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On the Balassa-Samuelson Effect in Japan

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Abstract

The real effective exchange rate (RER) is inherently a general equilibrium variable and its fluctuations are influenced by various factors. In addition to supply factors such as productivity, demand factors, home bias, risk sharing, fiscal and monetary policies also affect the RER. In this context, the "Balassa-Samuelson effect" (B-S effect) focuses on the role of productivity differentials in the tradable sector in explaining the long-run trend of the RER. In this paper, we quantitatively examine the extent to which the B-S effect has been observed in Japan's RER since the 1970s by constructing and estimating a two-country (Japan and the United States), two sector (tradable and non-tradable), dynamic stochastic general equilibrium (DSGE) model. In addition, we also examine cases where the law of one price does not hold in tradables (dominant currency pricing and local currency pricing) and restrictions on labor mobility across sectors. Our results indicate that the long-run trend of the RER in Japan and the United States can be explained to a considerable extent by the B-S mechanism. In other words, according to the model analysis, the yen's appreciation trend in the RER from the 1970s to the mid-1990s can be explained by the rising relative productivity of Japan's tradable sector relative to the U.S., as pointed out in previous studies, and the effects of the Plaza Accord in 1985. In addition, the depreciation of the yen in real terms since the mid-1990s can be explained by a decline in the relative productivity of Japan's tradable sector relative to the United States; the "reverse B-S effect" from Japan's perspective.

JEL Classifications: F41, F42, C51

Keywords: Balassa-Samuelson effect, productivity, real exchange rate

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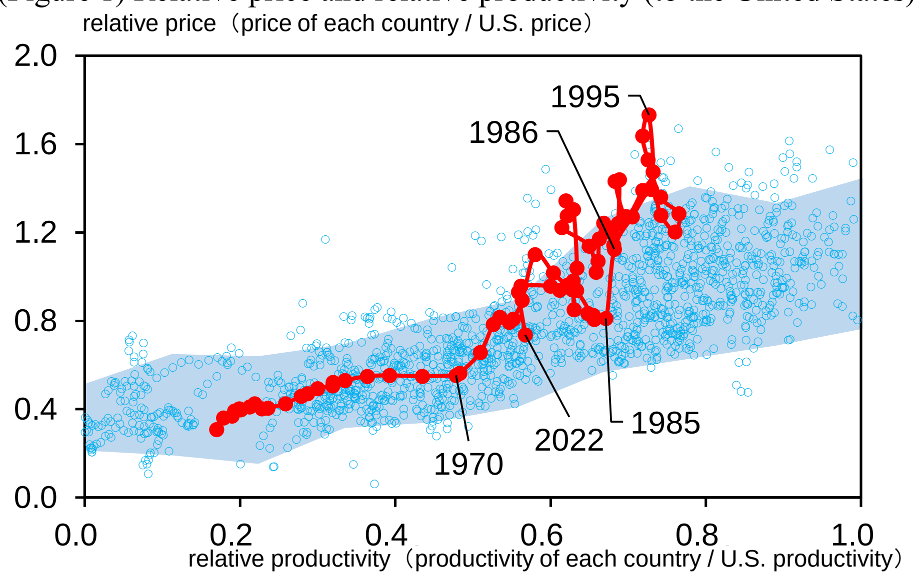
1 Introduction

The real effective exchange rate (RER) is defined as the nominal effective exchange rate (NER) multiplied by the relative price of domestic and foreign goods and services and resembles the deviation of the NER from the purchasing power parity (PPP) - the exchange rate at which the prices of goods and services are equal to those abroad.[1] The seminal paper by Rogoff [1996] showed that once the NER deviates significantly from the PPP, it takes a long time for the two to adjust, and this cannot be explained by financial factors or price stickiness alone (the "PPP puzzle"). One candidate explanation for the long-run divergence is the "Balassa-Samuelson effect" (hereafter the B-S effect), which focuses on the role of productivity differentials in the tradable sector. The B-S effect states that (1) if the productivity of tradables (relative to the non-tradable sector) increasees relative to other countries, (2) domestic wage increases in the tradable sector will spill over to wages and prices in the non-tradable sector, and (3) this mechanism will eventually cause the country's RER to appreciate. In this regard, as shown in Figure 1, Rogoff [1996] showed that there is a positive relationship between relative prices and productivity of tradables, and argued that the B-S effect is useful for explaining the long-run trends in the RER.[2]

(Figure 1) Relative price and relative productivity (to the United States)



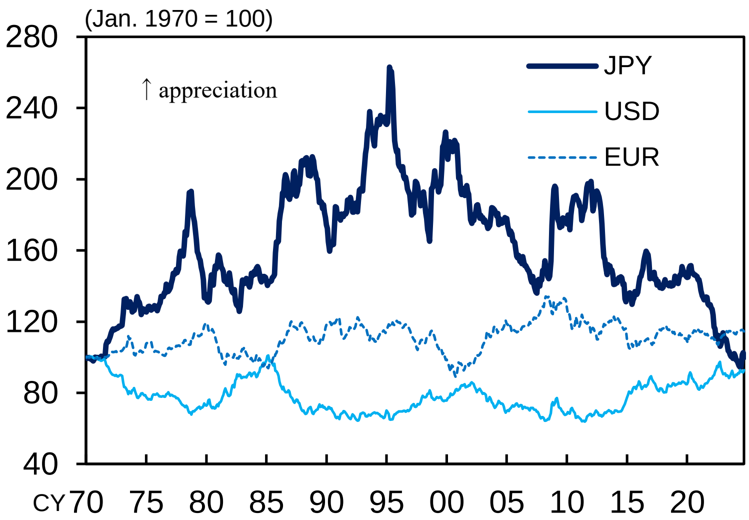
Note: Relative price and productivity of 29 developed countries. Sample period is from 1950 to 2022.
Shaded area indicate 95th percentile band. Red dotted line represents Japan. Relative prices are in U.S. dollars.
Sources: The Conference Board; OECD; Penn World Table

[1] This paper focuses on the mechanism of fluctuations in real exchange rates, and does not discuss fluctuations in nominal exchange rates.

[2] In Figure 1, we assume that productivity differentials of the non-tradable sector is small across countries, and consider the relative productivity of the economy as a whole to be a proxy variable for the tradable sector.

The long-term trend of RER in Japan since the 1970s shows that the trend has changed dramatically since the mid-1990s (Figure 2).[3] The appreciation of the yen observed in the RER from the 1970s to the mid-1990s is said to be due to the B-S effect during Japan's postwar catch-up in the tradable sector (Yoshikawa [1990], Rogoff [1996], Ito [1997, 2005, 2022], Itskhoki [2021]). In addition, the depreciation of yen's RER from the mid-1990s is interpreted as analogous to the appreciation of the RER that lasted until around 1995, and the "reverse B-S effect" is thought to have acted on the RER due to a decline in the relative productivity of the tradable sector (Ito [2022], Ito [2015]).

(Figure 2) Real effective exchange rate



Source: BIS

In light of these observations, productivity differentials in the tradable sector is thought to play a pivotal role in the long-run fluctuations of the RER. However, as Itskhoki [2021] points out, the RER is inherently a general equilibrium variable, and its fluctuations can be affected by various factors; in addition to supply factors such as productivity, demand factors, home bias, risk sharing, fiscal and monetary policy. For this reason, partial equilibrium analysis focusing on a certain sector or static B-S models are insufficient for analyzing RER fluctuations, and it is preferable to analyze them using dynamic stochastic general equilibrium (DSGE) framework taking into account various factors as mentioned above (Ueda and Tsuruoka [2023], Kiyota [2023]). In this regard, there are some cases in which the fluctuation of the RER has been analyzed by estimating a DSGE model (Rabanal [2009], Rabanal and Tuesta [2010]), but to the best of our knowledge, there have been no

[3] Although the share of Japan's trade has shifted from the United States to Asian countries such as China, the ratio of invoice currencies has remained stable, so the impact of changes in the weight of the real effective exchange rate is thought to be small (Reference Figure). In addition, the correlation between the Japan-U.S. RER and the real effective exchange rate has remained stable at a high level.

studies in Japan that have conducted such analysis.

In this paper, we construct and estimate a two-country (Japan and the United States) and two-sector (tradable and non-tradable) New Keynesian-type DSGE model to quantitatively examine the extent to which the B-S effect has worked on the RER in Japan. In this context, the definition of the tradable sector is based on the manufacturing and information and communication industries, following the literature as mentioned below. The baseline model of this paper considers standard assumptions of the B-S model: (1) law of one price (LOP) for tradable goods (producer currency pricing, or PCP) and (2) freedom of labor mobility across sectors. In addition, since some previous studies have questioned the traditional assumptions of the B-S model[4], we examine the following cases as robustness checks: (1) cases where LOP does not hold; dominant currency pricing (DCP) (Gopinath et al. [2020], Goldberg and Tille [2008]) and local currency pricing (LCP), and (2) the case of restrictions on inter-sectoral labor mobility (Katayama and Kim [2018]). To the best of our knowledge, this is the first paper to consider DCP and LCP currency regimes in a DSGE model estimation which incorporates the B-S effect. The analysis of this paper contributes to deepen the understanding of the long-run trends of the RER in Japan, and provide useful insights when looking back on the past quarter century of the Japanese economy.

The paper has three main results. First, the model analysis indicates that long-run trend of the RER can be explained to a considerable extent by the mechanism of the B-S effect. The variance decomposition of the baseline model shows that the contribution of productivity shocks in the tradable sector to the level of the RER in Japan is large. In addition, the shock decomposition of the RER shows that the appreciation of the RER from the 1970s to the mid-1990s was largely due to the rise in the relative productivity of Japan's tradable sector compared to the U.S. Furthermore, the depreciation of the RER from the mid-1990s onwards was suggested to have been due to a decline in the relative productivity of Japan's tradable sector compared to that of U.S. This supports the view that from Japan's perspective, the "reverse B-S effect" seems to have been effective (Ito [2022], Ito [2015]). In addition, the analysis also shows that the short-term fluctuations in the RER are weakly related to economic fundamentals due to effects of price stickiness (Rogoff [1996], Rabanal and Tuesta [2010], Miyamoto, Nguyen, and Oh [2023]).

Second, in cases where the LOP does not hold for tradable goods (DCP and LCP), the result that productivity shocks in the tradable sector explain the majority of long-run

[4] See Bordo *et al.* [2017], Cardi and Restout [2015], Gaston and Yoshimi [2023].

fluctuations in the RER (the contribution of productivity shocks in the tradable sector to the level of the RER is around 70 percent) remains unchanged. In addition, since the pass-through of shocks to the NER is smaller for DCP and LCP, the results show that the B-S effect caused by productivity shocks in the tradable sector is larger under DCP and LCP.

Third, in the case where restrictions were imposed on inter-sectoral labor mobility, the B-S effect is weakened, but the conclusion that productivity shocks in the tradable sector determine the long-run trend of the RER remained unchanged. This is because, even if labor mobility is physically constrained, the B-S effect manifests itself through excess demand, raising working hours and wage increases.

Related Literature

This paper is related to three strands of literature. First, many studies have shown that there is a long-run relationship between productivity and the RER.[5] According to Tica and Družić [2006], since Balassa [1964] and Samuelson [1964], approximately 90 percent of the 58 studies (in 65 countries) that have examined the B-S effect using time series methods or panel data analysis, have shown that there is a long-run relationship between productivity and the RER. Japan experienced one of largest swings in the RER among various countries (the top three countries since the 1970s in order are Sweden[6], Japan, and Mexico), and the appreciation of the RER since the post war to the mid-1990s is considered to be a typical example of the B-S effect (Yoshikawa [1990] , Ito [1997, 2005], Rogoff [1996], and Itskhoki [2021]). As for the period from the mid-1990s onwards, there is a view that a "reverse B-S effect" was at work on the RER (Ito [2022], Ito [2015]). Obstfeld [2010] points out that the simultaneous weakening of the yen and deterioration of the terms of trade since the mid-1990s in Japan was due to the decline in the competitiveness of Japan's tradable sector after the collapse of the bubble economy, which resulted in a loss of price control, as well as increased competition with China.[7]

Second, this paper is related to the long-run trend of productivity in Japan and the United

[5] Using data from 14 OECD countries (1970-1991), Chinn and Johnston [1996] point out that the RER appreciates when productivity (TFP) in the tradable sector increases. Lothian and Taylor [2008] showed that there is a strong relationship between (relative) per capita income and the RER in the United States, the United Kingdom, and France, and that there is a strong relationship between (relative) per capita income and the RER (the B-S effect explains around 40 percent of the RER, for the period 1820-2001). Chong, Jordà, and Taylor [2012] pointed out that there is a strong relationship between (relative) per capita income and long-run RERs (1973-2008). Lee and Tang [2007] argued that the B-S effect manifests itself through the relative price of tradable goods, using a two-country, two-sector model of 12 developed countries.

[6] In Sweden, relative stagnation of productivity was a factor in the depreciation of the RER (Belfrage [2021]).

[7] For information on the relationship between Japan's terms of trade and the RER, see Hogen *et al.* [2024].

