of country i	+
$\boldsymbol{C_i}$	Aggregate private consumption of country i	
$\boldsymbol{\frac{PPI_i}{CPI\ Service_i}}$	Relative domestic producer price index over service consumer price index of country i (a proxy for relative price of tradable goods)	−
$\boldsymbol{\frac{Y\_Manuf_i}{GDP_i}}$	Manufacturing output over real GDP of country i	+
$\boldsymbol{REER_i}$	Real effective exchange rate of country i	
$\boldsymbol{\frac{NetExports_i}{GDP_i}}$	Net exports over GDP of country i	

Table 7 Exogenous variables of US productivity shock in the manufacturing sector

US_t	Description
LP_Manuf_{US}	Quarterly labor productivity in the manufacturing sector of the US.
Y_Manuf_{US}	Index of manufacturing production of the US.

Five countries were included in the analysis of manufacturing productivity, namely Japan, Canada, France, South Africa, and Norway. The sample period for manufacturing productivity is 1980:1−2017:4. Quarterly labor productivity data for Canada and the US was downloaded from FRED, for Japan from the Japan Productivity Center, for South Africa from the CEIC, and for France and Norway from the Statistical Office of the European Union (Eurostat). The index for manufacturing output for Canada, France, and Norway was from the OECD, for Japan and South Africa from the CEIC, and for the US from FRED. The CPI for service was obtained from FRED, and the REER of each country, which is calculated based on the CPI, was also obtained from FRED. Other remaining variables were obtained from IFS.

Case 2. Productivity shock in total economy

$$Y_t = B_1(L)Y_{t-1} + B_2(L)US_t + U_t$$

$$Y_t = \begin{bmatrix} logLP\_Total_i \\ logY\_Total_i \\ logC_i \\ log\frac{PPI}{CPI_i} \\ logREER_i \ or \ \frac{NetExports_i}{GDP_i} \end{bmatrix}, \quad US_t = \begin{bmatrix} logLP\_Total_{US} \\ logY\_Total_{US} \end{bmatrix} \qquad \cdots\cdots(26)$$

Table 8 Endogenous variables for productivity shock in total economy

Variable	Description	Sign restrictions
LP_Total_i	Quarterly labor productivity of total economy of country i	+
Y_Total_i	Real GDP of country i	+
C_i	Aggregate private consumption of country i	
$\frac{PPI}{CPI_i}$	Domestic producer price index over consumer price index of country i	−
$REER_i$	Real effective exchange rate of country i	
$\frac{NetExports_i}{GDP_i}$	Net exports over GDP of country i	

Table 9 Exogenous variables of US productivity shock in total economy

US_t	Description
LP_Total_{US}	Quarterly labor productivity of total economy of the U.S.
Y_Total_{US}	Real GDP of the U.S.

Eight countries were included in the investigation of the productivity of the total economy, namely Japan, Canada, France, Finland, Germany, Ireland, Australia, and the UK. Japan, Canada, and France were included in both data sets. Quarterly data was used for the analysis, and the sample period for total economy productivity is 1974:1–2016:4. Quarterly labor productivity for total economy was calculated as the ratio of "real GDP" over "total hours worked." These two sets of data, real GDP, and consumption were obtained from the Ohanian–Raffo dataset.[26] The PPI, CPI,

[26] Ohanian–Raffo dataset was used for the study by Ohanian and Raffo(2012).

nominal exports, nominal imports, and nominal GDP were obtained from the IFS. The REER was obtained from FRED, calculated based on the CPI.

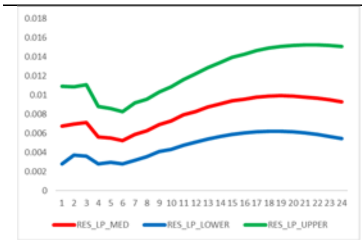
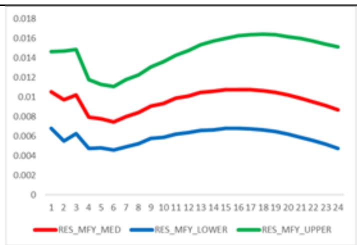
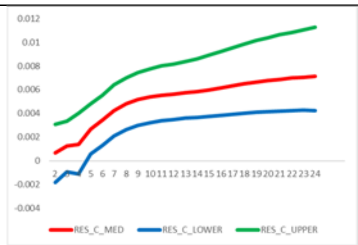
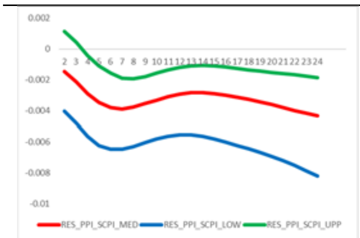
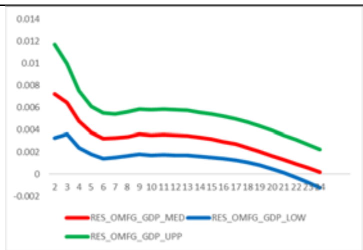
3.3 Empirical Results

A. Productivity shock in the manufacturing sector

Six endogenous variables of small open economies were included in the VAR model, with five variables fixed and the sixth variable set as REER or net exports in return to save the degree of freedom. Sign restrictions were imposed to raise labor productivity, manufacturing output, and relative production of manufacturing, and to lower relative domestic price of manufactured goods. Productivity shocks in the manufacturing sector were simulated for five countries, namely Japan, South Africa, Canada, France, and Norway.

The results for Japan are shown in Figure 9 as a representative case since the five endogenous variables of the VAR model responded in similar way for all five countries. The impulse responses to productivity shocks are reported in Figure 9 with median and 68% probability bands. The variables restricted with signs responded as expected. Consumption, an unrestricted variable, increased after productivity growth. The median labor productivity increased by 0.7% in response to productivity shock. The medians of manufacturing output, relative manufacturing output to GDP, and consumption rose by 1%, 0.7%, and 0.07%, respectively. The median of the relative price of tradable goods decreased by 0.15%.

Figure 9 Responses of variables to productivity shock in the manufacturing sector[27]

Labor Productivity	Manufacturing output	Consumption
		
PPI/CPI service	Manufacturing Output/GDP	
		

The variables of interest are the REER and net exports. Those variables of each country are shown in Figures 10 and 11. The US is reported to be a benchmark for comparing the results of small open economies. Figure 10 presents the responses of REERs to productivity shocks in the manufacturing sector. The REER appreciated in the US, but, among the five small open economies, it appreciated only in Japan. In fact, it depreciated in Canada, France, and Norway. The response in South Africa was not clear since it was not statistically significant. The US REER appreciated, and its median peaked at 12 quarters by appreciating 0.9%. The REER of Japan appreciated by 1.7% after 4 quarters in median. In Canada, the median REER depreciated by 1% after 4 quarters. The median REERs of France and Norway depreciated by 0.7% and 0.9%, respectively, after 4 quarters.

