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Globalization and Its Growing Impact on the Natural Rates of Interest in Developed Economies*

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Abstract

This paper quantitatively examines the effect of globalization on the natural rate of interest in developed economies, including Japan, the US, and the euro area. By incorporating into the model the variables that capture global economic and financial trends, such as demand and supply of safe assets and cross-border spillovers, with a smooth-transition framework, we account for the existence of non-linear regime change of their coefficients, driven by globalization. Our findings indicate that along with the progress of globalization, (i) the impact of global factors rapidly increased around 2000, and (ii) the commonly observed decline in the natural rate of interest can be largely attributed to these global factors. These findings underscore the importance of incorporating global factors such as demand and supply of safe assets and global spillovers, with their increasing impact, alongside the domestic factors such as productivity and demographics, when investigating developments in the natural rate of interest.

JEL classification：E43; E52; F41

Keywords：Natural Rate of Interest; Globalization; Smooth Transition Model

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1 Introduction

The natural rate of interest, which is the real interest rate at which economic activity and prices neither accelerate nor decelerate, is crucial because it could be one of the benchmarks for central banks to set short term interest rates.[1] However, the natural rate of interest cannot be directly observed; we need to estimate it using economic theories as a guide and make use of various econometric tools based on observable economic data. As a consequence, uncertainty regarding the estimation of natural rates of interest is inevitably high. Additionally, their determinants are still ambiguous, since the economic theories which should serve as guides also entail different views.[2] Given these circumstances, elaboration of the estimation of the natural rates of interest through various approaches and research regarding their determinants is still under investigation within central banks and academia.[3]

This highlights the fact that most existing models for estimating the natural rates of interest assume closed-economy models and disregard global factors to some extent.[4] The reason seems to be the limited accumulation of research regarding the relationship between global factors and the natural rate of interest. However, the amount of literature indicating that the domestic economies and financial conditions are greatly affected by spillovers from foreign economies is currently increasing (Holston et al. 2017, Del Negro et al. 2019, Kiley 2019,

[1] In this paper, we examine the so-called "long-term" natural rates of interest. Accordingly, we use long-term trends of each variable in estimation. It is important to note that the natural rate of interest in this paper is different from the one defined as the ex-ante real short-term interest rate in a hypothetical economy with flexible prices.

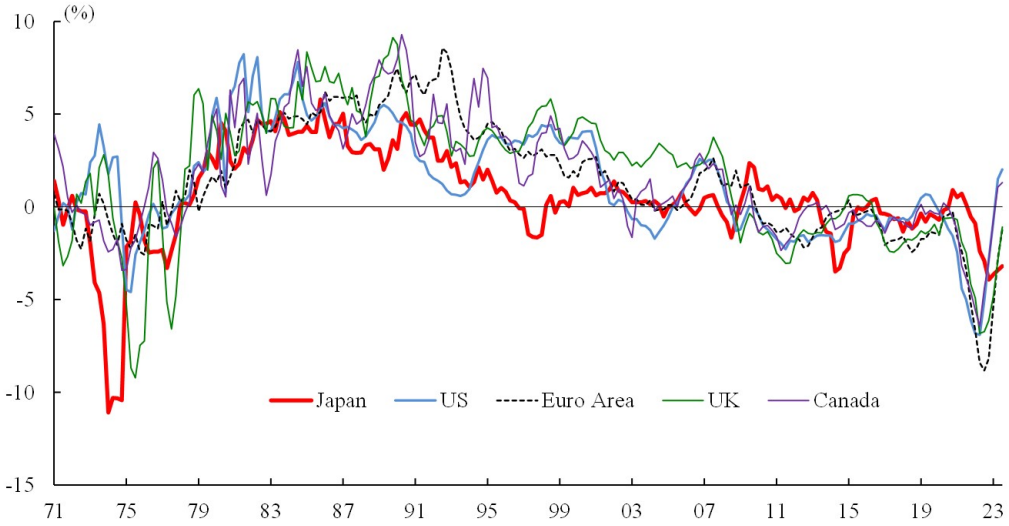
[2] Thus, it is widely known how hard it is to use them in practice. For example, Williams (2018b), Brand et al. (2018), Borio (2021), Lagarde (2024), and Powell (2024) argue that, although the natural rate of interest is useful as a conceptual tool, considering the high uncertainty regarding the estimations, central banks should not rely on the specific estimated value as a perfect guide for implementing the appropriate monetary policy.

[3] For instance, at the Bank of Japan, studies regarding the natural rate of interest are continuously being conducted, as can be seen in Oda and Muranaga (2003), Kamada (2009), Fujiwara et al. (2016), Imakubo et al. (2018), Okazaki and Sudo (2018), BOJ (2024), and Nakano et al. (2024), etc.

[4] For a representative example of the model frequently used by the Fed, see Laubach and Williams (2003) and Holston et al. (2023). For the ECB, see Brand et al. (2024). For the BOJ, see BOJ (2024) and Nakano et al. (2024), among others.

Ferreira and Shousha 2023, and Carvalho et al. 2023). In fact, when we look at the long-term development of real interest rates in developed economies in Figure 1, we can see a common declining trend, suggesting the existence of global factors which affect equally the natural rates of interest in various economies. If the impact of global factors cannot be neglected, then it would be essential to take appropriate account of these factors when we try to grasp developments in the natural rate of interest, including a detailed analysis of its determinants.

Figure 1. Real Interest Rates



Note: Data are until the third quarter of 2023. The real interest rates are calculated by subtracting CPI (headline) year-on-year inflation from the short term interest rates.
Source: HAVER; AWM; ECB

Accordingly, this paper quantitatively examines the effect of global factors on the natural rate of interest. To be precise, by using the smooth-transition model (hereafter the ST model), we extend the model by Ferreira and Shousha (2023), which incorporates global factors accounting for both global demand and supply of safe assets and global spillovers from the country- or region-specific real factors such as productivity and demographics. This approach allows us to analyze the development of the natural rate of interest taking into account the

existence of regime change, which considers that the impact of global factors would non-linearly increase as globalization progresses. We verify that because the linkages of the trade and financial aspects from the late 1990s to the early 2000s combined significantly, the extent to which global factors affect the natural rate of interest increased, and we then decompose the natural rate of interest for each economy. To the best of our knowledge, this paper is the first to estimate the effect of the global factors on the natural rate of interest taking into account the regime change associated with globalization.