States. According to Jorgenson, Nomura, and Samuels [2018], from the 1980s to the mid-1990s, Japan had higher rates of capital deepening and TFP growth than the United States, which led to a narrowing of the labor productivity gap. However, since the mid-1990s productivity trends have reversed, and the gap has widened again. Reasons for changes in productivity trends could be the global acceleration in information and communications technology (ICT) in the second half of the 1990s; Japan's domestic financial crisis; and the fact that investment in computer and electronic products and the ICT sector did not progress as much as in the United States. In addition, over the past decade or so, the growth rate of the machinery industry has stagnated in both Japan and the U.S., but in Japan there was no leading industry to replace the machinery industry (Shirota and Tsuchida [2024]).[8] In addition, Goldin *et al.* [2024], who examined the international slowdown in labor productivity growth, pointed out that Japan lagged behind other countries in terms of investment in intangible assets and the ICT industry. How the tradable sector is defined is also an important issue when considering the B-S effect (Tica and Družić [2006]). In this paper, based on previous research (Cardi and Restout [2015]) and the characteristics of the differences between Japan and the U.S. described above, the tradable sector is defined as the sum of the manufacturing and information and communication sectors.[9]

Third, this paper is related to model analysis incorporating the B-S effect. In previous studies, there are many examples that have studied the RER and inflation differentials within Europe under a common monetary regime. Berka, Devereux, and Engel [2018] used a two-country, two-sector DSGE model to show that RER fluctuations within Europe are consistent with the B-S effect. Rabanal [2009] showed that the productivity differential affects inflation in Spain using a two-country, two-sector model that covers Spain and other EU countries. Rabanal and Tuesta [2010] , analyzed the RER between the U.S. and Europe, and argued that the LCP and incomplete market assumptions are useful for explaining the dynamics of the RER. There are also cases where a medium-scale open economy model is estimated for the purpose of analyzing fluctuations in the RER (Adolfson *et al.* [2007]). One of the closest papers to our analysis is Hirakata, Iwasaki, and Kawai [2014] which calibrated a two-sector model three-country NK model (Japan, the U.S., and China) to

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[8] In addition, while Japan has higher labor productivity in the transport machinery industry than the United States, there is also the view that productivity in the service industry is lower than in the United States due to the stagnation of resource redistribution between companies (Baily, Bosworth, and Doshi [2020]).

[9] Although there is no strict definition of how to define the tradable sector, there are some criteria such as the ratio of export to production value exceeding 10 percent or more (De Gregorio and Wolf [1994]). In light of these views, it is reasonable to consider manufacturing and information and communication industries in Japan and the United States to be tradable sectors (the most recent figures for Japan and the United States are 10 percent or more).

show that the rise in productivity in emerging economies have pushed down consumer prices in Japan (compared to overseas). We differentiate from their work by conducting a Bayes estimation of a smaller set of countries. In addition, the model in this paper is an extension of the New Keynesian DSGE model in Rabanal and Tuesta [2010], which analyzed the RER between two countries (the U.S. and Europe), to a two-country, two-sector (tradable and non-tradable) setting.

Structure of Paper

The remainder of this paper is organized as follows. Section 2 covers the model. Section 3 considers model extensions where the LOP assumption for tradable goods is violated (DCP and LCP) and restrictions on labor mobility across sectors. Section 4 concludes.

2 Model

2.1 Outline

In this section, we lay the outline of the two-country (Japan and the United States) , two-sectors New Keynesian-type DSGE model (for details of the model, please refer to Appendix A.1) (see Figure 3).

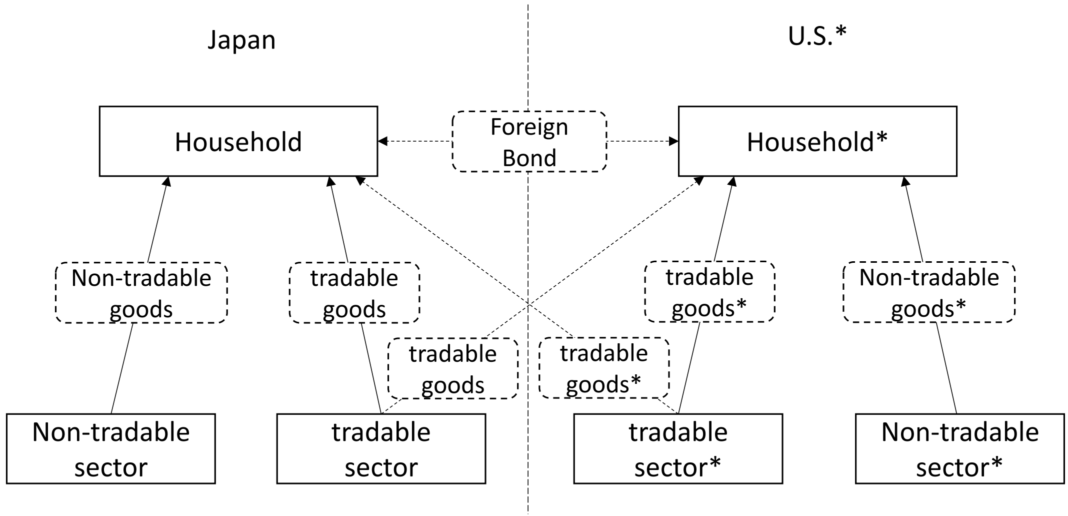
Each country has a tradable sector and a non-tradable sector, and while tradables are consumed internationally, non-traded goods are consumed only domestically. The baseline formulation assumes that domestic labor is used for production and that the tradable sector exports in the local currency (PCP, where the LOP holds). The model's demand system is structured in such a way that it is determined by changes in the relative prices of each good. The core building blocks of the model consists of the IS curve, the Calvo-type Phillips curve, and monetary policy rules which are symmetric for domestic and foreign economies. In addition, the open economy model is closed by assuming incomplete markets under international risk sharing in foreign bond transactions (Schmitt-Grohé and Uribe [2003]).[10] There are a total of 12 structural shocks in the model, specifically: productivity shocks (2 countries by 2 sectors, and global), demand shocks (2 countries by 2 sectors), monetary policy shocks (2 countries), and an UIP shock specific to the RER.

[10] Assuming incomplete markets, the interest rate parity for the NER (yen/dollar rate) s_t is given as,

$$\mathrm{E}[\Delta s_{t+1}] = r_t - r_t^* + \chi b_t \ ,$$

where r_t、r_t^*、b_t denotes domestic short term interest rate, U.S. short term interest rate, current account deficit of Japan respectively. The reason why the NER appreciates in Figure 4 is because Japan's current account is a surplus.

(Figure 3) Structure of the model



2.2 Model Estimation

In this section, we explain the outline of the Bayes estimation of the DSGE model. The model was estimated using a linear approximation of the economic model around the balanced growth path (BGP) and using a total of 11 variables: real GDP (2 countries by 2 sectors), consumer prices (2 countries by 2 sectors), nominal short-term interest rates (2 countries), and the bilateral Japan-U.S. RER.[11] Real GDP for the total economy and non-tradable sector is used, and consumer prices are for the total and service prices (proxy for prices of non-tradables). In addition, as the period when the interest rate was subject to the zero constraint is included in both Japan and the United States, the shadow rate of Krippner [2013] was used for the nominal short-term interest rate, and the RER was calculated using the consumer price and yen/dollar rate of Japan and the United States. The estimation period is from 1970/Q1 to 2022/Q4, which is the period for which sectoral data is available. Details of data are explained in Appendix A.2.

2.3 Estimation Results

(Calibration, Priors, Posterior estimates)

The calibration of parameters and the setting of priors were follow previous studies, and posterior estimates are mostly in-line with standard models (see Appendix A.3 for details).

[11] Since the nominal short-term interest rate and the RER were confirmed to be stationary, they were assumed to deviate from their long-term averages. In addition, the conclusion that productivity has a large explanatory power for the level of the RER did not change even in the model estimation using the short-term interest rate instead of the shadow rate.

(Dynamic Properties of the Model)

In this sub-section, we check how the B-S effect is incorporated in our estimated model (Figure 4). As mentioned above, the B-S effect propagates through initial change in the productivity of a country's tradable sector (relative to its non-tradable sector) compared to that of other countries. Inspecting the mechanism, a positive productivity shock in Japan, causes the price of the tradable sector to fall for both countries, and the inflation rate of the domestic non-tradable sector rises more than the U.S. as a result of wage increases in Japan. This corresponds to the inter-sectoral spillover of wage increases of the tradable sector, which is a key transmission channel for the B-S effect. Ultimately, the Japan's RER (level) appreciates in the long run, and it can be confirmed that the B-S effect is effective in the estimated model.[12] The impact of other shocks on the economy and inflation satisfies standard sign conditions, so we omit these figures for brevity (a positive demand shock pushes up both the economy and prices, while a positive monetary policy shock pushes down both the economy and prices, etc.). The impact of productivity shocks on the non-tradable sector on the RER is examined in detail in Section 3.1.

(Variance Decomposition of the RER and Shock Decomposition)

Variance decomposition of the level of the RER show that the contribution of productivity shocks in the tradable sector accounts for around 50 percent, which suggests that the B-S effect was effective throughout the whole sample period (Figure 5).[13] As in the literature, productivity and demand shocks play a fairly limited role in short-term fluctuations of the RER due to price stickiness (Rogoff [1996], Rabanal [2009], etc.).

The shock decomposition of the RER between Japan and the U.S. also show that from the Plaza Accord in 1985 to the peak of the yen's real appreciation in 1995, productivity shocks in the tradable sector accounted for about half of the appreciation (Figure 6). At the time, the growth in productivity in the tradable sector in Japan was higher than in the U.S., and this was the background to the appreciation of the RER. Furthermore, from the mid-1990s onwards, the yen's depreciation against the U.S. dollars in real terms continued as the productivity of Japan's tradable sector stagnated in the aftermath of the collapse of the bubble economy. The above results support the view that the “reverse B-S effect” has been at work on Japan's RER since the second half of the 1990s.

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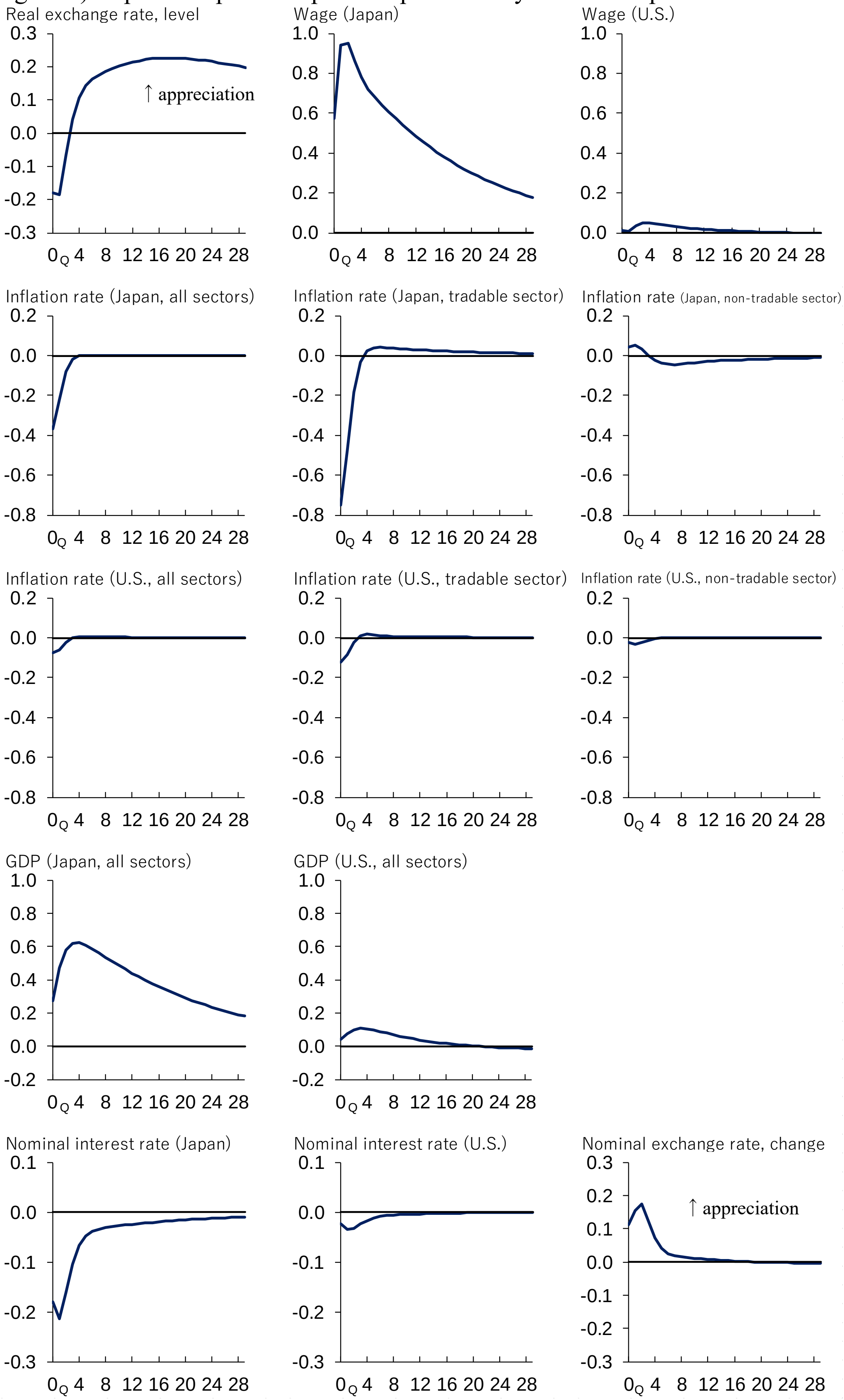
[12] The reason for the short term depreciation of RER is the fall in prices in Japan when viewed in yen terms.