[27] The figure describes the impulse responses of variables in Japan. Since the variables of other four countries show similar movements, Japan is presented as a representative case.

Figure 10 Responses of REERs to productivity shocks in the manufacturing sector[28]

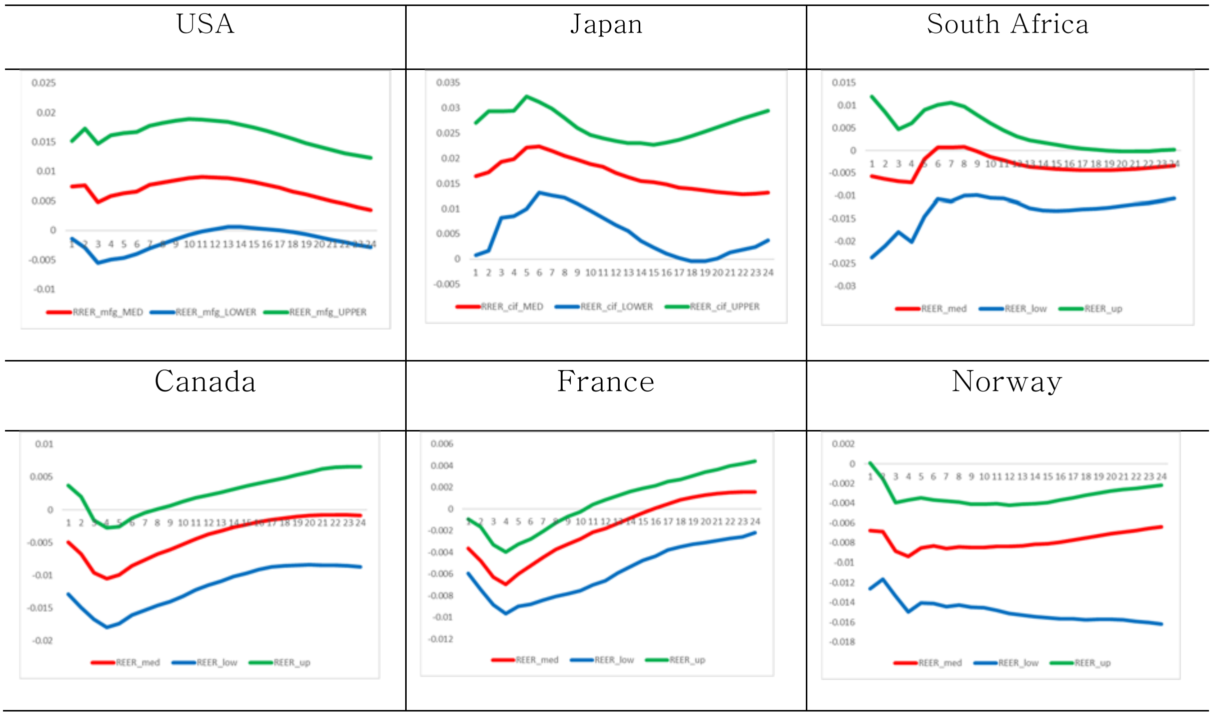
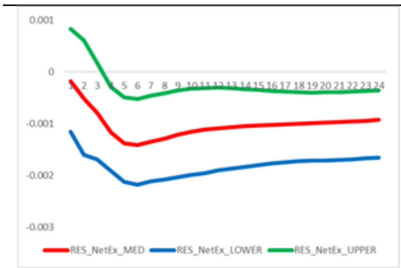


Figure 11 demonstrates the responses of net exports to productivity growth. Net exports decreased in the US. It also declined in Japan, Canada, and Norway. However, it increased in France and South Africa. The median net exports of the US decreased to 0.14% of GDP after 6 quarters. For Japan, net exports decreased to 0.08% of GDP after 11 quarters. The median net exports of Canada decreased to 0.06% of GDP after 15 quarters, and it decreased by 0.03% of GDP in Norway after 8 quarters. For France, the median net exports increased by 0.2% of GDP after 1 quarter. In the case of South Africa, net exports increased and the median peaked after 12 quarters by reaching 0.025% of GDP.

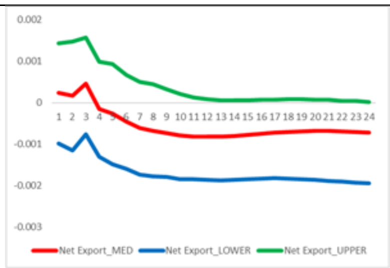
[28] USA is reported for comparison.

Figure 11 Responses of net exports to productivity shocks in the manufacturing sector

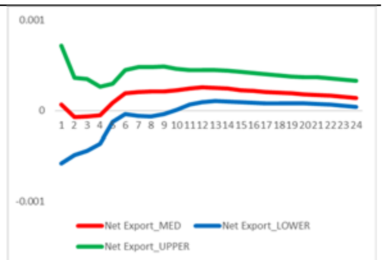
USA



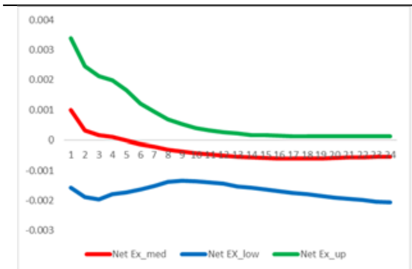
Japan



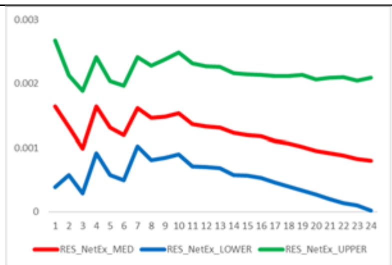
South Africa



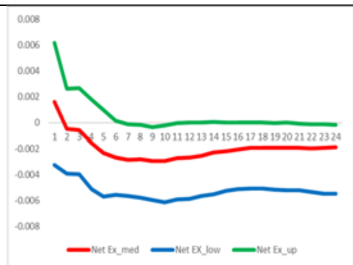
Canada



France



Norway



The responses of the REER and net exports in the US are consistent with the 2008 study by Corsetti et al. (2008) and their follow−up studies. Previous empirical studies investigated productivity shock in the US. This study extended the experiments to small open economies and finds that exchange rates and net exports in small open economies can react contrary to the responses in the US.

B. Productivity shock in total economy

Productivity growth in the entire economy and the responses of the REER and net exports were also investigated. Eight countries, whose data was available, were included in the sample, namely Japan, Canada, France, Finland, Germany, Ireland, Australia, and the UK. Positive sign restrictions were imposed to labor productivity and output, and negative sign restriction was applied to the price, PPI/CPI. Figures 12 and 13 illustrate the responses of the REERs and net exports, respectively, with median and 68% of probability bands. In Figure 12, the benchmark case of the US shows appreciation in the REER. Finland, Germany, and Japan also showed appreciation in the REER after productivity growth. However, the REERs in Canada and France depreciated. The responses of the REERs in Ireland, Australia, and the UK were statistically insignificant. Figure 13 demonstrates the response of net exports in each country. Net exports decreased in the US, and they moved in the same direction in Germany and the UK. However, net exports increased in France, Finland, and Australia. Similar to productivity shock in the manufacturing sector discussed in the previous section, the responses of variables in small open economies are not uniform and the variables of some countries show responses contrary to those in the US.