As a result, we found the following. First, it is revealed that as globalization progresses, the extent to which global factors affect the natural rate of interest rapidly increased around 2000. Second, according to the historical decomposition using the model in this paper, the common declining trend of the natural rate of interest can mostly be explained by global factors. Based on these findings, it is essential to take into account not only domestic real factors such as productivity and demographics, but also global factors such as global demand and supply of safe assets and global spillovers from overseas real factors, considering their increasing roles, when we try to understand developments in the natural rate of interest.[5]

Previous studies regarding the global factors that affect the natural rate of interest point out the importance of global demand and supply of safe assets. For example, Bernanke (2005), Williams (2016), Caballero et al. (2016), Rachel and Smith (2018), and Kiley (2019) highlight the higher demand for safe assets from emerging economies since the 1990s, including discussion of the so-called global saving glut. Aligning with them, Del Negro et al. (2019), Gourinchas et al. (2022), Carvalho et al. (2023), and Cesa-Bianchi et al. (2023) suggest the importance of taking into account the global demand and supply of safe assets on the premise of international arbitrage in the decomposition of the natural rate of interest.

[5] Against the backdrop of heightened tensions in geopolitics, such as Russia's military invasion of Ukraine and the US-China relationship, there has been much recent debate about de-globalization and decoupling. However, there has been no marked drop in demand for US Treasuries, nor in the convenience yield of US Treasuries, which suggests that these situations are not affecting the natural rate of interest at this point.

In addition to these financial approaches, an increasing number of studies point out that accurately understanding trends in the natural rate of interest requires considering the impact of global spillovers from overseas real factors. For instance, Beyer and Milivojevic (2023) suggest that country- and region-specific real factors move between nations and regions through trade transactions and capital flows, which could enhance the convergence of the natural rate of interest. Under these circumstances, several studies emphasize the importance of considering global spillovers from overseas real factors when estimating the natural rate of interest (Fries et al. 2018, Zhang et al. 2021, and Ferreira and Shousha 2023). Such real factors from abroad include potential growth rates (Wynne and Zhang 2018), productivity (Martínez-García 2021), and demographic trends (Krueger and Ludwig 2007, Gagnon et al. 2016, and Brand et al. 2022). In Carvalho et al. (2023), a strong assumption is made that overseas real short-term interest rates aggregate all the information about real factors to express the spillovers from overseas real factors.[6] However, in reality, short-term interest rates often deviate from fundamentals, making it difficult to argue that they fully aggregate all the information about real factors. In this regard, this paper more directly captures the spillover effects from overseas real factors by using a weighted average of the real factors from other economies as explanatory variables.

In estimating these global factors, Ferreira and Shousha (2023), which is most closely related to this paper in terms of selected variables, assumes that sensitivity to these factors remains constant over time and does not consider the possibility of regime change. In contrast, Carvalho et al. (2023) focus on how sensitivity to global factors changes with the progress of financial integration. However, while that paper assumes a priori that sensitivity changes

[6] Agnello et al. (2022), who follow Laubach and Williams (2003) and estimate the natural rate of interest in OECD countries, under the assumption that real factors are to some extent incorporated into the estimated natural rate of interest, measure the degree of spillover from the natural rate of interest of other economies to the natural rate of interest of a given economy using forecast error variance decomposition. The results suggest that the degree of spillover from overseas increased during the 1990s and 2000s, following events such as the Asian financial crisis and the Latin American currency crisis.

with the degree of globalization in a linear way, this paper conducts a more detailed analysis using an ST model capable of capturing non-linear regime changes.

The structure of this paper is as follows. In section 2, the determinants of the natural rate of interest that have been discussed in previous studies are reviewed, with a focus on global factors. Section 3 explains the estimation model we use. Section 4 presents the estimation results. Section 5 examines the implications for future natural rates of interest. Section 6 provides a conclusion.

2 Summary of Determinants of the Natural Rate of Interest

In this section, we will explain the mechanisms through which global factors can influence the natural rate of interest and briefly summarize domestic factors, focusing on productivity and demographics, which are also considered in the model in this paper.

2.1 Global Factors

2.1.1 Global Spillovers from Overseas Real Factors

Country- and region-specific factors such as changes in productivity and demographics can have spillover effects on other economies through trade transactions and capital flows. For example, even if there are differences in productivity or the working-age population ratio, capital may move from economies with lower potential growth rates and real interest rates to those with higher rates, leading to a convergence in the natural rates of interest.[7] In this regard, Beyer and Milivojevic (2023) have shown that the higher the trade volume, the stronger the synchronization of the natural rates of interest will be among the 50 economies analyzed.

[7]However, since real economic conditions such as potential growth rates and demographics are expected to transition much more gradually compared with financial markets, it is likely that the speed at which differences in real factors are equalized is slower than that of financial factors. Consequently, it is realistic to assume that new differences will arise before the existing ones are fully equalized, preventing a complete equilibrium state from being achieved.

Against this backdrop, there has been an increase in recent years in studies emphasizing the importance of considering global spillovers from overseas real factors when estimating natural rates of interest. For example, Fries et al. (2018), when estimating the natural rates of interest for France, Germany, Italy, and Spain, incorporate spillovers from overseas real factors through trade and productivity channels to account for the impact of external demand as a variable affecting domestic output gaps. Ferreira and Shousha (2023), when estimating the natural rate of interest for the United States, show that the results taking into account global spillovers from overseas real factors, such as productivity and demographics, are on average 0.9% points lower than those from counterfactual models that do not consider these factors. The study concludes that global real factors, such as the decline in global productivity and the aging observed since the 2000s, have contributed to this downward pressure.

Potential growth rates, productivity, and demographics could be incorporated into the model as global real factors. Wynne and Zhang (2018) extend the model in Laubach and Williams (2003) to a two-country model for the US and Japan, and suggest that not only the potential growth of a particular country but also the potential growth rates of other countries could affect the natural rate of interest. In particular, during the periods when Japanese potential growth was declining dramatically (1973-1975, 1991-1993, and 2008-2009), that lowered the natural rate of interest in the US at that time. On the other hand, the potential growth rate of the US, including the periods when it recovered from the global financial crisis, put upward pressure on the natural rate of interest in Japan. Martínez-García (2021) argues for the importance of taking into account global spillovers from overseas real factors, after realizing that fluctuations in the US natural rate of interest estimated using an open-economy DSGE model can be explained by the effect of productivity shocks from abroad through trade transactions. The results of Zhang et al. (2021) suggest that productivity shocks from overseas can explain 13-60% of fluctuations in the domestic short-term natural rate of interest, giving further support for the importance of considering global spillovers from overseas real factors

through trade transactions. For demographics, Krueger and Ludwig (2007), Brand et al. (2022), and Gagnon et al. (2016) point out that the downward pressure on the natural rate of interest from an aging population can be mitigated by the outflow of capital to economies with younger populations and higher potential growth rates. With these findings in mind, Carvalho et al. (2023) use a general equilibrium model and error correction model covering 19 OECD economies and argue that the natural rates of interest of more financially-connected economies are more greatly affected by the demographics of other economies through international trade transactions and capital flows.