[13] In the 1990s, in addition to the stagnation of capital investment due to the bursting of the bubble economy and the financial crisis, there was a lot of discussion about deregulation of the non-tradable sector to correct for price differentials (Baba [1995]). However, our analysis indicates that the impact of productivity shocks to the non-tradable sector to the RER is fairly small compared to tradables.

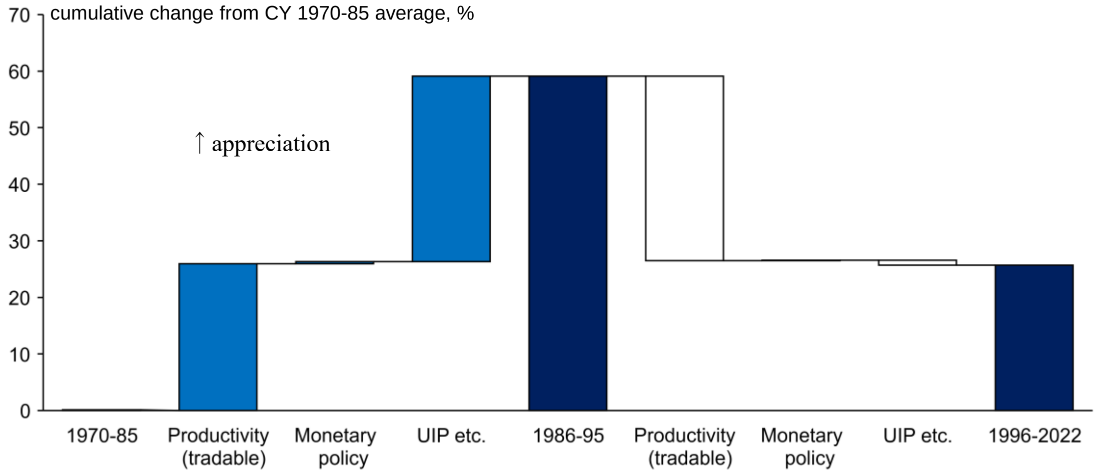
(Figure 4) Impulse response of positive productivity shock in Japan's tradable sector



(Figure 5) Variance decomposition of the RER (baseline) %

	Productivity			Demand			Monetary policy	UIP etc.
	Total	Tradable	Non-tradable	Total	Tradable	Non-tradable		
RER (level)	**63.2**	**45.5**	17.7	0.4	0.2	0.2	10.8	25.6
RER (short-run)	11.2	6.2	5.0	0.2	0.1	0.1	**23.1**	**65.5**

(Figure 6) Shock decomposition of the RER (baseline)



Note: Blue bar indicates appreciation factor, white bar indicates depreciation factor (The same applies to the following).

3 Robustness Checks of the B-S Model Assumptions

Up to this point, we assumed that LOP holds for tradables (PCP) and there are no restrictions on labor mobility across sectors. However, in reality, these assumptions are often violated, and the validity of the B-S effect is questioned due to these assumptions. Therefore in this section, we check whether the qualitative results of the baseline model holds under various assumptions related to LOP and labor mobility.

3.1 Violation of LOP in Tradables

First, we relax the assumption of LOP in tradables. Although many micro-level studies find that LOP does not hold in tradables, it is also worth noting that the violation of LOP itself does not necessarily negate the B-S effect (Crucini, Telmer, and Zachariadis [2005], Itskhoki [2021], Bordo *et al.* [2017]).

In addition, it is said that in recent years, Japanese firms tend to prefer LCP. In this regard, it is worth considering the DCP paradigm, where majority of trade transactions are invoiced in major settlement currencies such as the U.S. dollar (Goldberg and Tille [2008], Gopinath *et al.* [2020]). Assuming that the U.S. dollar is the dominant invoicing currency, this means that exports are priced under LCP from Japan's perspective and PCP for the U.S. exporters. In fact, looking at the ratio of invoicing currencies for Japan's exports and imports, around 50 percent of exports and 70 percent of imports are settled in U.S. dollars (see Reference Figure). Considering DCP in the B-S effect is a relatively new field, which has not been explored in the literature, this is a unique feature of this paper.

In theory, for a firm to export using LCP is equivalent to setting separate prices for tradable goods in domestic and foreign markets. In terms of economic modelling, the Phillips curve for domestic tradable goods in Appendix A.1 (Equation A29) is divided into two parts: domestic tradable goods inflation $\Delta\tilde{p}_t^{hh}$ and foreign tradable goods inflation $\Delta\tilde{p}_t^{hf}$ (Rabanal and Tuesta [2010]).[14]

$$\Delta\tilde{p}_t^{hh} - \varphi_h \Delta\tilde{p}_{t-1}^{hh} = \beta E_t\left(\Delta\tilde{p}_{t+1}^{hh} - \varphi_h \Delta\tilde{p}_t^{hh}\right) + \kappa_h\left(\widetilde{w}_t - z_t^h - \tilde{t}_t^{hh} - \tilde{t}_t^{Th}\right), \tag{1}$$

$$\Delta\tilde{p}_t^{hf} - \varphi_h \Delta\tilde{p}_{t-1}^{hf} = \beta E_t\left(\Delta\tilde{p}_{t+1}^{hf} - \varphi_h \Delta\tilde{p}_t^{hf}\right) + \kappa_h\left(\widetilde{w}_t - z_t^h - \tilde{t}_t^{hf} - \tilde{t}_t^{Tf} - Qju_t\right). \tag{2}$$

Here, φ_h is a parameter which determines the degree of inflation indexation, κ_h is a composite parameter of the slope of the Phillips curve, $\widetilde{w}_t$ denote real wages, z_t^h is the productivity of domestic tradable goods, $\tilde{t}_t^{hh}$, $\tilde{t}_t^{hf}$ are the relative price for tradable goods (against non-tradables) in Japan and the U.S., $\tilde{t}_t^{Th}$ is the relative price of tradable goods in Japan (against imports from the U.S.), $\tilde{t}_t^{Tf}$ is the relative price of tradable goods in the U.S. (against imports from Japan), and Qju_t is the RER. In this subsection, we also conduct a Bayesian estimation assuming different currency paradigms (DCP and LCP) in parallel with the baseline estimation.

In general, differences in the currency regime (PCP, LCP and DCP) affects the pass-through of NER to export prices. For example, when there is a (domestic) positive monetary policy shock, the appreciation of the NER is passed on to export prices under PCP, while export prices hardly move in the case of DCP and LCP (Figure 7). This is consistent with the fact that Japanese exporters tend to keep local prices unchanged given NER fluctuations (Bank of Japan [2018]). Furthermore, export prices hardly move under DCP and LCP in response to demand and UIP shocks.

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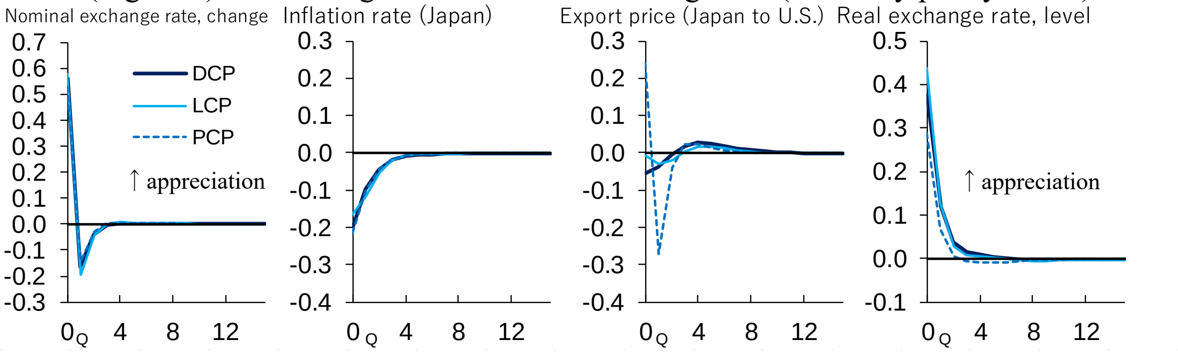
[14] For producer currency (PCP), see Obstfeld and Rogoff [1995], Gali and Monacelli [2005]; for local currency (LCP), see Betts and Devereux [2000], and Devereux and Engel [2003]. There are also views that LCP is more appropriate for observing changes in the RER (Bergin [2006], Rabanal and Tuesta [2010]).

(Figure 7) Pass-through of the nominal exchange rate (monetary policy shock)

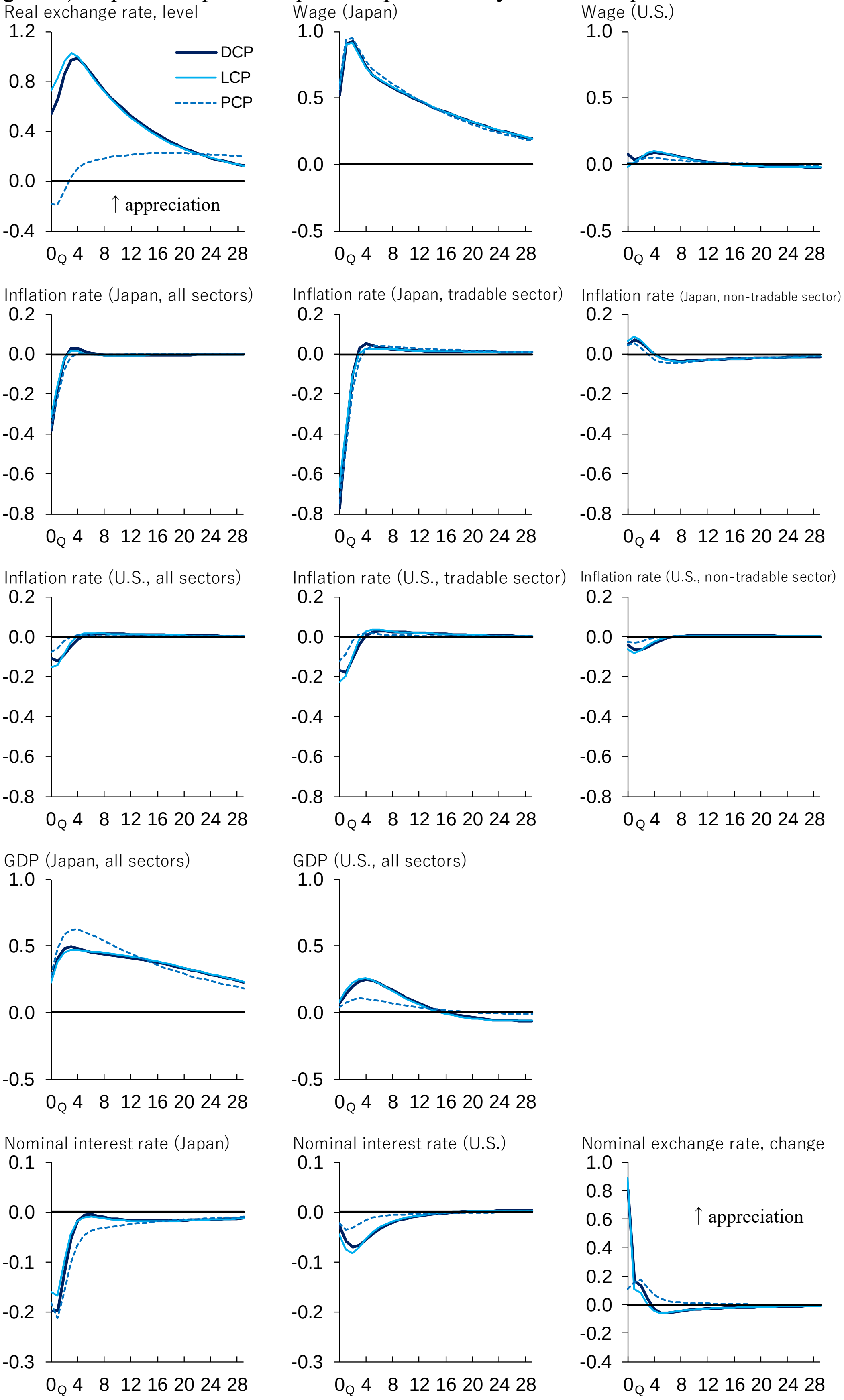


However, our estimation results indicate that the situation is somewhat different for productivity shocks in the tradable sector. Figure 8 shows impulse responses assuming that there is a positive productivity shock in Japan's tradable sector. The responses of the RER show that the B-S effect is also present under DCP and LCP and somewhat stronger. This is because the NER appreciation caused by the productivity shock[15] is passed on to export prices under PCP, which offsets some of the price decline of tradable goods in the U.S. and ultimately leads to a smaller impact on the RER. This shows that the magnitude of the B-S effect could differ depending on the underlying currency regime.