Figure 12 Responses of the REERs to productivity shocks in total economy

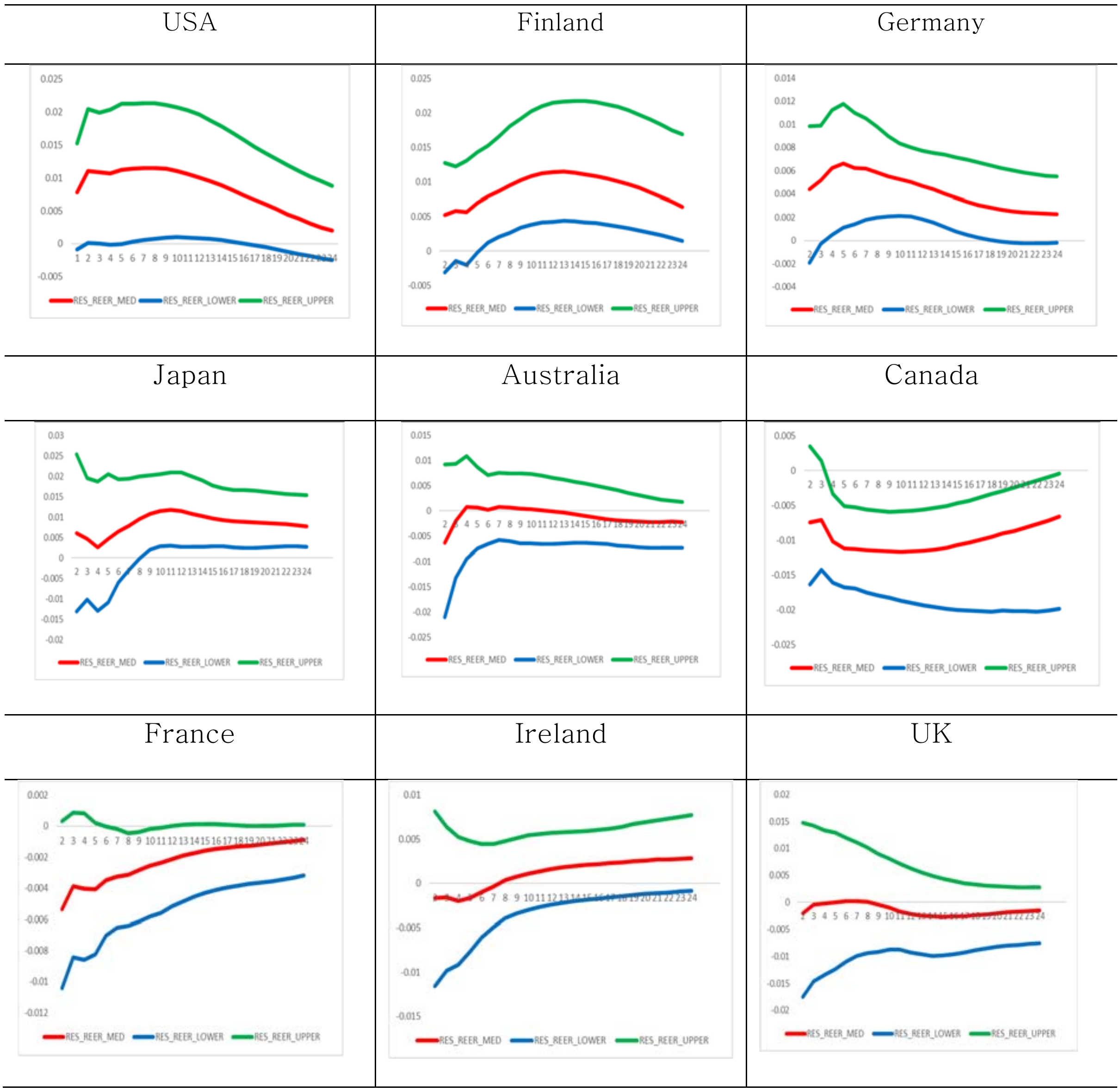
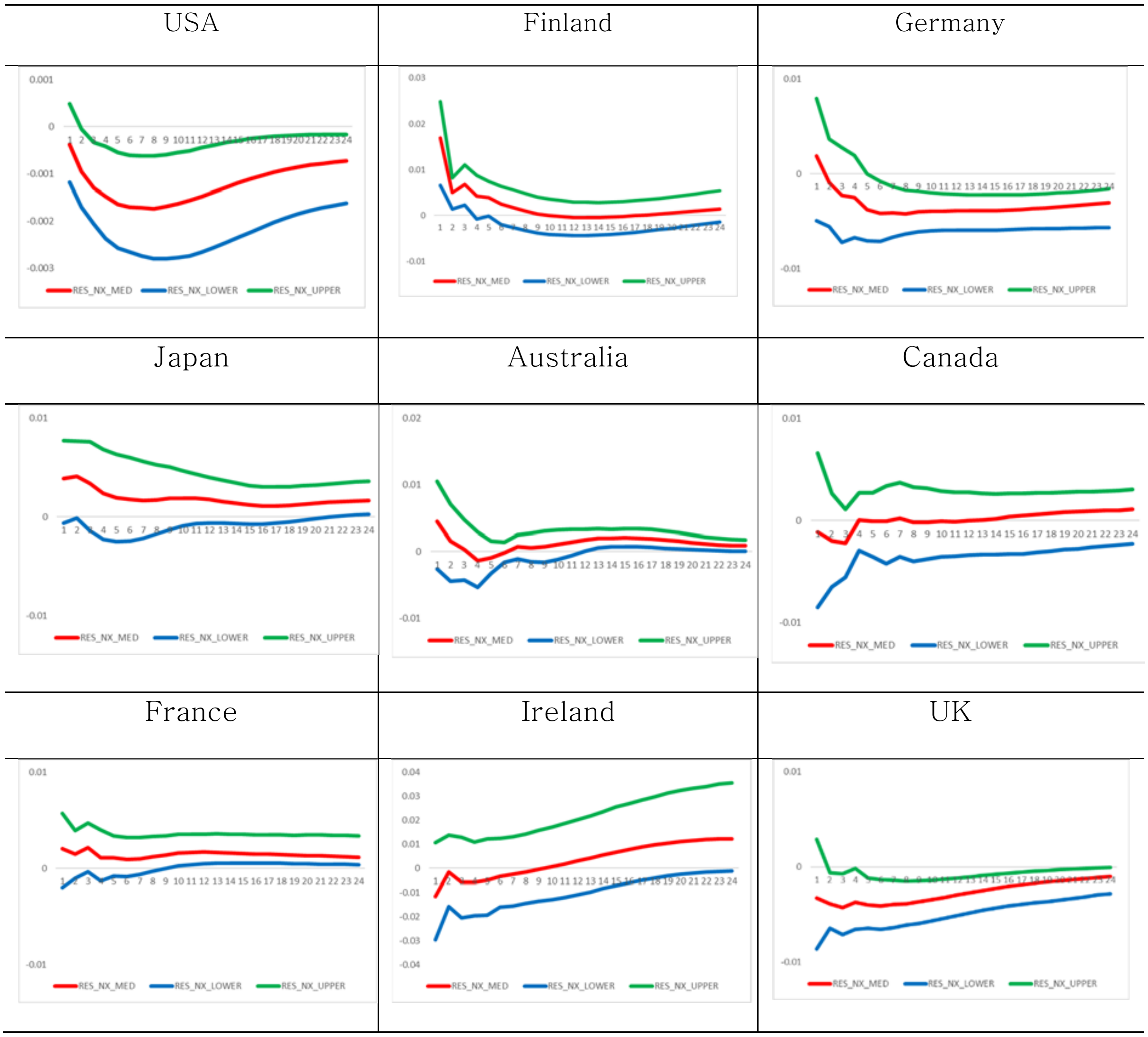