2.1.2 Global Demand and Supply of Safe Assets

In a simple model that assumes economic agents acquire direct utility from holding safe assets, the following holds in the steady state.[8]

$$R = \left(1 - \nu'\left(\theta; \xi\right)\right) \frac{g}{\delta} \tag{1}$$

Here, R is the real interest rate at the steady state, and one can interpret this as the natural rate of interest in this paper's context. ν' is the marginal utility which the agents can acquire from holding safe assets and depends on the amount of safe assets, θ, and the preference of the economic agents toward safe assets, represented by ξ. g and δ are growth rate and discount factor, respectively. As this equation implies, when economic agents do not hold enough safe assets because of a lack of supply (for example, where ν' is apparently deviating from zero as a result of θ being low), the demand and supply of safe assets can affect R.[9] Also, the preference of economic agents, ξ, can be interpreted as a change in the preference regarding liquidity due to emerging economies being motivated to hold foreign assets and to changes in financial regulations. A rise (or decline) in these preferences would lower (raise) R.

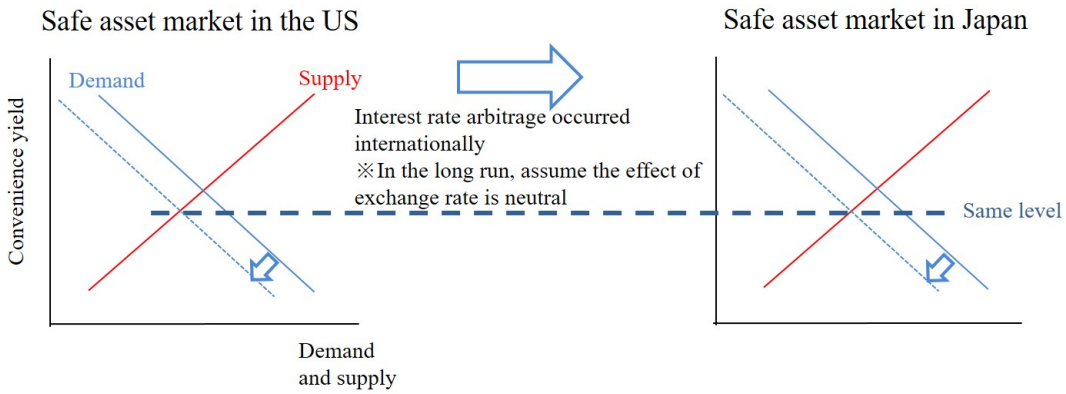
The demand and supply of safe assets can be a domestic specific factor; however, previous

[8] See Ferreira and Shousha (2023) for derivation.

[9] Note that $\nu' > 0$ and $\nu'' < 0$ are assumed.

studies suggest the importance of global demand and supply of safe assets (Gourinchas et al. 2022, Carvalho et al. 2023, and Cesa-Bianchi et al. 2023, etc). This is because the arbitrage of returns from financial assets is easier than that of real assets, and the speed is also much faster. As Figure 2 illustrates, the idea suggested in Del Negro et al. (2019) that the convenience yield determined from the demand and supply of safe assets can converge among economies under conditions where the relative purchasing power parity holds in the long term regarding the real foreign exchange rate.[10] Based on these previous studies, this paper uses the demand and supply of US Treasuries and the US convenience yield as the variables that capture the global demand and supply of safe assets.

Figure 2. Transmission Mechanism of Convenience Yield

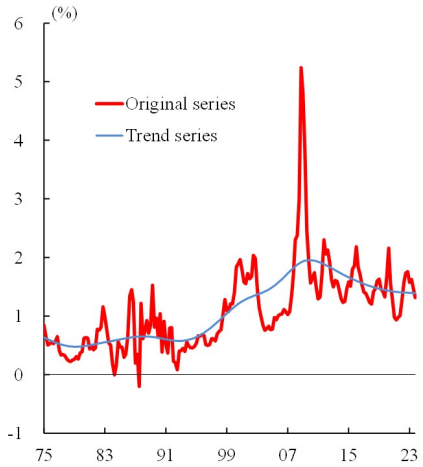


Source: Del Negro et al. (2019)

Figures 3 and 4 show the convenience yield and the demand and supply of safe assets. As Bernanke (2005), Rachel and Smith (2018), and Kiley (2019) mention, since the late 1990s, after the Asian currency crisis, emerging economies in particular increased investment in US Treasuries as safe assets, so as to ensure liquidity, and as a result of this, the speed of the

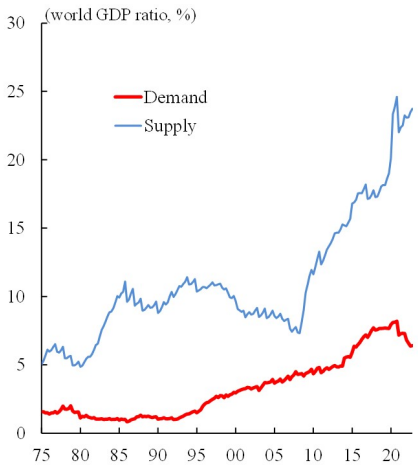
[10] When the arbitrage does not come into effect, domestic demand and supply of safe assets in each economy can additionally affect the natural rate of interest. However, recent studies such as Cesa-Bianchi et al. (2023) do not provide empirical support for this idea.

Figure 3. Convenience Yield



Note: Data are until the fourth quarter of 2023. Convenience yield is the spread between the US IG bond yields and US Treasury yields. Trend series is calculated using the HP filter.
Source: HAVER; FRB; FRED

Figure 4. Safe Assets



Note: Data are until the fourth quarter of 2022. The supply of safe assets is calculated by subtracting the non-marketable debt from the US public debt balance. The demand of safe assets is the international foreign exchange reserves in US dollars held by foreign governments.
Source: HAVER

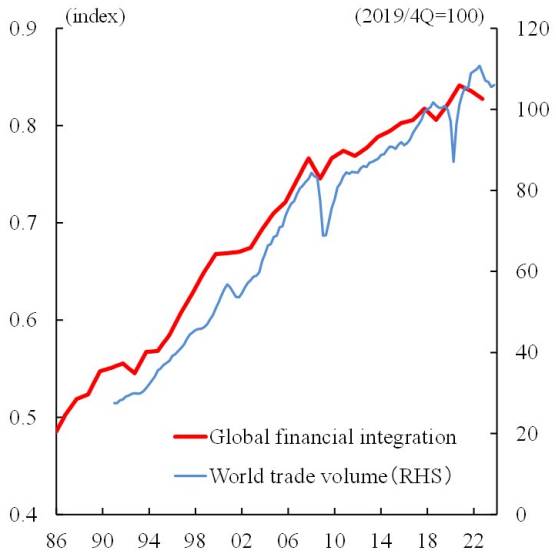
increase in convenience yield and the demand of safe assets accelerated. At the same time, as the price of crude oil followed a gradual rising trend, resource-rich developing economies especially saw an increase in saving, and therefore had sufficient capacity to invest in US Treasuries. In addition, since around 2000, emerging economies, mainly China, structurally increased demand for US Treasuries with the intention of holding foreign exchange reserves (Williams 2016 and Caballero et al. 2016). On the other hand, supply has been increasing way beyond demand, due for instance to large-scale fiscal stimulus. As a net, the effect of the increase in supply totally cancels out that of demand. This increase in the net supply of safe assets, interpreted based on Formula 1, could potentially reduce the extent of the decline in R through an increase in θ, assuming investors' preferences remain constant. However, it is important to note that the strengthening of the motive to hold foreign exchange reserves mentioned above may work to push R downward, if θ remains constant. On the other hand,

an increase in convenience yield is thought to have a negative impact on the natural rate of interest. That is, an increase in the convenience yield indicates that investors are relatively risk-averse, corresponding to a situation where demand for treasuries is rising, bond prices are increasing, and bond yields are declining.