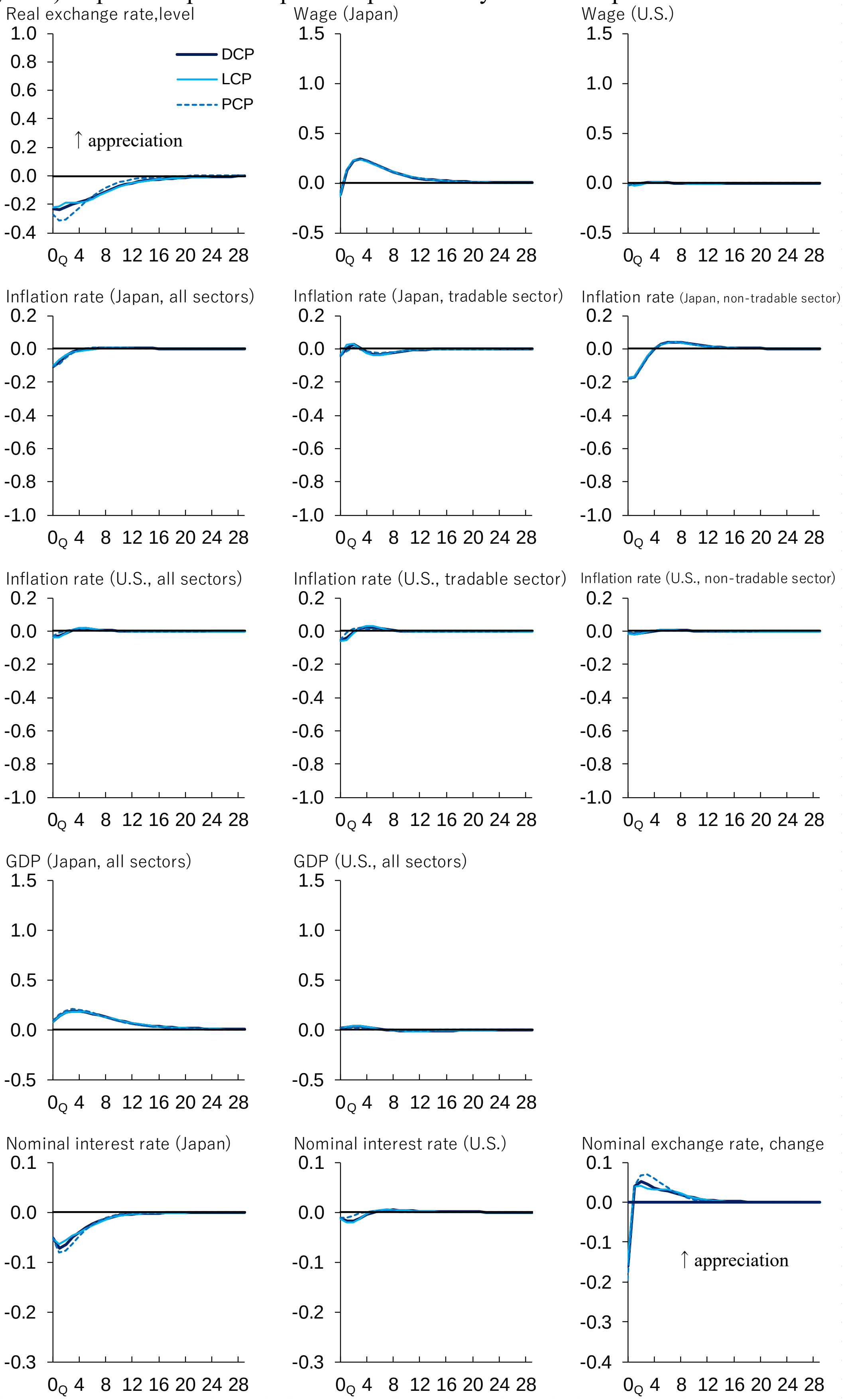
In terms of productivity shocks to the non-tradable sector, the RER depreciates, but the magnitude is smaller compared to productivity shocks to the tradable sector (Figure 9). This is because productivity shocks in the tradable sector have a greater multiplier effect for inducing production through trade, and in the process, wages are pushed up more significantly through factors such as excess demand for labor. Given that the transmission mechanism of the B-S effect stems from how much domestic wages rise, this effect is directly linked to the size of the B-S effect.

[15] While the difference between Japanese and U.S. interest rates is a major factor for NER fluctuations, in this paper, we assume incomplete markets, so a current account surplus works as an appreciation factor for the NER (see footnote 9). Another reason for the lower appreciation of RER under PCP is that the interest rate cut in the U.S. is larger under DCP and LCP.

(Figure 8) Impulse response of positive productivity shock in Japanese tradable sector



(Figure 9) Impulse response of positive productivity shock in Japanese non-tradable sector

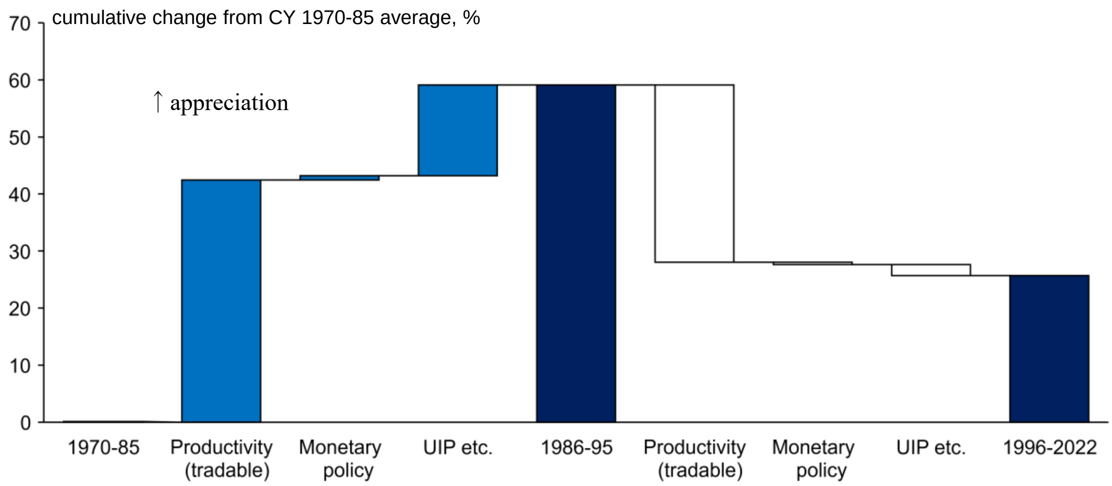


Variance decomposition of the RER show that productivity shocks to the tradable sector have a significant impact on the level of the RER in all currency regimes (Figure 10). The results also suggest that the B-S effect is stronger in DCP and LCP than in the baseline PCP. In addition, it was also confirmed that the majority of short-term fluctuations in the RER were due to financial factors, such as monetary policy shocks (shocks to domestic and foreign short-term interest rates) and UIP shocks (institutional factors and the incorporation of medium- to long-term interest rate differentials), consistent with the literature. The shock decomposition of the RER in Figure 11 shows that, as in the baseline, from the Plaza Accord to the peak of the yen's RER appreciation in 1995, cumulative effects from productivity shocks in Japan's tradable sector was a major factor. From the mid-1990s onwards, the RER of the yen followed a downward trend due to the sluggish growth in productivity in Japan's tradable sector compared to the U.S. In light of these results, even if we relax the assumption of the LOP, the reverse B-S effect can be considered to be effective in Japan.

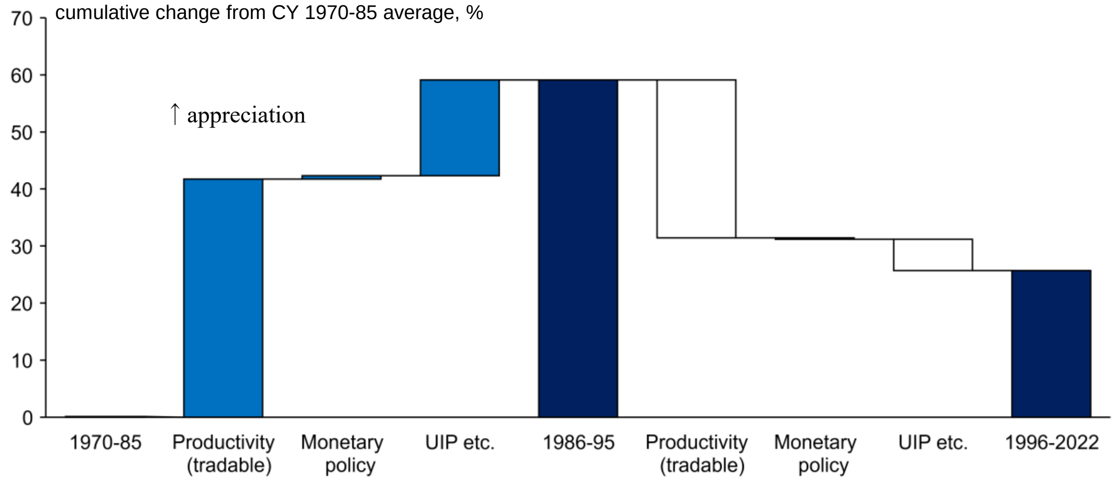
(Figure 10) Variance decomposition of the RER %

		Productivity			Demand			Monetary policy	UIP etc.
		Total	Tradable	Non-tradable	Total	Tradable	Non-tradable		
RER (level)	DCP	**64.5**	**60.3**	4.2	0.2	0.1	0.1	11.5	23.8
	LCP	**72.3**	**66.2**	6.1	0.5	0.2	0.3	0.7	26.5
	PCP	**63.2**	**45.5**	17.7	0.4	0.2	0.2	10.8	25.6
RER (short-run)	DCP	5.1	3.1	2.0	0.2	0.1	0.1	**24.4**	**70.3**
	LCP	2.4	1.4	1.0	0.2	0.1	0.1	**20.0**	**77.4**
	PCP	11.2	6.2	5.0	0.2	0.1	0.1	**23.1**	**65.5**

(Figure 11-1) Shock decomposition of the RER (DCP)



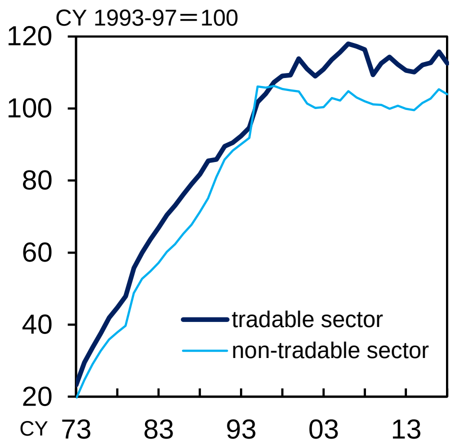
(Figure 11-2) Shock decomposition of the RER (LCP)



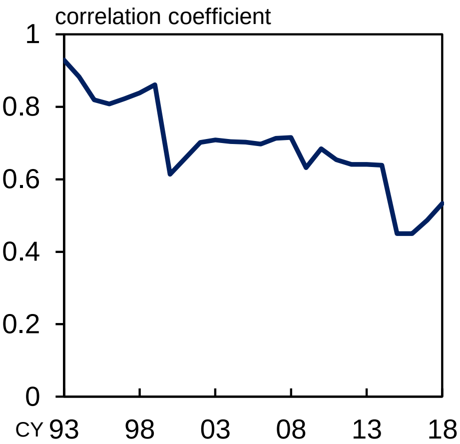
3.2 Labor Mobility restriction across Sectors

Next, we examine cases where there are restrictions on labor mobility across sectors. In the classic B-S model, a 1 percent increase in the productivity of the tradable sector ultimately leads to a 1 percent increase in the price of non-tradable goods. However, according to the empirical analysis of Cardi and Restout [2015], given the imperfect mobility of labor, a 1 percent increase in the productivity of the tradable sector only leads to an increase of 0.8 percent in the price of non-tradables (1970-2007, OECD countries). Although the effect may be weaker in reality, this result also indicates that wage arbitrage can continue to operate even if labor mobility is imperfect, through demand spillover effects from the tradable sector to the non-tradable sector. In Japan's context, wage negotiations for regular employees takes place through the spring negotiations (the so called *Shunto*), and in this process, the wage settings of most firms follows the decisions of large companies in the tradable sector, such as the automobile and electrical machinery industries. Therefore, there is a tendency for wage increases to be synchronized across industries. In fact, the correlation coefficient between the wage increase rates of the tradable and non-tradable sectors is around 0.6 even most recently, and while wages in manufacturing are affected by globalization (such as the increased demand for highly skilled labor), they are still reasonably linked (Figure 12).