Figure 13 Responses of net exports to productivity shocks in total economy



3.4 Robustness

The REER was measured by other price indices. In the baseline model, the REER was measured based on manufacturing CPI. For robustness, it was measured based on manufacturing ULC. Since there was no data available for South Africa, it was excluded. Figure 14 presents the results for productivity shock in the manufacturing sector. The movements of the newly measured REERs are similar to those in the baseline model in Figure 10. Figure 15 depicts the results for productivity shock in the total economy, where the results are also similar to the baseline model in Figure 12.

Figure 14 Responses of REERs to productivity shocks in the manufacturing sector

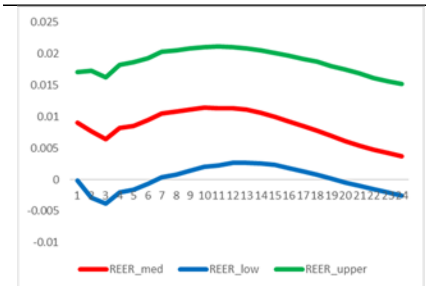
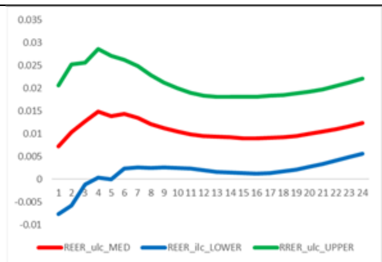
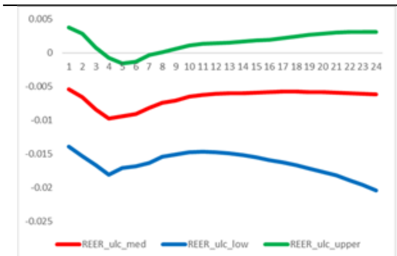
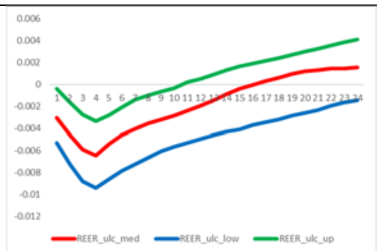
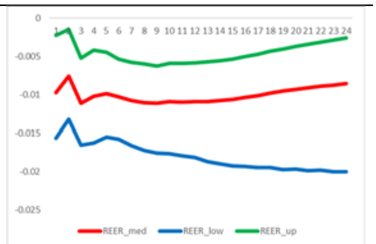
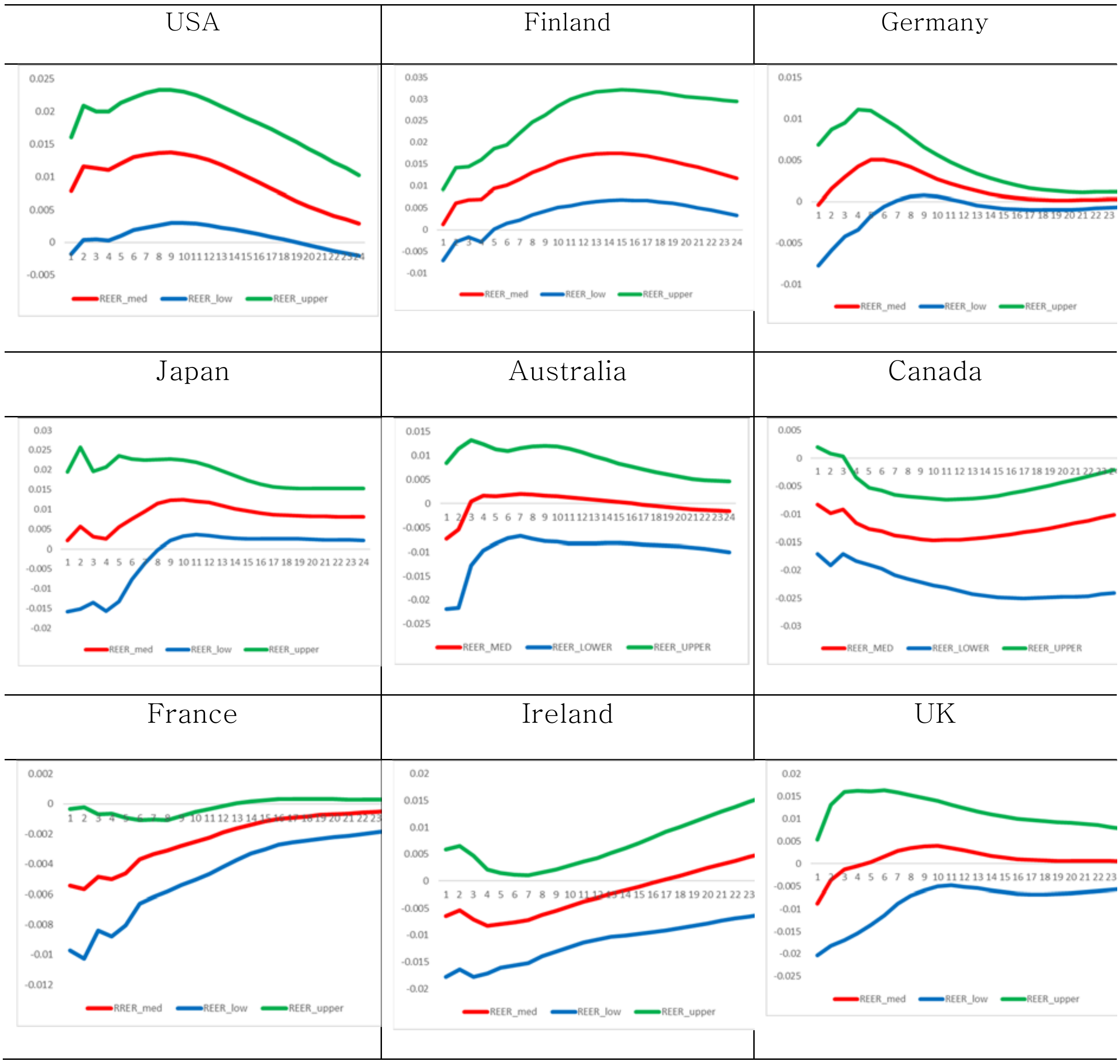
<table>
<tr><td>USA</td><td colspan="2">Japan</td></tr>
<tr><td>
</td><td colspan="2">
</td></tr>
<tr><td>Canada</td><td>France</td><td>Norway</td></tr>
<tr><td>
</td><td>
</td><td>
</td></tr>
</table>