2.1.3 The Degree of Progress in Globalization

Based on the explanations given in Section 2.1.2, the size of the effect of global factors on the natural rate of interest in each economy depends on the extent of the interconnectedness in goods and capital markets. Figure 5, which shows the integration in global capital markets since 1985 – the period examined in this paper – suggests that globalization proceeded rapidly from the late 1990s into the 2000s. The volume of world trade also increased at nearly the same time.

Figure 5. Global Financial Integration and World Trade Volume



Note: Global financial integration is calculated taking the sum of external financial assets and external financial liabilities in percent of GDP held by Japan, the US, the euro area, the UK, and Canada, standardizing them to a value from zero to one, and taking the average. Data are until the fourth quarter of 2022 for global financial integration, and the world trade volume is until the fourth quarter of 2023.
Source: HAVER; The Brookings Institution

As for the background to the progress of globalization during this period, the relaxation of financial regulations is the prime factor. Looking at the trend of the financial regulation openness index in the Figure 6, it is clear that after the strengthening of regulations due to the

Asian currency crisis (1997-1998),[11] the trend of deregulation accelerated with the resolution of the crisis. For example, in Indonesia, in 1997, foreign enterprises were allowed to purchase non-bank financial intermediary stocks in the Indonesian capital market without any upper limit. In South Korea, in 1998, all regulations in the domestic capital market were abolished, and the upper limit on FDI in South Korean stocks was also completely removed that year. In Malaysia, the minimum holding period for the stock market was abolished in 1997, and there were also reductions in tax rates.

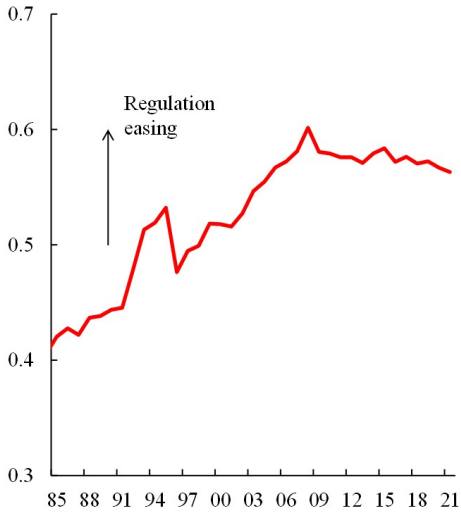
As can be seen in Figure 7, this period also saw an expansion in trade transactions, accompanied by qualitative changes such as the increase in trade agreements. From the late 1990s, there was growth in trade agreements focusing primarily on goods in Turkey, Europe, and Eastern and Southern Africa. By the early 2000s, these agreements had expanded to include services as well as goods.[12] China's accession to the WTO in December of 2001 is often cited as a symbolic event that contributed to the further expansion of trade transactions and the progress of globalization (Chow 2003).

It is therefore clear that globalization advanced rapidly in both trade transactions and financial markets from the late 1990s to the early 2000s. As a result, the influence of global factors on the natural rate of interest of various economies likely intensified. It is also worth noting that this wave of globalization not only strengthened the ties between advanced economies but also involved the participation in the global economy of emerging economies, which had previously been shielded by financial regulations. Compared with advanced economies, emerging economies often experienced greater volatility in their financial markets and had stronger motives for holding safe assets. As will be discussed later, this paper conducts estimation that takes into account the possibility of such regime changes.

[11] For instance, in 1997, the central bank of Thailand introduced regulations regarding the capital flow and the dual (official and market rates) foreign exchange rate policy to control speculative movements (introduced in July 1997, and abolished in January 1998), as mentioned in Schmukler and Kaminsky (2003).

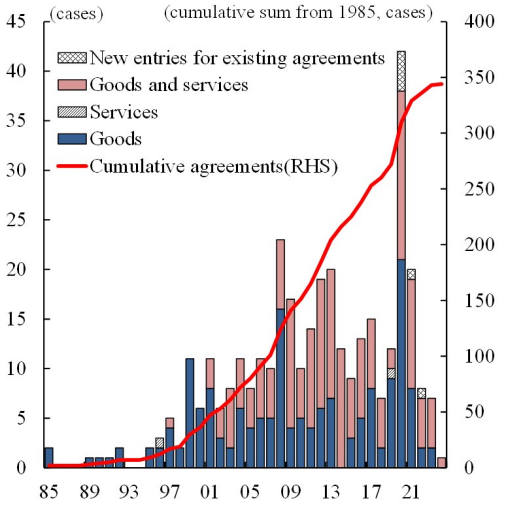
[12] For further details, refer to the WTO regional trade agreements database (https://rtais.wto.org/UI/PublicMaintainRTAHome.aspx).

Figure 6. Financial Openness Index



Note: The value is the average of 183 economies' data in "The Chinn-Ito Financial Openness Index." Data are until 2021; accessed November 2023.
Source: Chinn and Ito (2006)

Figure 7. Trade Agreements



Note: Data are until 2024 (specifically, 15th of January). The aggregated value of all trade agreements signed between nations and regions, including the Free Trade Agreement (FTA), Economic Partnership Agreement (EPA), Preferential Trade Agreements (PTA), and Customs Union (CU).
Source: WTO

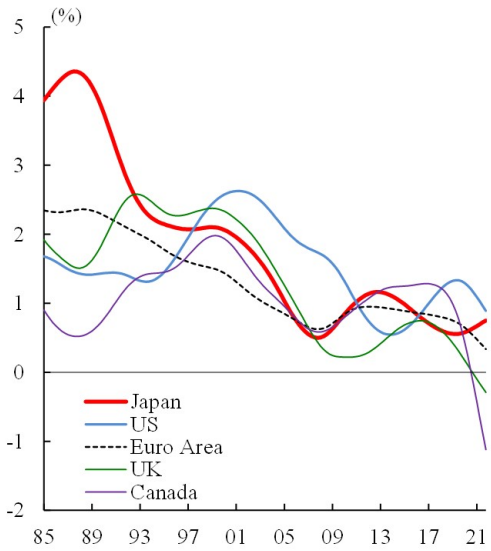
2.2 Domestic Factors

2.2.1 Productivity

As shown in Figure 8, productivity has been on a downward trend in many countries, and this is often cited as a major cause of the decline in the natural rate of interest (Holston et al. 2017 and Rachel and Smith 2018). The decline in productivity is thought to suppress the natural rate of interest through several channels. First, according to simple macroeconomic theory, the equilibrium interest rate is determined by productivity. When productivity declines, the marginal product of capital decreases, leading to fewer investment opportunities and a reduction in investment demand. As the opportunity cost of saving diminishes, lenders are inclined to set lower interest rates (Cesa-Bianchi et al. 2022 and Mankiw 2022). Additionally,

the decline in household income expectations increases precautionary saving motives, leading to a change in the savings-investment balance, which in turn pushes down the natural rate of interest (Ferreira and Shousha 2023 and Cesa-Bianchi et al. 2023).