(Figure 12-1) Wage level



(Figure 12-2) Correlation of wage growth rate between two sectors



Note: Figure 12-2 represents correlation coefficient of total cash earnings between sectors (20 years moving average).
Source: EU KLEMS

However, there is also an additional aspect in Japan where the proportion of people who change jobs across the tradable and non-tradable sectors is actually quite low, at around 10 percent (Labour Force Survey). In a situation, like this, where labor mobility between sectors is restricted, wage arbitrage is thought to become less effective and the B-S effect to weaken (Gaston and Yoshimi [2023], Kiyota [2023]). In this paper, we investigate whether the B-S effect is effective under imperfect labor mobility across sectors following the method of Katayama and Kim [2018]. In Katayama and Kim [2018], restrictions on labor mobility across sectors are imposed by introducing the elasticity of substitution of labor supply across sectors (how easy it is to move to other sectors). Ultimately, we can impose restrictions on inter-sectoral labor mobility by expressing the labor supply equation in Appendix A.1 (A9) as a combination of the following two equations.

$$\left(1+\frac{1-\gamma^c}{\theta_L}-\left(\omega-\frac{1}{\phi}\right)\gamma^c\right)L_t^h = (1-\gamma^c)\left(\frac{1}{\theta_L}+\omega-\frac{1}{\phi}\right)L_t^N, \tag{3}$$

$$L_t = L_t^h + L_t^N. \tag{4}$$

In this equation, ϕ denotes Frisch elasticity, γ^c is the weight of tradable goods in consumption, L_t, L_t^h, and L_t^N are the total labor supply, labor supply in the tradable sector, and labor supply in the non-tradable sector, respectively. θ_L is the elasticity of substitution of labor supply across sectors, and ω is the sectoral preference of workers. The degree of labor mobility is determined by the inter-sectoral labor supply elasticity θ_L; smaller parameter value indicate stronger restrictions on labor mobility.

Results of the variance decomposition of the RER with restrictions on labor mobility across sectors is shown in Figure 13. Comparing this with results in Figure 10, as indicated in the literature, imperfect labor mobility weakens the effect of productivity shocks in the tradable sector but the B-S effect still remains effective. In addition, it was confirmed that, as in the case of free labor mobility, the majority of short-term fluctuations in the RER are due to financial factors such as UIP shocks and monetary policy shocks.

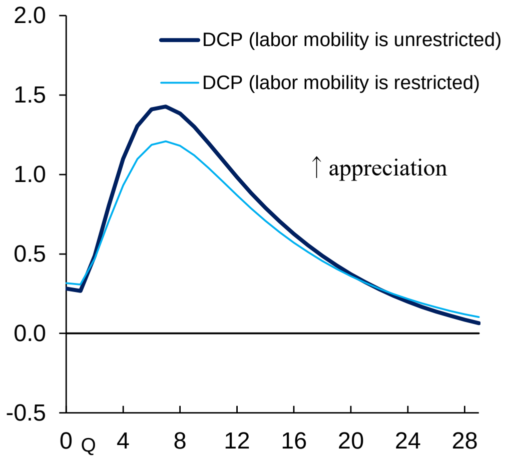
(Figure 13) Variance decomposition of the RER (restricted labor mobility) %

		Productivity			Demand			Monetary policy	UIP etc.
		Total	Tradable	Non-tradable	Total	Tradable	Non-tradable		
RER (level)	DCP	**56.6**	**52.4**	4.2	0.4	0.1	0.3	0.5	42.5
	LCP	**62.6**	**59.1**	3.5	1.6	0.2	1.4	0.7	35.1
	PCP	**49.0**	**35.6**	13.4	0.3	0.2	0.1	11.0	39.7
RER (short-run)	DCP	5.2	3.7	1.5	0.2	0.1	0.1	**17.9**	**76.7**
	LCP	2.1	1.1	1.0	0.2	0.1	0.1	**15.9**	**81.9**
	PCP	10.2	7.0	3.2	0.2	0.1	0.1	**21.3**	**68.3**

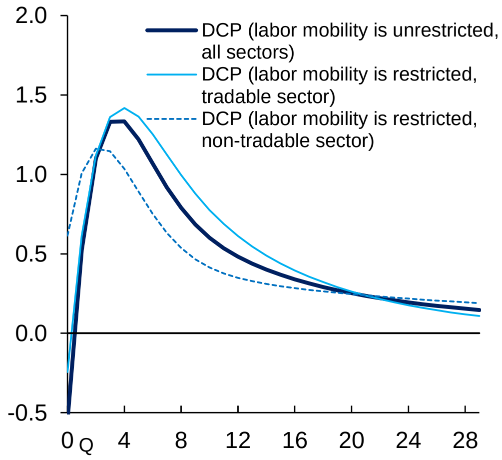
Lastly, we check how impulse responses change with restrictions on labor mobility (Figure 14). Assuming a positive productivity shock in Japan's tradable sector, when labor mobility is free, dynamics of wages in both sector are equivalent and the ratio of non-tradable and tradable sector is unchanged. Imposing mobility restrictions creates a difference in the rate of wage increases between sectors, weakening the B-S mechanism which operates through the price of non-tradable goods. Wages in the non-tradable sector increase even with labor mobility restrictions and this can be viewed as a result of a positive spillover effect from the tradable sector to the non-tradable sector.

(Figure 14) Impulse response of positive productivity shock in Japan's tradable sector

Real exchange rate, level



Wage



4 Conclusion

The real effective exchange rate (RER) is inherently a general equilibrium variable and its fluctuations are influenced by various factors. In addition to supply factors such as productivity, demand factors, home bias, risk sharing, fiscal and monetary policies affect the RER. With this in mind, this paper examined the B-S effect on the Japan's RER by estimating a two-country (Japan and the U.S.), two-sector DSGE model, and focusing on Japan's RER depreciation trend since the second half of the 1990s. The results of the model analysis showed that the long-run trend in the Japan's RER can be explained to a considerable extent by the mechanism of the B-S effect. As pointed out in the literature, appreciation of the yen's RER from the 1970s to the mid-1990s can be viewed as the result of rise in relative productivity of Japan's tradable sector compared to the U.S. and the effects of the Plaza Accord in 1985. Furthermore, the yen's RER depreciation since the mid-1990s was suggested to have been the result of a decline in the relative productivity of Japan's tradable sector compared to the U.S., and the "reverse B-S effect" from Japan's perspective.

Our analysis indicate that these results were robust even if the LOP assumption in tradables are relaxed (DCP and LCP) and restrictions were imposed on labor mobility. With regard to Japan's capital investment related in the tradable sector, the proportion of R&D was high until the 1980s, but the share of maintenance and renewal has risen in the past 30 years. In addition, in the 2010s, against the backdrop of a declining population, foreign direct investment continued to grow significantly, and the current account composition changed from positive trade balance to a positive primary surplus (Hogen *et al.* [2024]). In addition, it has also been pointed out that the background to the recent RER depreciation of the yen can be attributed to the fact that Japan's balance of payments in the digital sector has been in red, and that imports of fossil fuels have increased since the Great East Japan Earthquake. All of these factors can be considered as factors which drag relative productivity of the tradable sector, and propagate through the B-S effect.

There are also several points to note for future work. The first is how the changing position of China in the global economy will affect Japan's economy. In recent years, there has been a lively debate about the impact of deglobalization, triggered by measures such as restrictions on trade between the U.S. and China. In addition, in recent years, there has been a trend towards the reallocation of global production sites in the corporate sector in response to the rise in geopolitical risk. In this context, it is important to consider how the domestic production system of Japan's tradable sector will be positioned in the global economy in the future, and how this will affect Japan's productivity. In this regard, it is worthwhile to carefully examine the impact on the RER as further data is accumulated in the future.

Secondly, it is vital to consider how recent changes in corporate behavior are affecting productivity. The mid-1990s, when the U.S. and Japan experienced a reversal in productivity trends, was also the time when IT investment accelerated globally. During this time, Japan experienced a domestic financial crisis, and as a result missed out on investment opportunities, and has since often been on the user side of IT related products (Shirota and Tsuchida [2024]). In order to increase Japan's economic growth rate in the future, it is necessary to (1) encourage existing companies to engage in product innovation and create new leading industries, or (2) promote the spread of common industrial factors through AI and other means. In this way, determining future productivity trends has important implications for the long-run trend of RER.

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Appendix

A.1 Full Model

In this model, we assume that the growth rates of the tradable and non-tradable sectors differ in the balanced growth path (BGP), and we explain this based on the assumptions of the domestic production system and technological progress (the overseas economy is also symmetric with the domestic economy).[16]

Production Structure and Technology

This model has two economic regions: Japan (hereafter, "domestic") and the United States (hereafter, "overseas"), each of which has a trade sector and a non-tradable sector. The size of the domestic (*H*) and foreign (*F*) economies are different, and their sizes are represented by s for the domestic economy and $1-\mathrm{s}$ for the foreign economy. In the tradable sector, each country produces differentiated (imperfect substitutes) tradable goods, and the range of domestic tradable goods is represented by $h \in [0, \mathrm{s}]$, and the range of foreign tradable goods is represented by $f \in [\mathrm{s}, 1]$. Similarly, for the non-tradable sector, the range of domestic non-tradable goods is represented as $n \in [0, \mathrm{s}]$, and the range of overseas non-tradable goods is represented as $n^* \in [\mathrm{s}, 1]$ (hereafter, overseas variables are represented with an asterisk).

Tradable Sector

A company in the domestic trade sector (h) has the following production function, with labor as a factor of production,

$$Y_t^H(h) = A_t\, Z_t^T L_t^T(h). \tag{A1}$$

Here, $Y_t^H(h)$ is the output of domestic tradable goods, A_t is the total factor productivity common to all sectors worldwide, Z_t^T is the productivity of the home tradable sector, and $L_t^T(h)$ is the labor demand of the home tradable sector. The reason for introducing the world-wide common total factor productivity A_t is to detect the BS effect caused by productivity fluctuations, etc., by making the steady growth rate of each country and each sector in the BGP relative to A_t (Rabanal [2009]). The global common total factor productivity A_t is assumed to grow at a constant growth rate g in the BGP, based on the initial value $A_0 > 0$ (hereafter, the normalization on the BGP uses the notation $\tilde{X}_t$).

16 We assume BGP is to capture the rise and fall of each industry as an economic shock.

$$A_t \ = (1+g)^t A_0 \,. \tag{A2}$$

The productivity Z_t^T of the domestic tradable sector grows at a constant growth rate α^T and follows the following process.

$$Z_t^T = (1+\alpha^T)^t \tilde{Z}_t^T, \tag{A3}$$

$$\log(\tilde{Z}_t^T) = \rho^{Z,T} \log(\tilde{Z}_{t-1}^T) + \varepsilon_t^{Z,T} + \varepsilon_t^Z. \tag{A4}$$

Here, $\rho^{Z,T}$ is the inertia of productivity, $\varepsilon_t^{Z,T}$ is the productivity shock to the domestic tradable sector, and ε_t^Z is the common productivity shock to the tradable sector. In this study, we have introduced a common productivity shock to the tradable sector in line with previous studies (Stockman and Tesar [1995]、Baxter and Crucini [1993]、Rabanal [2009]), based on the assumption that productivity in the tradable sector is strongly correlated across countries.

Non-Tradable Sector

Domestic non-tradable sector firms (n) also follow the following production function, with labor as a factor of production.

$$Y_t^N(n) = A_t \ Z_t^N L_t^N(n). \tag{A5}$$

Here, $Y_t^N(n)$ represents the output of the domestic non-tradable sector, Z_t^N represents the productivity of the domestic non-tradable sector, and $L_t^N(n)$ represents the labor demand of the domestic non-tradable sector. The productivity of the domestic non-tradable sector grows at a constant growth rate α^N in the BGP, and follows the following process;

$$Z_t^N = (1+\alpha^N)^t \tilde{Z}_t^N, \tag{A6}$$

$$\log(\tilde{Z}_t^N) = \rho^{Z,N} \log(\tilde{Z}_{t-1}^N) + \varepsilon_t^{Z,N}. \tag{A7}$$

Here, $\rho^{Z,N}$ represents the inertia of productivity, and $\varepsilon_t^{Z,N}$ represents the productivity shock to the domestic non-tradable sector.