Figure 15 Responses of REERs to productivity shocks in total economy



3.5 Comparison to The US

The traditional IRBC model predicts that the RER depreciates in response to productivity shock. However, recent empirical studies provide evidence that real exchange rate can appreciate, specifically with the data from the US. According to Corsetti et al. (2008, 2014), appreciation is possible if 1) strong wealth effect occurs due to incomplete financial markets and 2) consumption bias for home goods exists. The traditional IRBC model assumes that financial markets are complete and that agents of the economy are fully hedged against consumption risk and their consumption is not affected by wealth level. However, Corsetti et al. (2008) assume that financial markets are incomplete, and then consumption changes along with wealth. Positive productivity shock raises wealth, and consumption increases accordingly. If consumption is biased for home goods, then the consumption of home goods rises strongly. This induces the relative price of domestic goods to increase and the RER to appreciate. Net exports decline due to the higher demand for domestic goods and RER appreciation. Wealth effect and consumption home bias are key factors to cause the RER to appreciate. These parameters are mentioned in the theoretical models of previous studies but have rarely been measured or investigated.[29]

This study investigated the responses of the RER and net exports in response to productivity growth in the US, and it showed results consistent with recent empirical literature. The RER appreciates and net exports decline. However, the responses of those variables in small open economies are not uniform, and some of them move contrary to the responses in the US. Since the appreciation in the RER

---

[29] Corsetti et al.(2008) assumed incomplete financial market and it was not measured. Home bias was included in the model as a parameter and it was calibrated using US trade and output data.

and the decline in net exports in the US can be explained by the wealth effect and high home bias, those parameters can also account for the different movements in small open economies.

The wealth of a country increases when its productivity grows. If the wealth effect exists due to incomplete financial markets, consumption rises accordingly. If consumption rises along with productivity growth, we can assume that the wealth effect has occurred. If the wealth effect is strong, consumption will increase more. This study measured the ratio of consumption increase over output increase after productivity shock as a proxy for wealth effect.

$$\text{wealth effect} = \frac{\sum_{k=1}^{p} C_k}{\sum_{k=1}^{p} Y_k} \quad \cdots\cdots(27)$$

where $\sum_{k=1}^{p} C_k$ is the sum of consumption increase for p quarters, and $\sum_{k=1}^{p} Y_k$ is the sum of output increase for p quarters after productivity growth. Consumption and output data was obtained from the responses of the VAR model of each country described in Section 3.3. The period p is 4, 8, or 12 quarters.

Consumption home bias is another key parameter, and this study measured it as the ratio of consumption of domestically produced goods divided by total consumption.

$$\text{Home Bias} = \frac{\textit{Consumption of domestic goods}}{\textit{Consumption of domestic and imported goods}} \quad \cdots\cdots(28)$$

The data of each component was obtained from the Inter-Country Input-Output Table of the OECD. Average consumption for the period from 1995 to 2015 was used for the calculation.

The magnitude of the wealth effect for each country is demonstrated in Tables 10 and 11. Table 10 illustrates countries with productivity shocks in the manufacturing sector, and Table 11 shows countries with productivity shocks in the total economy. Table 10 shows that the REER appreciated in the US and Japan, where wealth effects exist, and they deviate from zero with 84% of probability for 8 quarter and 12 quarter horizons. The wealth effect of the remaining four countries were not clear since their 68% probability bands include positive and negative values. Table 11 shows that the REER appreciated in USA, Japan, Finland, and Germany, where the wealth effect exists, and they deviate from zero with 84% of probability for 8 quarter and 12 quarter horizons. The wealth effect of the UK was similar to those four countries, but the REER response was not statistically significant. The remaining four countries, Canada, France, Ireland, and Australia, demonstrated unclear wealth effects and their REERs depreciated or were not statistically significant. Consequently, the REER appreciated in the countries where the wealth effects were strong, which is consistent with expectations.

Table 10 Productivity shocks in the manufacturing sector and wealth effect

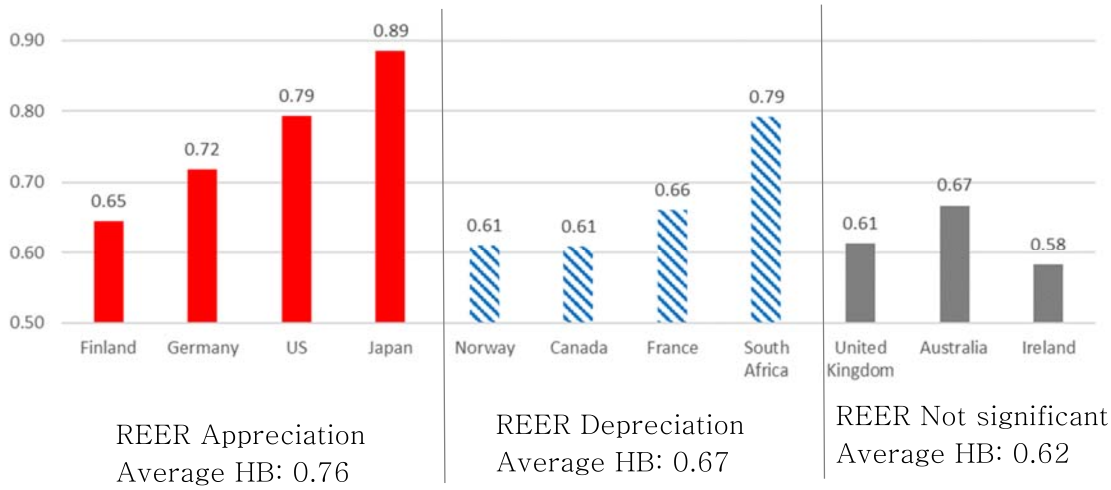
	USA	1. Japan	2. Canada	3. France	4. South Africa	5. Norway
REER	App.	App.	Dep.	Dep.	Dep.	Dep.
Net Exports	Decrease	Decrease	Decease	Increase	Increase	Decrease
Wealth effect for 4 quarters, (C/Y, %)						
upper 84%	28.5	31.7	49.5	21.6	9.5	40.9
median	17.6	20.7	36.1	−7.5	−22.6	14.2
lower 16%	−13.9	−4.1	−12.0	−96.1	−98.6	−53.9
Wealth effect for 8 quarters, (C/Y, %)						
upper 84%	31.0	39.6	51.3	23.8	4.1	44.9
median	23.5	37.1	37.0	−0.4	−34.3	19.7
lower 16%	4.8	25.8	−10.2	−68.0	−134.6	−46.6
Wealth effect for 12 quarters, (C/Y, %)						
upper 84%	33.4	43.6	47.3	24.0	3.0	44.5
median	26.9	46.0	37.3	1.8	−39.4	26.1
lower 16%	10.3	40.7	−9.7	−73.7	−158.4	−39.6