Figure 8. Labor Productivity



Note: Data are the trend values extracted by the HP filter (λ=2,500) after converting annual data on GDP growth per hour worked from 1985 to 2022 to quarterly data using linear interpolation.
Source: Bergeaud et al. (2016)

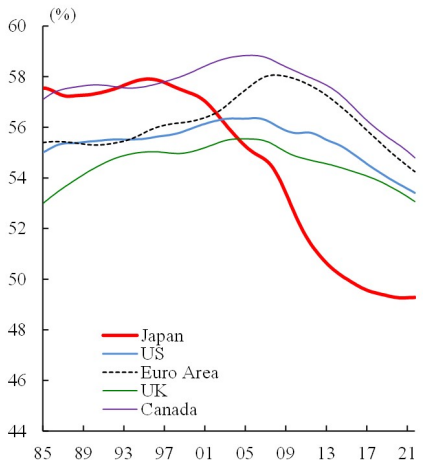
2.2.2 Demographics

Although it is well known that demographics somehow affect the natural rate of interest, the variable used as a proxy for demographics depends on the literature, and the relationship between the two is not determined (Blanchard 2023). For example, it is pointed out in Sudo et al. (2018) and Brand et al. (2022) that the decrease in working-age population ratio due to aging affects marginal production of capital through an increase in the capital-labor ratio, while Brand et al. (2022) mention the possibility that the decline in the working-age to population ratio means a decrease in the share of young population, who generally have a tendency to save more than the elderly population does, which in turn means that population aging possibly

pushes up the natural rate of interest through the decline in the macro propensity to save.

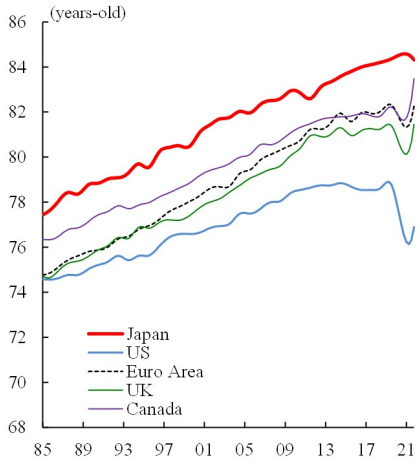
Also, both the enhancement of longevity and longer life expectancy, which underpin the aging population, means households expect a longer life after retirement and gives them greater incentive to increase their precautionary savings. This eventually leads the natural rate of interest to decline (Carvalho et al. 2016 and Gagnon et al. 2016). However, Goodhart and Pradhan (2020) point out the possibility that it can put upward pressure on the natural rate of interest because the longer life expectation makes people think that they are able to work and get compensation for longer than before, which leads people to use their savings and increase consumption. As we have seen so far, there can be various channels through which demographics affect the natural rate of interest, and these effects have to be investigated through empirical analysis.

Figure 9. Working-age Population



Note: The working-age (20-60 years-old) population is divided by total population as a ratio. The annual data is interpolated by spline method and converted into quarterly data.
Source: United Nations "World Population Prospects 2022"

Figure 10. Life Expectancy



Source: World Bank

2.2.3 Other Factors

Although not considered in this paper, there are factors that could affect the natural rate of interest other than those mentioned above, including the following:

- Fiscal policy（Summers and Rachel 2019 and Eggertsson et al. 2019）
  - Under circumstances where the Ricardian debt neutrality does not hold, fiscal expense leads the increase in aggregate demand and pushes up the natural rate of interest. With an increase in monetary demand by the government, more private savings are needed as a way of funding, therefore, an increase in borrowing by the government is accompanied by a rise in interest rates. Note that the degree of the rise in the interest rate depends on how much investment in the private sector is restrained due to the additional public debt.
- Inequality（Summers 2014 and Mian et al. 2021）
  - Recently in the US, inequality is widening such that there has been an increase in the income share of the wealthy class out of the aggregate income in the whole economy. Since people with higher income tend to save more, widening inequality leads lower consumption and higher saving, eventually pushing down the natural rate of interest.
- Financial friction（Okazaki and Sudo 2018 and Reis 2022）
  - Financial friction, such as a decline in the function of financial intermediaries' activities during a financial crisis, can, for example, trigger a decrease in borrowing demand of firms and households. When inefficiency in allocation regarding saving-to-investment occurs in these circumstances, treasury yields deviate from the marginal productivity of private capital, and eventually lower the natural rate of interest.
- Relative price of capital goods (Summers 2014, Sajedi and Thwaites 2016, and

Okazaki and Sudo 2018)

- The cheaper capital goods become, the less borrowing and expense are required for investment in capital goods and the lower the macro propensity for investment, therefore, the natural rate of interest declines. On the other hand, as more investments are induced, the natural rate of interest might be pushed up. Which effect dominates depends on the elasticity of labor and capital.

3 Model Specification and Outline

3.1 Estimation Model

In this section, we describe the details of the estimation model. Our baseline model follows Ferreira and Shousha (2023), but introduces an ST mechanism.

First, consider the case without any regime change. The change in the natural rate of interest of country j at quarter t from the last quarter, $\Delta r^*_{j,t}$, can be described as the linear sum of the change in each variable affecting the natural rate of interest and the factors specific to country j excluding those variables, $\epsilon_{j,t}$, as shown in the equation below.[13]

$$\Delta r^*_{j,t} = \beta_{pt}\Delta pt_{j,t} + \beta_{ws}\Delta ws_{j,t} + \beta_{cy}\Delta cy_t + \beta_{sa}\Delta sa_t + \beta_{gs}g_{j,t-1} + \epsilon_{j,t} \tag{2}$$

Here, $pt_{j,t}$ and $ws_{j,t}$ are country j's productivity and working-age population ratio, respectively, and they are the country-specific factors. On the other hand, cy_t and sa_t are global convenience yield and the net supply of safe assets, respectively, and they represent the global common factors.[14] The net supply of safe assets captures the effect on the natural rate of

[13] As discussed later in this paper, data for emerging economies are not used in the estimation, but the impact of investment trends from emerging economies on the natural rate of interest in developed economies is also captured indirectly in the model as a result of adding globally common variables such as convenience yield and the demand and supply of safe assets as the explanatory variables.