Households and Bond Market Structure

Household Preference

Representative household $j \in [0, s]$ in Japan maximizes the following utility function

(U_t) to determine their consumption (C_t), total labor supply (L_t), and holdings of domestic and foreign bonds (B_t^H, B_t^F).

$$U_t \;= E_o \sum_{t=0}^{\infty} \beta^t \left\{ [\log(C_t - b\bar{C}_{t-1})] - \frac{L_t^{1+\phi}}{1+\phi} \right\}. \tag{A8}$$

Here, E_o is the expectation operator at time 0, β is the discount rate, and ϕ is the elasticity of substitution of labor (Frisch-elasticity). Habit formation is determined by the consumption level $\bar{C}_{t-1}$ of the previous period, and $b \in [0,1]$ is a parameter that expresses its importance. In the baseline model, we assume that labor mobility between sectors is free, so households supply labor to the tradable and non-tradable sectors (L_t^T, L_t^N), and the total labor supply (L_t) is expressed as follows,

$$L_t \;= L_t^T + L_t^N. \tag{A9}$$

Domestic consumption C_t is a composite of tradable goods consumption C_t^T and non-tradable goods consumption C_t^N, using a CES-type function, as shown below (the same type of function is assumed for aggregation).

$$C_t \;= \left\{ \gamma_c^{\frac{1}{\varepsilon}} (C_t^T)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\gamma_c\;)^{\frac{1}{\varepsilon}} (\xi_t^{N,C})^{\frac{1}{\varepsilon}} (C_t^N)^{\frac{\varepsilon-1}{\varepsilon}} \right\}^{\frac{\varepsilon}{\varepsilon-1}}. \tag{A10}$$

Here, γ_c is the consumption weight of tradable goods, ε is the elasticity of substitution between tradable and non-tradable goods, and $\xi_t^{N,C}$ is a preference shock for non-tradable goods that is used to ensure the model's steadiness. This preference shock is introduced for the sake of convenience to estimate various elasticities, etc. in the BGP, following previous studies (the same applies below; see Rabanal [2009] for details).

The amount of consumption of tradable goods, C_t^T, is defined as the composite of the amount of consumption of domestic tradable goods, C_t^H, and the amount of consumption of foreign tradable goods, C_t^F, as follows.

$$C_t^T = \left\{ \gamma_x^{\frac{1}{\theta}} (C_t^H)^{\frac{\theta-1}{\theta}} + (1-\gamma_x\;)^{\frac{1}{\theta}} (\xi_t^{F,C})^{\frac{1}{\theta}} (C_t^F)^{\frac{\theta-1}{\theta}} \right\}^{\frac{\theta}{\theta-1}}. \tag{A11}$$

Here, γ_x is the consumption weight of domestic tradable goods, θ is the elasticity of substitution between domestically produced and foreign-produced tradable goods, and $\xi_t^{F,C}$ is the preference shock for foreign tradable goods. The amount of consumption of domestic tradable goods C_t^H, the amount of consumption of foreign tradable goods C_t^F, and the amount of consumption of domestically non-tradable goods C_t^N are defined as follows, using an elasticity between goods of $\sigma > 1$.

$$C_t^H = \left[\left(\frac{1}{s}\right)^{\frac{1}{\sigma}} \int_0^s C_t \ (h)^{\frac{\sigma-1}{\sigma}} dh\right]^{\frac{\sigma}{\sigma-1}}, \ C_t^F = \left[\left(\frac{1}{1-s}\right)^{\frac{1}{\sigma}} \int_s^1 C_t \ (f)^{\frac{\sigma-1}{\sigma}} df\right]^{\frac{\sigma}{\sigma-1}}, \qquad \text{(A12)}$$
$$C_t^N = \left[\left(\frac{1}{s}\right)^{\frac{1}{\sigma}} \int_0^s C_t^N(n)^{\frac{\sigma-1}{\sigma}} dn\right]^{\frac{\sigma}{\sigma-1}}.$$

Bond Market

Households hold domestic bonds (complete market) and foreign bonds are traded internationally (incomplete market). In general, in an open economy model with an incomplete market, in order to ensure the model's stationarity, it is necessary to devise measures such as adjustment costs for bond transactions and interest rate premiums that depend on the size of debt (Schmitt-Grohé and Uribe [2003]).[17] In this paper, we assume that households share risk internationally by holding risk-free domestic (nominal) bonds (B_t^H) and also holding foreign currency-denominated (nominal) bonds (B_t^F) that are traded internationally. Based on the above, the budget constraint for households is as follows.

$$C_t + \frac{B_t^H}{P_t R_t} + \frac{S_t \ B_t^F}{P_t R_t^* \Phi\left(\frac{S_t \ \bar{B}_t^F}{P_t Y_t}\right)} + \frac{T_t}{P_t} \leq \frac{B_{t-1}^H}{P_t} + \frac{S_t \ B_{t-1}^F}{P_t} + W_t L_t + \Pi_t. \qquad \text{(A13)}$$

Here, P_t is the domestic consumer price level, R_t is the domestic nominal interest rate (gross), R_t^* is the foreign nominal interest rate (gross), S_t is the nominal exchange rate (yen/dollar), T_t is lump-sum tax to finance government spending, W_t is real wages in the domestic economy, Π_t is dividends, and Φ is the adjustment cost for foreign bond transactions (foreign bond holdings / nominal output).

Consumer price P_t is defined as follows, by combining tradable goods price P_t^T and non-tradable goods price P_t^N, and tradable goods price P_t^T is defined as follows, by combining domestic tradable goods price P_t^H and foreign tradables price P_t^F (γ is the weight within consumer prices).

[17] Schmitt-Grohé and Uribe [2003] show that the means of ensuring the steadiness of an open economy model include the adjustment costs of foreign bonds, interest rate premiums, endogenous discount rates, etc., and that there is not much difference between them.

$$P_t \;=\left\{\gamma (P_t^T)^{1-\varepsilon}+(1-\gamma)\xi_t^{N,C}(P_t^N)^{1-\varepsilon}\right\}^{\frac{1}{1-\varepsilon}}, \tag{A14}$$

$$P_t^T=\left\{\gamma_x\ (P_t^H)^{1-\theta}+(1-\gamma_x\ )\xi_t^{F,C}(P_t^F)^{1-\theta}\right\}^{\frac{1}{1-\theta}}. \tag{A15}$$

P_t^N, P_t^H, and P_t^F, which define these dynamics, are determined in the pricing behavior of companies, which will be discussed later.

The real exchange rate Q_t (based on the domestic currency) is expressed as follows, using the nominal exchange rate S_t (yen/dollar) and the consumer price index for each country.

$$Q_t \;\equiv \frac{S_t P_t^*}{P_t}. \tag{A16}$$

The growth rate of the real exchange rate is as follows (lowercase letters indicate logarithmic values).

$$\Delta q_t \;= \Delta s_t \;+ \Delta p_t^* - \Delta p_t \;. \tag{A17}$$

Here, $\varDelta$ is the difference operator from the previous term.

Household Optimization

Domestic households decide how much to consume, how much to supply labor, and how much to hold domestic and foreign bonds, so as to maximize (A8) under the budget constraint in (A13). Combining these first-order conditions, the Euler equation and the risk-sharing equation are as follows;[18]

$$\frac{1}{C_t-bC_{t-1}}=\beta E_t\left(\frac{1}{C_{t+1}-bC_t}\frac{R_tP_t}{P_{t+1}}\right), \tag{A18}$$

$$E_t\left(\frac{C_t^*-bC_{t-1}^*}{C_{t+1}^*-bC_t^*}\frac{P_t^*}{P_{t+1}^*}\right)=E_t\left(\frac{C_t-bC_{t-1}}{C_{t+1}-bC_t}\frac{P_t^*}{P_{t+1}^*}\frac{Q_{t+1}}{Q_t}\right)\Phi\left(\frac{S_t\bar{B}_t^F}{P_tY_t}\right). \tag{A19}$$

Assuming that C_t grows at $(1+g)(1+a)$, we can define a variable that adjusts the growth trajectory as $\tilde{C}_t=C_t/[(1+g)(1+a)]^t$ (the same notation is used for the

[18] We assume that the adjustment costs are exogenous for the household.

normalization on the BGP below), and the linearized versions of (18) and (19) around the BGP are as follows;

$$b\Delta\tilde{c}_t = -(1+g)(1+a-b)(r_t - E_t\Delta p_{t+1}) + (1+g)(1+a)E_t\Delta\tilde{c}_{t+1}, \tag{A20}$$

$$\begin{aligned} E_t(q_{t+1}) - q_t \; &= \left[\frac{(1+g)(1+a^*)E_t\Delta\tilde{c}_{t+1} - b\Delta\tilde{c}_t}{(1+g)(1+a^*-b)}\right], \\ &\quad - \left[\frac{(1+g)(1+a)E_t\Delta\tilde{c}^*_{t+1} - b\Delta\tilde{c}^*_t}{(1+g)(1+a-b)}\right] + \chi b_t \; + uip_t. \end{aligned} \tag{A21}$$

Here, $\Delta\tilde{c}_t$ is the growth rate of consumer spending, $b_t \; = (S_t\bar{B}^F_t / P_tY_t)$ is the domestic holdings of foreign bonds, r_t is the domestic nominal interest rate, $E_t\Delta p_{t+1}$ is the expected inflation rate for the next period, and $\chi = -\Phi' \; (0)\tilde{\mathrm{Y}}$ is the sensitivity of the RER to foreign bond holdings based on the steady state, and uip_t represents the idiosyncratic shock to the RER (AR(1) process). Equation (A20) is the standard IS curve, and equation (A21) is the risk sharing equation that defines the dynamics of the RER.

The determination of the amount of labor supplied in a household is determined by the standard, first-order condition below.

$$L^{\phi}_t = \frac{1}{C_t - bC_{t-1}} W_t \; . \tag{A22}$$

The following is a linearization of this around BGP.

$$\widetilde{w}_t \; = \varphi l_t \; + \frac{(1+g)(1+a)}{(1+g)(1+a-b)}\tilde{c}_t \; - \frac{b}{(1+g)(1+a-b)}\tilde{c}_{t-1}. \tag{A23}$$

Firms' Price Setting

We assume that firms' pricing behavior is characterized by Calvo-type price stickiness and indexation (the domestic and foreign sectors are heterogeneous). The domestic consumer price in equation (A14) is a composite of the prices of the domestic non-tradable sector, P^N_t, the domestic tradable sector, P^H_t, and the foreign tradable sector, P^F_t. For the price stickiness of the Calvo model, the probability that a firm will change its price (each period) is set to $1-\theta_N$ for the non-tradable sector and $1-\theta_H$ for the tradable sector. In addition, with regard to indexation, when firms are unable to set optimal prices, we assume that a proportion φ of firms will link prices to the inflation rate in the relevant sector in the previous period, and a proportion $1-\varphi$ of firms will link prices to the steady inflation rate Π (gross) (we denote the non-tradable sector as *N* and the tradable sector as *H*, and the foreign sector is also symmetrical). The following section explains the details of the domestic non-tradable sector in detail, and the other sectors are similar, so they are described briefly.

Non-Tradable Sector

Domestic non-tradable sector firms (*n*) determine their sales price $p_t^N(n)$ by solving the following profit maximization problem subject to the demand function $y_{t+k}^{N,d}(n)$.

$$\max_{p_t^N(n)} E_t \sum_{k=0}^{\infty} \theta_N^k \Lambda_{t,t+k} \left\{ \left[\frac{p_t^N(n) \left(\frac{P_{t+k-1}^N}{P_{t-1}^N} \right)^{\varphi^N} (\Pi^N)^{k(1-\varphi^N)}}{P_{t+k}} - MC_{t+k}^N \right] y_{t+k}^{N,d}(n) \right\}, \quad \text{(A24)}$$

$$\text{s.t.} \qquad y_{t+k}^{N,d}(n) = \frac{(1-\gamma)}{s} \left[\frac{p_t^N(n)}{p_{t+k}^N} \left(\frac{P_{t+k-1}^N}{P_{t-1}^N} \right)^{\varphi^N} (\Pi^N)^{k(1-\varphi^N)} \right]^{-\sigma} Y_{t+k}^N. \quad \text{(A25)}$$

Here, *t* represents the timing at which the firm set the optimal price most recently. $\Lambda_{t,t+k}$ is a stochastic discount factor, and $y_{t+k}^{N,d}(n)$ represents the demand for product *n* at time *t*+*k*. Y_t^N is the total demand for non-tradable goods (the same as equation A12), and Π^N is the steady-state inflation rate (gross) for the domestic non-tradable sector. The real marginal cost MC_t^N for the non-tradable sector is expressed as follows, using real wages W_t and various productivity measures.

$$MC_t^N = \frac{W_t}{A_t Z_t^N}. \quad \text{(A26)}$$

Given this, the transition equation for the price level of the non-tradable sector is;

$$P_t^N = \left\{ \theta_N \left[P_{t-1}^N (\Pi_{t-1}^N)^{\varphi^N} \left(\Pi^N\right)^{1-\varphi^N} \right]^{1-\sigma} + (1-\theta_N) \left[\hat{P}_t^N\right]^{1-\sigma} \right\}^{\frac{1}{1-\sigma}}. \quad \text{(A27)}$$

$\hat{P}_t^N$ is the optimal price for the domestic non-tradable sector, and Π_{t-1}^N is the inflation rate (gross) for the non-tradable sector in the previous period. From equation (A27), the linearized Phillips curve can be written as;

$$\Delta\tilde{p}_t^N - \varphi_N \Delta\tilde{p}_{t-1}^N = \tilde{\beta} E_t(\Delta\tilde{p}_{t+1}^N - \varphi_N \Delta\tilde{p}_t^N) + \kappa_N(\widetilde{w}_t - \tilde{z}_t^N - \tilde{t}_t^N). \tag{A28}$$

Here, $\tilde{\beta} = \beta(1+a_N)/(1+a)$, $\kappa_N = (1-\theta_N)(1-\beta\theta_N(1+a_N)/(1+a))/\theta_N$, and $\Delta\tilde{p}_t^N$ is the inflation rate of domestic non-tradable goods, $\widetilde{w}_t$ is real wages, $\tilde{z}_t^N$ is the productivity of the non-tradable sector, and $\tilde{t}_t^N$ is the relative price (in the home country) of non-tradable goods. Looking at equation (A28), we can see that when the relative price ($\tilde{t}_t^N$) is low, an increase in demand for non-tradable goods becomes inflationary pressure.