Table 11 Productivity shocks in total economy and wealth effect

	USA	1. Japan	2. Canada	3. France	4. Finland	5. Germany	6. Ireland	7. Australia	8. UK
REER	App.	App.	Dep.	Dep.	App.	App.	Not sig.	Not sig.	Not sig.
Net Exports	Decrease	Not sig.	Not sig.	Increase	Increase	Decrease	Not sig.	Increase	Decrease
Wealth effect for 4 quarters, (C/Y, %)									
upper 84%	85.4	73.7	105.5	100.5	83.8	86.1	13.5	63.1	116.5
median	5.0	70.5	66.0	81.4	55.2	89.5	−25.3	37.2	90.6
lower 16%	65.4	52.8	−81.7	−22.0	−23.0	92.6	−116.6	−43.7	−12.5
Wealth effect for 8 quarters, (C/Y, %)									
upper 84%	89.0	73.1	110.3	94.7	94.5	98.1	17.5	67.9	117.0
Median	90.4	73.1	49.0	78.5	74.6	103.2	−18.0	50.5	95.2
lower 16%	82.6	65.9	−173.9	0.6	17.2	111.8	−106.7	−10.1	10.8
Wealth effect for 12 quarters, (C/Y, %)									
upper 84%	92.5	76.3	105.4	93.1	100.6	108.0	21.7	78.0	116.8
median	94.7	77.4	26.2	76.7	83.6	114.8	−11.9	62.7	98.3
lower 16%	92.6	73.6	−268.6	−2.2	37.1	129.5	−100.7	9.0	19.5

Figure 16 shows consumption home bias for each country and the response of the REER after productivity shock. Productivity shock was measured in the manufacturing sector or in the total economy. Figure 16 presents the results from the two measures together. The US, Japan, Canada, and France are included in both measures and the REER response of each country was identical in the two measures. In the US and Japan the REER appreciated, and it depreciated in Canada and France in both measures. Consumption home bias is 0.5 when there is no preference for domestic goods. All countries appear to have biased consumption toward domestic goods since all home biases are greater than 0.5. Japan has the highest home bias at 0.89, and the US is second with 0.79. The RER of a country is expected to appreciate when consumption home bias is high. The RER of Japan, the US, Germany, and Finland appreciated, and their average consumption home bias is 0.76. The RER depreciated in South Africa, France, Canada, and Norway and their average consumption home bias is 0.67. The responses of the RER for the remaining three countries were not clear and their average consumption home bias is 0.62. This relationship indicates that the REER tends to appreciate in a group where consumption home bias is high. Since the number of countries is small, more rigorous analysis could not be conducted and remains to be done in further research.

Figure 16 Consumption home bias



Note: HB stands for consumption home bias.

The RER of the US appreciated after productivity shock in the simulation discussed in the previous section. The wealth effect and home bias of the US were measured and were compared to the values of small open economies. The RER appreciated in Japan, Finland, and Germany. The wealth effects of those countries were positive and deviated from zero for 8 quarter and 12 quarter horizons, and their consumption home biases were relatively higher than in other countries. The US also presented a strong wealth effect and high home bias, and the RER appreciated in this group of countries. The RER depreciated in Norway, Canada, France, and South Africa. In this group, the wealth effect was not clear and consumption home bias was relatively low. Small open economies with strong wealth effect and high home bias showed an appreciation in the RER along with the US.

3.6 Conclusion

Previous empirical literature on productivity shock examined shocks in large countries, mainly the US. This study investigated shocks in 10 small open economies and compared the movements of the RER and net exports to the findings in the literature. The 10 countries are 1) Japan, 2) Germany, 3) Canada, 4) France, 5) Ireland, 6) Australia, 7) The UK, 8) South Africa, 9) Norway, and 10) Finland. Shocks in those countries were simulated with the VAR model, imposing sign restrictions on certain variables to identify productivity shocks. Since small open economies are affected by the shocks in large economies, this study controlled the shock in the US as exogenous variables. Productivity was measured in the manufacturing sector or in the total economy. The results show that the responses of the RER and net exports in small open economies are not uniform, and in some countries there are opposite responses to what was seen in the US. In the US, the literature shows that the RER appreciates and net exports decline, and these results are confirmed in this study. While the RER appreciates in Japan, Finland, and Germany as in the US, it depreciates in Norway, Canada, France, and South Africa. Net exports decline in Japan, Norway, Germany, and the UK, as the US, but they improve in France, Finland, Australia, and South Africa.

The appreciation in the RER and decline in net exports reported from the US data are possible when the wealth effect is strong and consumption is biased for home goods, according to the theoretical model of Corsetti et al.(2008). This study measured the wealth effect and home bias of each country. In the US, home bias is the second highest, followed by Japan, and the wealth effect is strong. The responses of US variables and the level of the parameters are in line with the predictions in the literature. In terms of small open economies, the RER appreciates where the wealth effect is strong and home bias is relatively high. The wealth effects of those countries, namely Japan, Germany, and Finland, are positive and deviate from zero for 8 quarter and 12 quarter horizons. The RER depreciates where the wealth effect is not clear and consumption home bias is relatively low. This study finds that the responses of the RER and net exports to productivity shock are not uniform in small open economies. The countries with similar features to the US, namely a strong wealth effect and high consumption home bias, tend to experience appreciation in the RER.

Chapter 4. Conclusion and Discussion

International transmission of productivity shock and its effects on the RER is widely discussed in the literature. However, a large share of the studies is theoretical modeling and the predictions of the models are inconsistent. Empirical studies are limited to shocks in large economies, mainly the US, and investigate aggregate impacts on the global economy. Previous studies investigated the effect of productivity growth in a large economy on the world economy as a whole and did not address the effects on an individual country level. This thesis, however, investigated the effects of US productivity shocks on 48 countries and finds that country characteristics can cause the responses to vary. In addition, productivity shocks in small open economies were also investigated and the results were compared to the responses in the US.