[14] While it is possible that the degree to which global effects spillover to the domestic economy may differ for

interest of the factors related to foreign reserves and the supply of treasuries through the international safe asset market. Convenience yield captures the effect on the natural rate of interest of the factors related to the demand and supply of treasuries which could not be fully captured by the net supply of safe assets – for example, the strength of investors looking for hedging risks – through the international arbitrage of interest rates. $g_{j,t-1}$ represents the spillover effect of the productivity and demographics of countries other than j to country j, and it is defined as the weighted average of the contribution of domestic real factors in other economies, as shown in the equation below.

$$g_{j,t-1} = \sum_{i \neq j} w_i^j (\beta_{pt} \Delta pt_{i,t-1} + \beta_{ws} \Delta ws_{i,t-1}) \tag{3}$$

In the equation above, w_i^j is the trade weight of country i from the perspective of country j. Therefore, the natural rate of interest of country j is assumed to be affected not only by changes in the domestic real factors of the country itself and changes in the global demand and supply of safe assets but also by changes in the real factors of other economies through trade transactions.

Next, we extend this model to the ST model. The ST model assumes that the regime will continuously change along with economic conditions, allowing the economic model to change continuously as the regime changes. Specifically, this paper assumes that the effects from the global factors Δcy_t, Δsa_t, $g_{j,t-1}$ change transitionally along with globalization.

$$\Delta r^*_{j,t} = \beta_{pt} \Delta pt_{j,t} + \beta_{ws} \Delta ws_{j,t} + \beta_{cy,t} \Delta cy_t + \beta_{sa,t} \Delta sa_t + \beta_{gs,t} g_{j,t-1} + \epsilon_{j,t} \tag{4}$$

For the number of regimes, we assume two regimes before and after globalization, based on the insights that the Section 2 has given us. Let the coefficient of Regime 1 be β_1, and

each economy, following Ferreira and Shousha (2023), this paper assumes that such differences are limited because we only cover the major developed economies, and that the coefficients of global factors are the same across the economies, to avoid model complexity.

the coefficient of Regime 2 be β_2. Using the transition function $F_t = F(s_t)$ which takes the value between 0 and 1 and a function of the transition variable s_t that captures the change in globalization, the coefficient β_t of each time t can be written as the weighted average of β_1 and β_2 as in the equation below.

$$\begin{aligned}
\beta_{cy,t} &= (1 - F_t)\beta_{cy1} + F_t\beta_{cy2} \\
\beta_{sa,t} &= (1 - F_t)\beta_{sa1} + F_t\beta_{sa2} \\
\beta_{gs,t} &= (1 - F_t)\beta_{gs1} + F_t\beta_{gs2}
\end{aligned} \tag{5}$$

For F_t, which can be considered as the weight of Regime 2, this paper will use the logistic function and the global financial integration index of the last period, ϕ_{t-1}, as the transition variable in order to analyze the structural change that accompanies globalization.

$$F_t = \frac{1}{1 + \exp(-\gamma(\phi_{t-1} - c))}, \quad \gamma > 0 \tag{6}$$

In this specification, as $s_t = \phi_{t-1}$ increases, F_t will change from 0 to 1. When $s_t = \phi_{t-1}$ is small, then F_t will take a value near 0, making each time varying parameter β_t take a value near β_1. Hence, Regime 1 is the regime before the progress of globalization. On the other hand, as $s_t = \phi_{t-1}$ increases, F_t gets closer to 1, and the value of β_t will be close to β_2, therefore, Regime 2 can be taken as the regime after the progress of globalization. How F_t, the weight of Regime 2, will change is defined by the parameters of F_t, c, and γ. To be precise, c represents the threshold of the regime change, and if the transition variable is smaller than c, then the weight of Regime 1 will be greater than 0.5, while if the transition variable is bigger than c, then the weight of Regime 2 will be bigger than 0.5. The parameter γ indicates the speed of regime change. The bigger it is, the faster the transition of the economic model will be, since the change from Regime 1 to Regime 2 when the transition variable exceeds the threshold is a drastic one.

The equations described above (3), (4), (5), and (6) are the estimation equations based on the ST model.

3.2 Model Outline

The economies in focus are Japan, the US, the euro area, the UK, and Canada. We use pooled data for these economies and estimate simultaneously β, c, and γ, using the Maximum likelihood method. β_{gs1} and β_{gs2} are restricted to take values between 0 and 1, following Ferreira and Shousha (2023). The estimation period is from the second quarter of 1985 to the first quarter of 2022 due to the availability of data for productivity, etc. For details of the data used, refer to Appendix A.

4 Estimation Results

4.1 Esimation Results of Baseline Model

Table 1 shows the estimation results for the baseline parameters. First, the coefficient for productivity which captures domestic factors is positive, consistent with the discussion in Section 2. In other words, a decline or increase in productivity affects the natural rate of interest accordingly. Next, the sign of the working-age population ratio is also positive. This indicates that the progression of aging leads to a decline in the natural rate of interest.

Looking at the coefficients for the global variables, all variables meet the expected sign constraints, and the estimation values for Regime 2, which corresponds to the period after globalization progressed, are larger in absolute terms compared with the estimation values for Regime 1, which corresponds to the period before globalization, and to the estimation values from regression models that do not consider structural changes.[15] Specifically, the coefficients for the convenience yield, which captures the strength of the impact of demand for safe assets, and for the net supply of safe assets have increased by about three times from

[15]For the coefficients of global factors, we test the null hypothesis that the coefficients between two regimes are equal and confirm that the coefficient of Regime 2 is statistically different from that of Regime 1.