Tradable Sector

The domestic tradable sector is also assumed to solve the same profit maximization problem as the non-tradable sector. The Phillips curve for domestic tradable goods is

$$\Delta\tilde{p}_t^h - \varphi_h \Delta\tilde{p}_{t-1}^h = \tilde{\beta} E_t\left(\Delta\tilde{p}_{t+1}^h - \varphi_h \Delta\tilde{p}_t^h\right) + \kappa_h\left(\widetilde{w}_t - \tilde{z}_t^h - \tilde{t}_t^h - \tilde{t}_t^T\right). \tag{A29}$$

Here, $\Delta\tilde{p}_t^h$ is the inflation rate of domestic tradable goods, $\widetilde{w}_t$ is real wages, $\tilde{z}_t^h$ is the productivity of tradable goods, $\tilde{t}_t^h$ is the relative price of tradable goods between domestic and foreign markets, and $\tilde{t}_t^T$ is the relative price of tradable goods (in the domestic market). The inflation rate of domestic tradable goods rises when the relative price in the domestic market or the price of tradable goods produced overseas falls, as demand for domestic tradable goods increases.

Monetary Policy, Market Clearing, External Balance

As for model elements other than the above, first, we assume that domestic monetary policy follows a Taylor rule with interest rate smoothing (the same applies to U.S.).

$$R_t^H = \bar{R}^{(1-\rho_r)} R_t^{\rho_r} (\Pi_t/\Pi^*)^{(1-\rho_r)\gamma_\pi} (Y_t/Y^*)^{(1-\rho_r)\gamma_y} \exp(\varepsilon_t^m). \tag{A30}$$

Here, R_t^H is the domestic nominal short-term interest rate (gross), $\bar{R}$ is the steady-state interest rate, ρ_r is the inertia of the interest rate, γ_π and γ_y are the sensitivity of the inflation gap (Π_t/Π^*) and the output gap (Y_t/Y^*) to the Taylor rule, and ε_t^m is the monetary policy shock.

Next, market clearing for the domestic economy are as follows (same for U.S.);

$$Y_t^H = C_t^H + C_t^{H*} + G_t^T, \tag{A31}$$

$$Y_t^N = C_t^N + G_t^N, \tag{A32}$$

$$Y_t \;= \frac{P_t^H}{P_t} Y_t^T + \frac{P_t^N}{P_t} Y_t^N, \tag{A33}$$

$$L_t \;= L_t^{D,T} + L_t^{D,N}. \tag{A34}$$

Here, the value of production in the domestic tradable sector, Y_t^H, is equal to the sum of domestic and foreign tradable demand (C_t^H, C_t^{H*}) and exogenous government demand G_t^T. We also assume that there is a similar government demand G_t^N in the non-tradable sector. These government expenditures are financed by a lump-sum tax on households, and we assume that the fiscal balance is balanced each period. Finally, the calculated amount Y_t for the entire economy is the sum of the output of the tradable and non-tradable sectors at relative prices. In addition, the labor market is such that the total labor supply of households (L_t) matches the total labor demand of each sector ($L_t^{D,T}$, $L_t^{D,N}$).

Finally, the transition equation for foreign bonds held by the domestic sector is expressed as follows, using the domestic nominal trade balance (NX_t).

$$\frac{S_t \; B_t^F}{P_t R_t^* \Phi\left(\frac{S_t \; \bar{B}_t^F}{P_t Y_t}\right)} = \frac{S_t \; B_{t-1}^F + NX_t}{P_t}. \tag{A35}$$

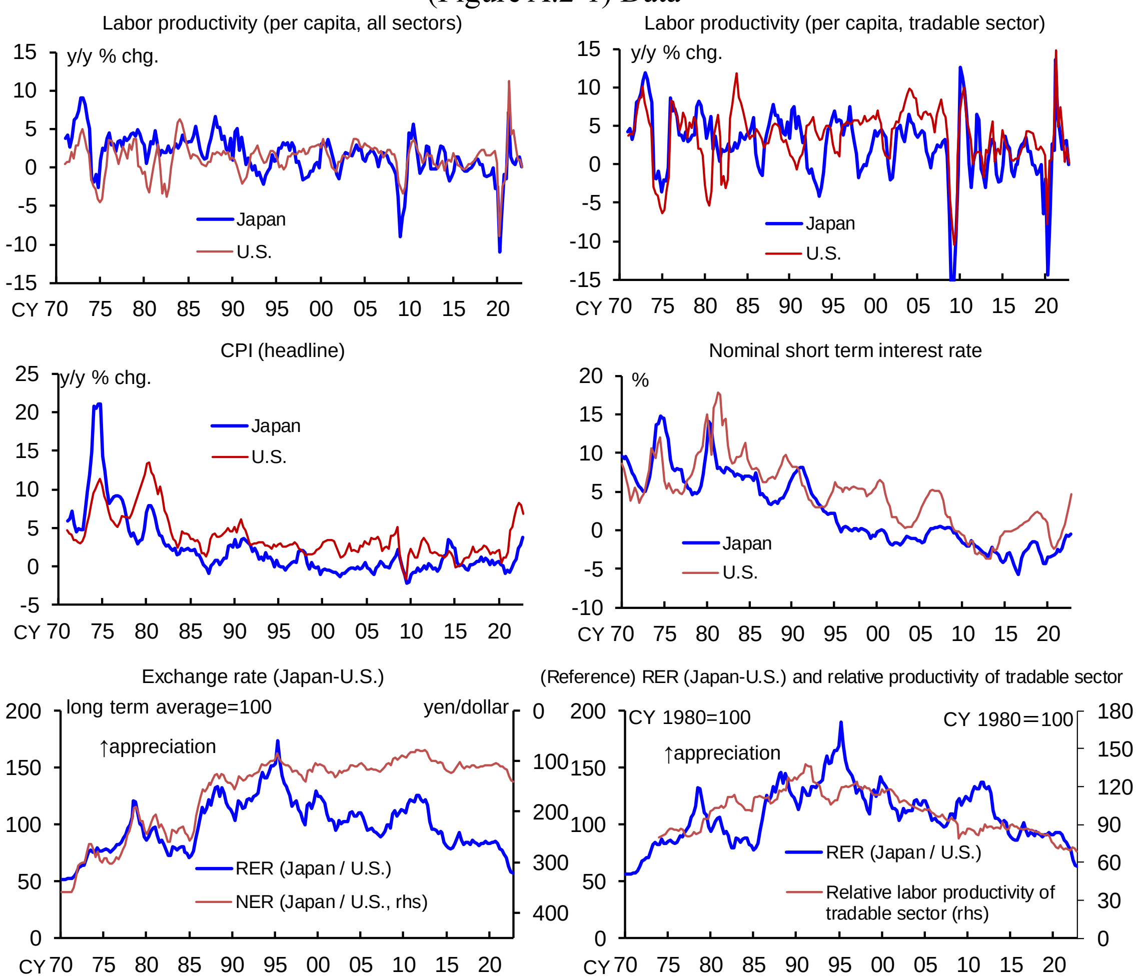
This formula is a transition formula for the amount of foreign bonds held, and shows that if the trade balance is in surplus ($NX_t \; > 0$), the amount of foreign bonds held ($B_t^F > 0$) will increase by that amount. In other words, if the amount of foreign bonds held is positive, it means that the overseas trade balance is being financed. If we define the logarithm of the domestic trade balance nx_t as $nx_t \; \equiv (1 - \gamma_x \;)\gamma_c \; (x_t \; + \tilde{t}_t^T - x_t^*)$ (where x_t ,$x_t^*, \hat{t}_t^T$ represent Japan's nominal export value, nominal import value, and terms of trade, respectively), Equation (A35) is expressed as follows;

$$nx_t \;= \beta b_t - \frac{1}{(1+g)(1+a^*)} b_{t-1.} \tag{A36}$$

A.2 Data

A total of 11 variables were used in the Bayes estimation of the model: real GDP (2 countries, 2 sectors), consumer prices (2 countries, 2 sectors), nominal short-term interest rates (2 countries), and the RER (NER) for Japan and the United States (created from NER and consumer prices). Real GDP figures were obtained from the Cabinet Office for Japan and the BEA (Bureau of Economic Analysis) for the U.S., CPI are from the Ministry of Internal Affairs and Communications for Japan and the BLS (Bureau of Labor Statistics) for the U.S., nominal short-term interest rates were taken from HAVER etc. (shadow rates for both Japan and the U.S. from 1995 onwards), and labor figures from the Ministry of Health, Labor and Welfare for Japan and the BLS for the U.S., and NER (yen/dollar rate) from the Bank of Japan. Looking at the data in Figure A.2-1, note that labor productivity growth (per worker) was higher in Japan than in the U.S. until the mid-1990s, but the relationship reversed in the latter half of the sample. Also, looking at trends in the exchange rates between Japan and the U.S. in the chart in the lower left panel, (1) until the mid-1990s, the NER and RER between Japan and the U.S. appreciated almost in parallel, and (2) from the mid-1990s to around 2010, the NER appreciated while the RER depreciated. (3) Since then, both the NER and RER have been depreciating. The results of this paper's analysis suggests that the trend in productivity in Japan's tradable sector with the United States has been the main starting point for long-term fluctuations in the RER.

(Figure A.2-1) Data



Note: Calculation of relative productivity of tradable sector is based on PPP ratio calculated by EU KLEMS.
Sources: Ministry of Internal Affairs and Communications; Cabinet Office; Bank of Japan; BEA; BLS; EUKLEMS; HAVER; etc.

A.3 Details of the Bayes Estimation

The observation equation for the estimation is as follows (variables with *obs* are data, and the lowercase letters *y* and *p* represent the logarithm of GDP and CPI, respectively);

(real GDP) Domestic $y_t^{obs} - y_{t-1}^{obs} = g + a + \bar{g}_t^{pop} + \Delta\tilde{y}_t$

Domestic (non-tradable) $y_t^{N,obs} - y_{t-1}^{N,obs} = g + a^N + \bar{g}_t^{N,pop} + \Delta\tilde{y}_t^N$

Foreign $y_t^{*,obs} - y_{t-1}^{*,obs} = g + a^* + \bar{g}_t^{*,pop} + \Delta\tilde{y}_t^*$

Foreign (non-tradable) $y_t^{N*,obs} - y_{t-1}^{N*,obs} = g + a^{N*} + \bar{g}_t^{N*,pop} + \Delta\tilde{y}_t^{N*}$

(CPI) Domestic $p_t^{obs} - p_{t-1}^{obs} = \bar{\pi} - a + \Delta\tilde{p}_t$

Domestic (non-tradable) $p_t^{N,obs} - p_{t-1}^{N,obs} = \bar{\pi} - a^N + \Delta\tilde{p}_t^N$

Foreign $p_t^{*,obs} - p_{t-1}^{*,obs} = \bar{\pi}^* - a^* + \Delta\tilde{p}_t^*$

Foreign (non-tradable) $p_t^{N*,obs} - p_{t-1}^{N*,obs} = \bar{\pi}^* - a^{N*} + \Delta\tilde{p}_t^{N*}$

(nominal interest rate) Domestic $r_t^{obs} = g + \bar{g}_t^{pop} + \bar{\pi} + r_t$

Foreign $r_t^{*,obs} = g + \bar{g}_t^{*,pop} + \bar{\pi}^* + r_t^*$

(Real exchange rate (Japan-U.S.)) $q_t^{obs} = q_t$.

Here, g denotes the growth rate of global labor productivity, a, a^N are labor productivity growth in the domestic economy as a whole and in the domestic non-tradable sector, $\bar{g}_t^{pop}$ and $\bar{g}_t^{N,pop}$ are trend growth rates of the number of workers in the domestic economy as a whole and the domestic non-tradable sector, respectively[19], and $\bar{\pi}$ is the long-term trend of inflation (* denote U.S.).[20] Among these parameters, there are seven parameters that need to be set (g, a, a^N, a^*, a^{N*}, $\bar{\pi}$, $\bar{\pi}^*$), the parameters related to the productivity trend (a, a^N, a^*, a^{N*}) play a role in adjusting the gap between the real growth rate and inflation in each country and sector (Rabanal [2009]).

Some parameters were calibrated based on previous research (Figure A.3-1) (Rabanal [2009], Rabanal and Tuesta [2010]). The parameter for household preferences (β) was set at 0.995, the elasticity of substitution for labor (ϕ) was set at 1, and the habit formation parameter (b) was set at 0.7 for both countries. In addition, the global growth rate, the weight of consumption of tradable goods, and the weight of imports of tradable goods were set based on GDP and consumer price data.