This thesis investigated two topics. First, it investigated the effects of US productivity shock on 48 countries while the literature analyzed the impact on the global economy. US productivity shock was identified via sign restrictions in the VAR model and the role of country characteristics on the effects was tested with cross−country OLS. The results in this study is consistent with the literature, namely that aggregate US RER appreciates and net exports deteriorate. However additional analysis found novel evidence that US bilateral RER and net exports relative to a country can respond in either direction, increase or decrease. Cross−country OLS established that a country experiences appreciation in US RER if it has high consumption home bias, a strong trade relationship with the US, or an economy more open to trade. These results suggest that trade can be an important transmission channel of productivity shock. In terms of net exports, aggregate US net exports decline, but bilateral US net exports to a country can decline or increase. Net exports decline after productivity growth when the US RER appreciates. When decomposing net exports into exports and imports, US exports to countries where the US RER appreciates decrease and the US increases imports of intermediate goods. In addition, US net exports increase to countries where the financial markets are more complete.

Second, this study investigated productivity shocks in 10 small open economies and found that responses of aggregate RER and net exports can differ from those in the US. The 10 countries are Japan, South Africa, Canada, France, Norway, Finland, Germany, Ireland, Australia, and the UK. While the RER appreciates and net exports decrease in the US after productivity growth, these parameters show varied movements in small open economies. An appreciation in the RER, as in the US, is witnessed in a group of countries where a strong wealth effect occurs and consumption home bias is high.

Recent empirical studies reveal that productivity shock can cause an appreciation in the RER of the country where the shock occurs. This evidence is shown with productivity growth in the US or in the EU. The appreciation in the US RER after productivity growth can be regarded as negative impact on the global economy since the rest of the world have to import US products at a higher price. This study finds that this negative impact, appreciation in the US RER, is apparent in respect of the global economy, but the impact can differ across individual countries. Countries with high home bias, strong trade ties with the US, or higher trade openness can face a negative impact with the appreciation in the US RER after productivity growth in the US. Productivity growth in small open economies was also investigated, and the RER appreciates when the wealth effect is strong and consumption home bias is high. The results of this study show that the appreciation in the RER in response to productivity growth, suggested by recent empirical studies, is not applicable in all cases. The RER of a country appreciates with productivity growth when it experiences a strong wealth effect and consumption home bias is high. Even though the aggregate RER of a country appreciates due to productivity growth, bilateral RER relative to its trade partner can vary according to characteristics of the partner. A partner country will experience a negative spillover of productivity growth in its neighbor if home bias is high, trade ties are strong with the neighbor, or the economy is open to trade.

Further research is required to consider the structural changes brought about by the 2008 financial crisis. It is accepted that there is a structural change after the global financial crisis of 2008. Therefore, previous studies excluded the post-crisis periods from their analysis and used the data before 2008.[30] The basic model of this study investigated the RER and net exports up to 2017:Q4, including the 2008 financial crisis. To check the robustness, the VAR model was tested up to 2004:Q4, in line with the previous studies by Corsetti et al. (2008, 2014), and it found that the RER appreciates in both samples. Even though this comparison shows consistent results, further research should be conducted with a more rigorous method. For instance, the Markov Switching

[30] Nam and Wang(2018) used a sample of 1975:1-2007:4 to exclude 2008 global financial crisis and Corsetti et al.(2018) analyzed a sample of 1973:1-2004:4.

Structural VAR model can divide regimes before and after the financial crisis and can determine whether there has been structural change since the global financial crisis. This remains for further studies.

References

Akkoyun H., Arslan Y. and Kinlinc M. (2017). Risk Sharing and Real Exchange Rates: The Role of Non-tradable Sector and Trend Shocks. *BIS Working Papers, No.613*

Backus D., Kehoe PJ., and Kydland FE. (1994). Dynamics of the Trade Balance and the Terms of Trade: The J Curve?. *American Economic Review, 84(1)*:84-103

Balassa B. (1964). The Purchasing Power Parity Doctrine: A Reappraisal. *Journal of Political Economy,* 72(6):584-596

Bang H., and Park M. (2017). Global Value Chain and Its Impact on the Linkage between Exchange Rate and Export: Cases of China, Japan and Korea. *The World Economy*, 41(9):2552-76

Berka, M., Devereux MB., and Engel C. (2018). Real Exchange Rates and Sectoral Productivity in the Eurozone. *American Economic Review,* 108(6):1543-81.

Bordo MD., Choudhri EU., Fazio G., and MacDonald R. (2017) The Exchange Rate in the Long Run: Balassa-Samuelson Effects Reconsidered. *Journal of International Money and Finance*, 75:69-92

Breock MD., and Slok T. (2006). Interpreting Real Exchange Rate Movements in Transition Countries. *Journal of International Economics*, 68(2):368-383

Chari V., Keoe P., and McGrattan E. (2007). Are Structural VARs with Long-Run Restrictions Useful in Developing Business Cycle Theory?. *Staff Report 364,* Federal Reserve Bank of Minneapolis

Chinn MD., and Ito H. (2006). What Matters for Financial Development? Capital Controls, Institutions, and Interactions. *Journal of Development Economics,* 81(1):163-192

Chinn MD., and Johnston LD. (1997). Real Exchange Rate Levels, Productivity and Demand Shocks: Evidence from a Panel of 14 Countries. *IMF Working papers,* 1997/066

Choudri EU., and Schembri LL. (2014). Productivity, Commodity Prices and the Real Exchange Rate: The Long-Run Behavior of the Canada-U.S. Real Exchange Rate. *International Review of Economics and Finance,* 29:537-551

Cole HL., and Obstfeld M. (1991). Commodity Trade and International Risk Sharing: How Much Do Financial Markets Matter?. *Journal of Monetary Economics,* 28(1):3-24

Corsetti G., Dedola L., and Leduc S (2008). International Risk-Sharing and the Transmission of Productivity Shocks. *Review of Economic Studies,* 75(2): 443-473

Corsetti G., Dedola L., and Leduc S (2014). The International Dimension of Productivity and Demand Shocks in the US Economy. *Journal of the European Economic Association,* 12(1):153-176

Enders Z., and Müller GJ. (2009). On the International Transmission of Technology Shocks. *Journal of International Economics*, 78(1):45-59

Faust J., and Leeper EM. (1997). When do Long-Run Identifying Restrictions Give Reliable Results?. *Journal of Business and Economic Statistics*, 15:345-353

Gubler M., and Sax C. (2019). The Balassa–Samuelson Effect Reversed: New Evidence from OECD Countries. *Swiss Journal of Economics and Statistics*, 155 article no.3

Harrod RF. (1933). International Economics, *Nisbet & Cambridge University Press*

Hamano M. (2013). The Consumption–Real Exchange Rate Anomaly with Extensive Margins. *Journal of International Money and Finance,* 36:26–46

International Monetary Fund. (2019). World Economic Outlook, April 2019: Growth Slowdown, Precarious Recovery. International Monetary Fund.