Table 1. Estimation Results

		ST model		Regression model
		Regime 1	Regime 2	(Supplementary)
Domestic variables	Productivity	0.284		0.319
		(0.027)		(0.039)
	Working-age population	0.108		0.088
		(0.019)		(0.022)
Global variables	Convenience yield	-0.707	-1.977	-1.446
		(0.046)	(0.176)	(0.109)
	Net supply of safe assets	0.015	0.047	0.037
		(0.005)	(0.003)	(0.003)
	Global spillovers	0.000	0.702	0.600
		–	(0.042)	(0.213)
Parameters of transition function	Threshold of regime change	0.672		–
		(0.005)		
	Speed of regime change	73.736		–
		(7.515)		

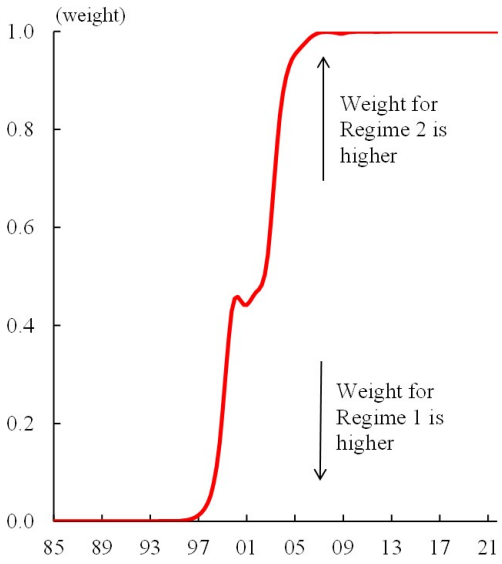
Notes: Standard errors are in brackets. "ST model" is the result of Equation (4) and "Regression model" is the result of Equation (2). "Global spillovers" in "ST model" is restricted between 0 and 1 following Ferreira and Shousha (2023) and the value for "Regime 1" is 0 as a result of this treatment. Therefore, the standard error for "Global spillovers" of "Regime 1" is not written.

Regime 1 to Regime 2. Similarly, while the global spillovers from overseas real factors are found to have no impact on the natural rate of interest in Regime 1, in Regime 2 the coefficient is around 0.7. Considering that a $\beta_{gs,t}$ of 1 would indicate full pass-through of overseas real factors, a coefficient of 0.7 is relatively large.

Now, looking at the parameters of the transition function, c, which represents the threshold for regime change, is 0.672, and γ, which represents the speed of regime change, is 73.736. This suggests that regime change occurred relatively rapidly around the time when the global financial integration index, the transition variable, was 0.672 (2001-2002). When confirming the time-series changes of the transition function based on these parameters in Figure 11, we can see that the regime was in Regime 1 until the late 1990s, shifted from Regime 1 to Regime 2 between the late 1990s and early 2000s, and has remained in Regime 2 since then. What is noteworthy is the speed of this structural change. Although the global financial integration

index, the transition variable, rose at a fairly rapid pace, as shown in Figure 5, the structural change occurred even more quickly around the time when the global financial integration index passed the threshold. This non-linear change suggests that some qualitative changes, such as shifts in investor preferences, occurred around the time the global financial integration index was near the threshold.

Figure 11. Transition Function



4.2 Historical Decomposition of the Natural Rate of Interest

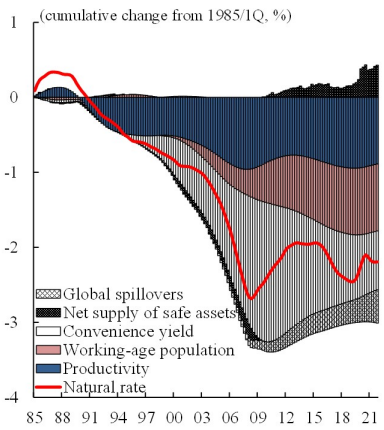
Using the parameters in Table 1, we decompose the fluctuations in the cumulative change in the natural rates of interest in Japan, the US, and the euro area, as can be seen in the Figures in 12, 13, 14.[16] Here, we represent both (a) "Actual Decomposition" and (b) "Global Variables Coeffs Constant" which is counterfactually calculated assuming that the variables were always in Regime 1 during the estimated period, in order to confirm the effect of globalization on the

[16]The cumulative change of natural rates of interest shown by the red line in (a) and (b) are actual values. Decomposition is depicted without error terms, therefore, please note that the sum of stacked bar graphs and the line graph are not the same.

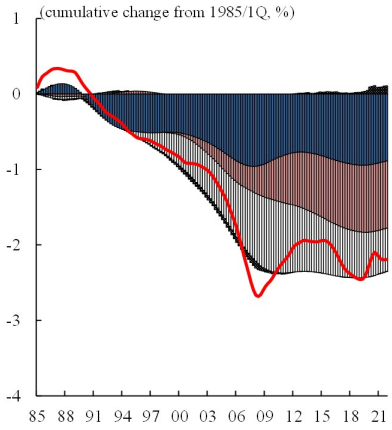
fluctuation in the natural rate of interest.[17]

Figure 12. Decomposition of the Natural Rate of Interest (Japan)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant



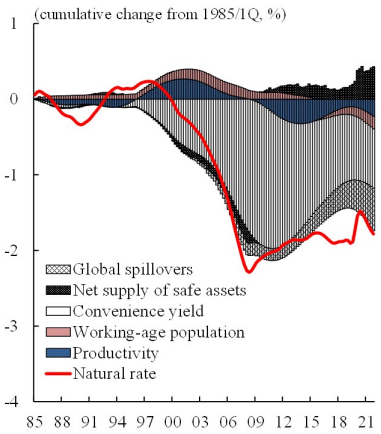
There are two features in particular shared by each economy. First, according to the results from (a), it is implied that global factors such as convenience yield and global spillovers from overseas real factors pushed the natural rate of interest down to some extent. In this regard, Zhang et al. (2021) also suggest that, in addition to domestic factors, the effect from global factors cannot be ignored in terms of the fluctuation in the natural rate of interest, as this paper demonstrates.[18] For the natural rates of interest estimated without taking into account global

[17] It is possible that other channels of globalization have affected the natural rate of interest, besides the change in sensitivity of the natural rate of interest to global factors, such as the progress globalization has prompted in immigration inflows with changes in the working-age population ratio, or changes in productivity through higher integration of goods and capital markets. However, we do not consider those channels in this paper.

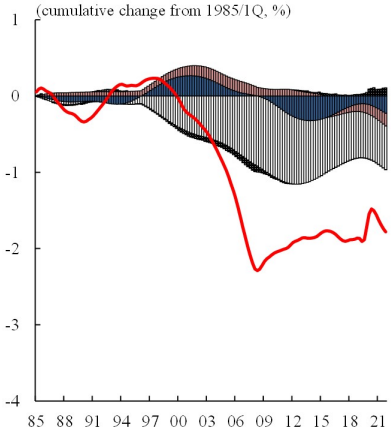
[18] That paper analyzed fluctuations in the natural rate of interest in 6 countries (Australia, Canada, South Korea, Sweden, Switzerland, and the UK) using the forecast error variance decomposition. The results suggest that foreign productivity shocks can explain 13-60% of the fluctuations in the natural rate of interest forecast within the short-term (one quarter ahead), and more than 60% for the long-term forecast (more than two years ahead). On the other hand, this paper suggests that global factors can explain on average 53% of the cumulative change in the natural rate of interest since the first quarter of 1985 (in particular, the US is the highest, at about 70%). The results of Zhang et al. (2021) are different from ours for the following reasons: they use different countries and regions for their analysis; they only use productivity, output abroad, and preference (which is the unobserved exogenous shock that would

Figure 13. Decomposition of the Natural Rate of Interest (US)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant



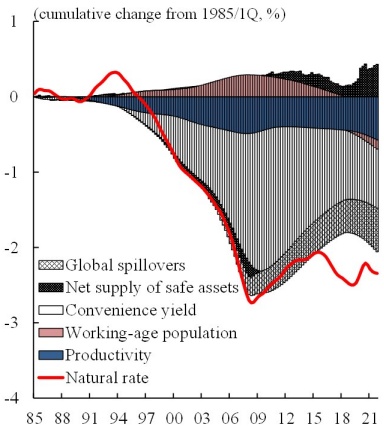
factors, as in Laubach and Williams (2003) and all subsequent studies, there are contributions that cannot be explained only by changes in the potential growth rate. This suggests that those contributions can be explained by global factors, to some, not insignificant, extent.