[19] The trend growth rate of workers in each country and sector was calculated using HP filters.

[20] It is also possible to consider making the trend of inflation variable, but as the purpose of this paper is to confirm the long-term trend, we will leave this exploration for a future issue.

(Figure A.3-1) Calibration

Parameter	Figure	Value	Reference
Household preferences	β	0.995	Rabanal [2009]、Rabanal and Tuesta [2010]
Elasticity of substitution for labor	ϕ	1	Rabanal [2009]、Smets and Wouters [2003]
Weight of government expenditure	γ、γ^*	0.2	Rabanal [2009]、Rabanal and Tuesta [2010]
Weight of tradables goods (Japan)	γ_c	0.52	Weight of CPI goods (CY1970-2022)
(U.S.)	γ_c^*	0.52	Weight of CPI goods (CY1970-2022)
Global productivity growth rate	g	0.3	Based on growth rate of Japan and U.S.
Weight of imports (Japan)	$1 - \gamma_x$	0.13	Weight of imports of GDP
(U.S.)	$1 - \gamma_x^*$	0.12	Weight of imports of GDP

In setting the priors, Beta distribution was used for parameters taking values from 0 to 1, Gamma distribution for parameters taking positive values, and normal distribution for unconstrained parameters (Figure A.3-2). Looking at the individual set up, the mean of the prior distribution of the substitution elasticity (θ) between domestic and foreign goods in tradable goods in equation (A11) is assumed to be 4, based on the fact that reasonably high elasticity values have been reported in micro empirical studies of tradable goods (Sugita *et al.* [2019]). Other parameters are based on Rabanal [2009] and Rabanal and Tuesta [2010]. That is, the substitution elasticity (ε) between tradable and non-tradable goods in equation (A10) is set to 1 with the Cobb-Douglas function in mind, and the parameter for the adjustment cost of foreign bond holdings (χ) is set to a small value (0.02) to ensure stationarity in an open economy model with imperfect markets (Schmitt-Grohé and Uribe [2003], Elekdag, Justiniano, and Tchnkarov [2006]). The price stickiness parameters (θ_H , θ_H^N, θ_H^*, θ_H^{N*}) were set to 0.75 for both Japan and the U.S., and the price inertia was set to 0.6 for goods and services in each country (φ_h, φ_N, φ_N^*, φ_h^*) The Taylor rule for Japan and the U.S. are standard, with the inflation gap term (γ_π, γ_π^*) set at 1.5, the supply and demand gap term (γ_y, γ_y^*) set at 1.0, and the interest rate inertia (ρ_r, ρ_r^*) set at 0.7. There are 12 structural shocks in the model (demand shocks [2 countries, 2 sectors], supply shocks [2 countries, 2 sectors, global], monetary policy shocks (2 countries), and an UIP shock specific to the RER). The inertia and variance of these shocks are based on Rabanal [2009] and Rabanal and Tuesta [2010]. In addition, the steady-state values of inflation ($\bar{\pi}$, $\bar{\pi}^*$) were set at 2 percent per year for both countries, based on long-term mean from the 1970s onwards, and average productivity growth (a, a^N , a^* , a^{N*}) for each sector was set at 0.

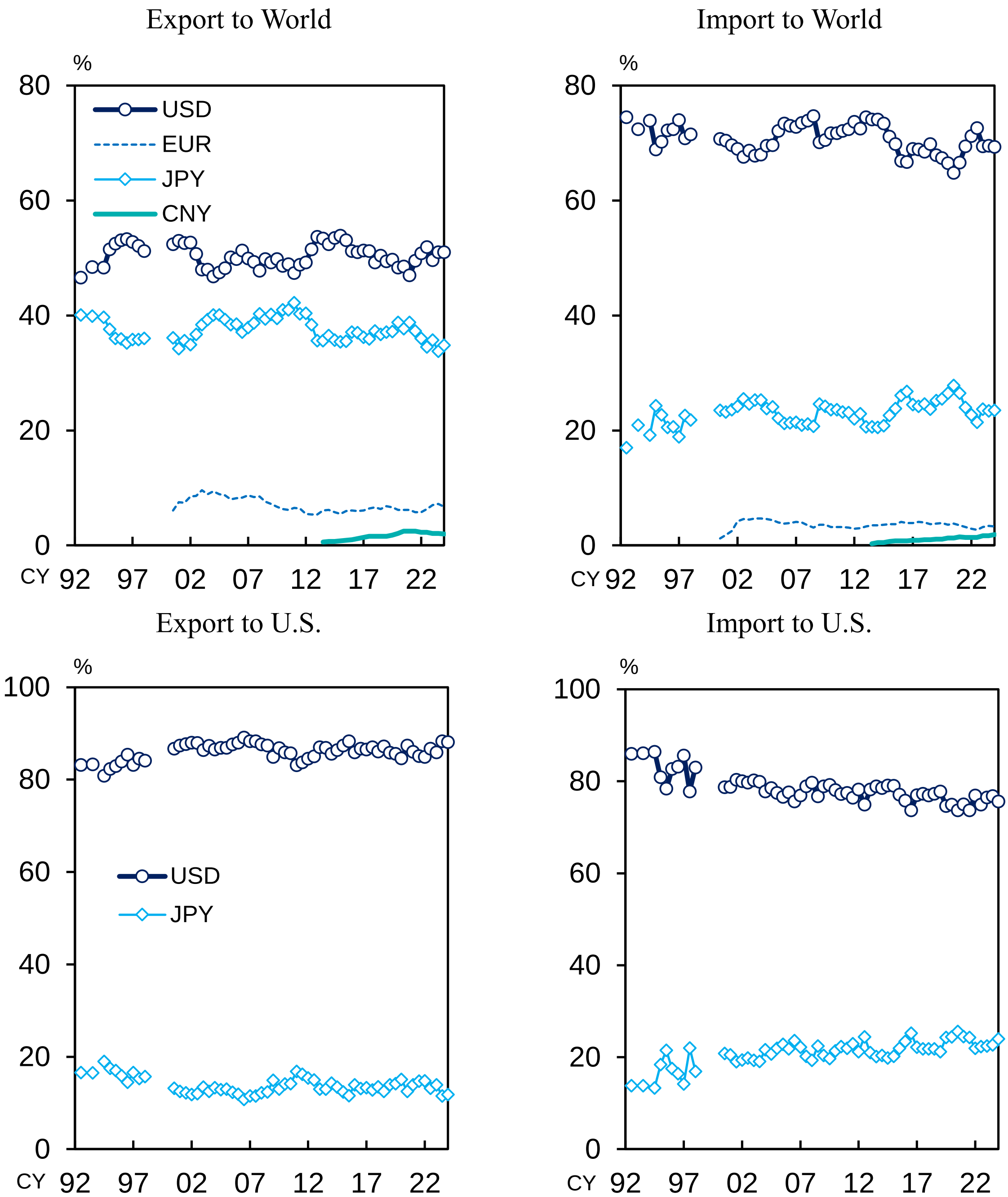
Looking at the posterior estimates, the elasticity of substitution for tradables (θ) was around 3, and the elasticity between tradable and non-tradable goods (ε) was around 1. With regard to prices, the results show that the non-tradable sector is more sticky than the tradable sector, and that Japan is relatively more sticky, which is consistent with price research on prices in Japan and the U.S. (Higo and Saita [2007], Nakamura and Steinsson [2008]). Taylor rule parameters are standard and the steady state inflation rate was estimated around 2.4 percent per in both Japan and the U.S., close to the long-term average.

(Figure A.3-2) Estimation of parameters

Parameter		Prior distribution			Posterior distribution ( ) 10-90% tile band
		Distribution	Average	Variance	
Substitution elasticity between domestic and foreign goods in tradable goods	θ	Gamma	4.0	0.5	2.99 (2.85 - 3.10)
Substitution elasticity between tradable and non-tradable goods	ε	Gamma	1.0	0.5	0.91 (0.83 - 0.97)
Adjustment cost of foreign bond holdings	χ	Gamma	0.02	0.014	0.01 (0.00 - 0.01)
1 − price stickiness tradable Japan・U.S.	θ_H	Beta	0.75	0.15	0.43 (0.36 - 0.46)
non-tradable Japan	θ_H^N	Beta	0.75	0.15	0.72 (0.65 - 0.77)
U.S.	θ_H^{N*}	Beta	0.75	0.15	0.67 (0.62 - 0.72)
Price indexation non-tradable Japan	φ_N	Beta	0.6	0.2	0.65 (0.58 - 0.75)
U.S.	φ_N^*	Beta	0.6	0.2	0.52 (0.45 - 0.56)
tradable Japan・U.S.	φ_h	Beta	0.6	0.2	0.37 (0.31 - 0.46)
Taylor rule inflation Japan	γ_π	Normal	1.5	0.25	2.13 (2.06 - 2.20)
U.S.	γ_π^*	Normal	1.5	0.25	1.94 (1.87 - 2.03)
Taylor rule output gap Japan	γ_y	Normal	1.0	0.2	0.98 (0.90 - 1.08)
U.S.	γ_y^*	Normal	1.0	0.2	1.00 (0.98 - 1.03)
Interest rate inertia Japan	ρ_r	Beta	0.7	0.1	0.65 (0.61 - 0.74)
U.S.	ρ_r^*	Beta	0.7	0.1	0.79 (0.74 - 0.82)
Shock inertia productivity tradable Japan	$\rho^{Z,T}$	Beta	0.7	0.1	0.94 (0.91 - 0.98)
U.S.	$\rho^{Z,T*}$	Beta	0.7	0.1	0.81 (0.75 - 0.90)
productivity non-tradable Japan	$\rho^{Z,N}$	Beta	0.7	0.1	0.81 (0.72 - 0.91)
U.S.	$\rho^{Z,N*}$	Beta	0.7	0.1	0.83 (0.78 - 0.91)
demand tradable Japan	$\rho^{G,T}$	Beta	0.7	0.1	0.82 (0.77 - 0.88)
U.S.	$\rho^{G,T*}$	Beta	0.7	0.1	0.94 (0.91 - 0.98)
demand non-tradable Japan	$\rho^{G,N}$	Beta	0.7	0.1	0.86 (0.77 - 0.96)
U.S.	$\rho^{G,N*}$	Beta	0.7	0.1	0.91 (0.90 - 0.96)
UIP	ρ^{uip}	Beta	0.7	0.1	0.32 (0.15 - 0.63)
Productivity trend Japan	a	Normal	0.0	0.1	0.23 (0.15 - 0.30)
U.S.	a^*	Normal	0.0	0.1	-0.11(-0.19 - -0.03)
Productivity trend (non-tradable) Japan	a^N	Normal	0.0	0.1	-0.02(-0.04 - 0.02)
U.S.	a^{N*}	Normal	0.0	0.1	-0.01(-0.08 - 0.03)
Inflation (steady state) Japan	$\bar{\pi}$	Normal	0.5	0.1	0.63 (0.59 - 0.74)
U.S.	$\bar{\pi}^*$	Normal	0.5	0.1	0.59 (0.50 - 0.70)
Shock variance demand tradable Japan	$\varepsilon_t^{G,T}$	Gamma	1.0	0.5	1.10 (0.98 - 1.32)
U.S.	$\varepsilon_t^{G,T*}$	Gamma	1.0	0.5	1.09 (0.84 - 1.44)
demand non-tradable Japan	$\varepsilon_t^{G,N}$	Gamma	1.0	0.5	1.07 (1.03 - 1.22)
U.S.	$\varepsilon_t^{G,N*}$	Gamma	1.0	0.5	1.02 (0.99 - 1.09)
monetary policy Japan	ε_t^{m}	Gamma	0.4	0.2	0.34 (0.30 - 0.37)
U.S.	ε_t^{m*}	Gamma	0.4	0.2	0.49 (0.45 - 0.54)
productivity tradable Japan	$\varepsilon_t^{Z,T}$	Gamma	0.7	0.3	2.04 (2.00 - 2.06)
U.S.	$\varepsilon_t^{Z,T*}$	Gamma	0.7	0.3	2.01 (1.97 - 2.07)
productivity non-tradable Japan	$\varepsilon_t^{Z,N}$	Gamma	0.7	0.3	1.03 (0.99 - 1.11)
U.S.	$\varepsilon_t^{Z,N*}$	Gamma	0.7	0.3	1.01 (0.98 - 1.05)
UIP	ε_t^{uip}	Gamma	1.0	0.5	1.21 (1.15 - 1.30)
productivity Japan・U.S.	ε_t^{Z}	Gamma	0.2	0.1	0.09 (0.05 - 0.11)

(Reference Figure)

(Reference Figure) Share of invoicing currency in Japan's trade[21]



Note: Data from 1992 to 1998 are based on Ministry of Economy, from 2000 are based on Ministry of Finance.
Sources: Ministry of Finance; Ministry of Economy, Trade and Industry

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[21] Japanese manufacturing companies tend to choose the currency of the destination country for exports to developed countries, with over 85 percent of exports to the U.S. being in U.S. dollars and around 55 percent of exports to the EU being in euros (Ito *et al.* [2018]).