Ilzetzki E., Reinhart CM., and Rogoff. KS. (2018). Exchange Arrangements Entering the 21st Century: Which Anchor Will Hold?. *The Quarterly Journal of Economics, 134(2):599–646*

Juvenal L. (2011). Sources of Exchange Rate Fluctuations: Are They Real or Nominal?. *Journal of International Money and Finance*, 30(5):849–876

Kidland FE., and Prescott EC. (1982). Time to Build and Aggregate Fluctuations. *Econometrica,* 50(6):1345–1370

Kim S. (2015). Country Characteristics and the Effects of Government Consumption Shocks on the Current Account and Real Exchange Rate. *Journal of International Economics,* 97(2):436–447

Kollmann R. (2016). International Business Cycles and Risk Sharing with Uncertainty Shocks and Recursive Preferences. *Journal of Economic Dynamics and Control*, 72(c):115–124

Lee J., and Tang MK. (2007). Does Productivity Growth Lead to Appreciation of the Real Exchange Rate?. *Review of International Economics,* 15(1):164-187

Lian W., Novta N., Pugacheva E., Timmer Y., and Topalova P. (2020). The Price of Capital Goods: A Driver of Investment Under Threat. *IMF Economic Review*, 68:509-549

MacDonald R., and Ricci LA. (2005). The Real Exchange Rate and the Balassa-Samuelson Effect: The Role of the Distribution Sector. *Pacific Economic Review,* 10(1):29-48

Miyamoto W., and Nguyen TL. (2017). Understanding the Cross-Country Effects of U.S. Technology Shocks. *Journal of International Economics,* 106. :143-164

Mountford A., and Uhlig H. (2009). What Are the Effects of Fiscal Policy Shocks?. *Journal of Applied Econometrics,* 24(6):960-992

Nam D., and Wang J. (2018). Understanding the Effect of Productivity Changes on International Relative Prices: The Role of News Shocks. *Pacific Economic Review,* 23(3):490-516

Ohanian LE, and Raffo A. (2012). Aggregate Hours Worked in OECD Countries: New Measurement and Implications for Business Cycles. *Journal of Monetary Economics*, 59(1):40-56

Ramey VA. (2016). Macroeconomic Shocks and Their Propagation. *Handbook of Macroeconomics*, Volume2, Chapter 2, pages 71-162

Rogoff K. (1992). Traded Goods Consumption Smoothing and the Random Walk Behavior of the Real Exchange Rate. *Monetary and Economic Studies*, Bank of Japan, 10(2):1–29

Samuelson PA. (1964). Theoretical Notes on Trade Problems. *Review of Economics and Statistics,* 46(2):145–154

Stockman, AC., and Tesar LL. (1995). Tastes and Technology in a Two–Country Model of the Business Cycle: Explaining International Comovements. *American Economic Review,* 85(1):168–185

Tica J., and Druzic I. (2006). The Harrod–Balassa–Samuelson Effect: A Survey of Empirical Evidence, *EFZG Working Paper Series,* 0607

Uhlig H. (2004). Do Technology Shocks Lead to a Fall in Total Hours Worked?, *Journal of European Economic Association*, 2:361–371

Uhlig H. (2005). What Are the Effects of Monetary Policy on Output? Results from an Agnostic Identification Procedure. *Journal of Monetary Economics*, 52(2):381–419

국문초록

생산성 충격이 실질환율과 순수출에 미치는 영향의 국별 비교

박 미 숙
경제학부 경제학 전공
서울대학교 대학원

생산성 증가 충격이 실질 환율에 미치는 영향에 대한 연구는 다양하게 이루어졌다. 그러나 그간의 연구는 이론 연구의 비중이 높고, 실증 분석은 미국을 대표로 하는 대규모 경제에서의 생산성 증가가 전세계 경제에 미치는 영향으로 한정되어 있다. 또한 이론 연구에서는 모델 별로 환율의 변화방향을 다르게 예측하고 있어 연구 결과에 일관성이 결여되어 있다. 이 논문은 다수의 국가 샘플을 이용해 생산성 충격의 파급효과를 분석하고, 국가의 특성에 따라 영향이 달라질 수 있다는 결과를 제시한다. 또한 소규모 개방경제에서 생산성 충격이 발생했을 때 환율과 순수출의 변화를 분석하고, 미국의 결과와 비교한다.

첫째, 기존 연구가 미국의 생산성 증가가 전세계 경제에 미치는 영향을 분석한데 반해, 이 논문은 미국의 생산성 충격이 48 개 개별 국가에 미치는 영향을 분석한다. 미국의 생산성 충격은 VAR(Vector Autoregressive) 모델에서 변수에 sign restriction 을 적용해 식별하고, 국가별 영향의 차이가 발생하는 원인은 cross-country OLS(Ordinary Least Square)를 이용해 분석한다. 분석 결과 전체적인 미국의 실질 환율은 절상하고 순수출은 감소하지만, 개별 국가에서는 미국의 실질 환율이 절상과 절하가 모두 존재하고 순수출도 감소와 증가가 모두 관찰된다. 실질 환율의 경우, 소비에서 자국 제품 선호도가 높고 미국과 강한 무역 관계를 가지거나 무역 개방도가 높은 국가에서 미국의 실질 환율이 절상하는

것으로 분석됐다. 무역의 경우, 미국의 실질 환율이 절상한 국가로는 미국의 수출이 감소하고, 미국은 생산성 증가 이후 중간재 수입을 늘리는 것으로 나타났다. 전체적인 미국의 수출은 감소하지만, 금융시장이 발전한 국가로의 수출은 오히려 증가하는 것으로 분석됐다.

둘째, 기존 연구는 대규모 경제에서 생산성 충격을 분석했지만, 이 연구는 소규모 개방경제에서 생산성 충격이 발생할 경우 그 국가의 실질 환율과 순수출의 반응을 분석하였다. 소규모 개방경제 샘플은 일본, 남아프리카 공화국, 캐나다. 프랑스, 노르웨이, 핀란드, 독일, 아일랜드, 호주, 영국의 10 개 국가로 구성된다. 미국에서는 생산성이 증가했을 때 실질 환율이 절상하고 순수출이 감소했지만, 소규모 개방경제에서는 미국과 반대방향으로 변수가 반응하는 경우가 나타났다. 미국의 경우처럼 생산성 증가 이후 실질 환율이 절상하는 국가에서는 공통된 특징이 발견되었다. 생산성 증가 이후 자산 효과가 크고 소비에서 자국 제품을 선호하는 경향이 높은 국가에서는 실질 환율이 미국의 경우처럼 절상하였다.

주요어: 생산성 충격, 실질환율, 순수출, 국가 특성, 소규모 개방경제, VAR, 자국제품 선호, 자산효과

학번: 2012-30051