Second, by comparing (a) and (b), downward pressures were significantly affected by the regime change along with the progress of globalization. Specifically, without the coefficient change in global factors driven by globalization, it is suggested that the natural rate of interest was about 0.4% points higher on average for the 35 years since 1985. When we look carefully at the differences in the degree of contribution, convenience yield is 0.2% points, global spillovers from overseas real factors is 0.5% points, and net supply of safe assets is -0.3% points. Based on these results, it is clear that we can understand the degree of the decline in the natural rate of interest and the reasons behind it more clearly if we appropriately incorporate regime change along with globalization.

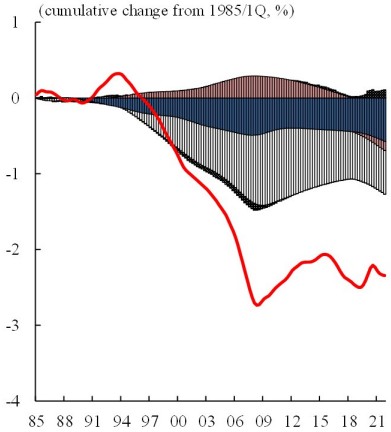
fluctuate the discount factor of domestic households) as explanatory variables; and the data used was until the first quarter of 2018, excluding the COVID era, for example.

Figure 14. Decomposition of the Natural Rate of Interest (euro area)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant



Next, moving on to the features of each economy. First, in Japan, the cumulative decline is bigger than the US and the euro area because of the downward pressure from domestic factors (−1.8% points cumulatively in 1985-2022). In particular, it is apparent that the aging population has lowered the natural rate of interest since the 2000s. This point was also suggested by Sudo et al. (2018), who argue that demographics was one of the factors that pushed the natural rate of interest down after the 2000s.

For the US, the contribution of domestic factors is not so marked (−0.4% points). Productivity since the global financial crisis and the working-age population ratio since around 2016 have lowered the natural rate of interest, but they are marginal. On the other hand, the contribution from global factors, especially global spillovers from overseas real factors, contributed much more significantly compared with other economies.[19] This is probably because the US

[19]For convenience yield, as we discussed in Section 2.1.2, international arbitrage is premised, and we assume that it can converge in the long term among the economies. Therefore, even though the data used is technically for the US, we can interpret it as the global convenience yield, which is a global factor and not a domestic factor for the US. In addition, for the net supply of safe assets, although we use the US Treasury data, based on the effect of demand from other economies, mainly from emerging economies, we take it to be a global factor.

"imports" the effects of the decline in productivity and population aging from Japan and the euro area through the strong linkage in trade transactions, and these bring downward pressure onto the natural rate of interest. From the perspectives of Japan and the euro area, as the literature shows (such as Brand et al. 2022 and Gagnon et al. 2016), the decline in the natural rate of interest was mitigated somewhat through the following mechanism: the downward pressure from population aging was diminished through capital outflows to economies with a higher younger population ratio and higher potential growth rate.

For the euro area, although downward pressure from productivity among domestic factors has been prolonged (ECB 2021), the negative contribution from the working-age population ratio is relatively small. This is probably because the immigration inflow is mitigating the decline of the working-age population ratio (Freier et al. 2023). On the other hand, among global factors, the euro area "imports" the effect of productivity decline and population aging in the UK through the strong linkage in trade, and this is part of the global spillover from overseas real factors which pushes down the natural rate of interest.

4.3 Robustness Checks

We conduct robustness checks of the baseline estimation considering the three following viewpoints and confirm that we can acquire mostly the same results as the baseline. First, to check the robustness of measurement of the demand and supply of safe assets, in Appendix B.1, we re-estimate the model with the demand and supply of safe assets separately as explanatory variables and confirm that we can replicate the result.

Second, as we reviewed in Section 2, there are various alternative methods of measurement for demographics. In Appendix B.2, we re-estimate the model with life expectancy instead of working-age population ratio and confirm the robustness of the effect of fluctuations in demographics on the natural rate of interest.

Third, we look into the uncertainty regarding the transition variable. In the baseline

estimation, we used external financial assets and liabilities as a proxy variable for the degree of globalization, but there is no consensus as to how to measure globalization. Hence, in Appendix B.3, we re-estimate the model using the time trend as a transition variable, based on the assumption that globalization progressed linearly with simply a time trend. We confirm the same implication as the baseline.

5 Implications for the Outlook of the Natural Rate of Interest

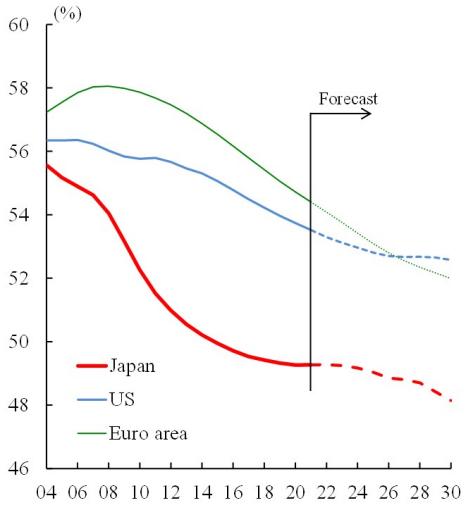
So far, we have analyzed the factors contributing to fluctuations in the natural rate of interest, focusing on the discussion regarding globalization. One of the advantages of this type of qualitative evaluation based on factor-reductionism is that, even if it is difficult to forecast developments in the natural rate of interest itself, when the factors that determine movements can be relatively easily identified, we can acquire some implications for forecasts of the natural rate of interest based on the outlook of its determinants. In the following, we estimate the upward/downward pressure of the working-age population ratio and the net supply of safe assets – since the forecasts for these are made by several organizations and highly likely to fluctuate – on the future natural rate of interest in Japan, the US, and the euro area, to gain implicit indications regarding the future direction of the natural rate of interest. Note that productivity and convenience yield are assumed to be constant from now on.

First, we estimate the working-age population ratio based on the figures forecast by the United Nations. According to Figure 15, which plots the forecast figures until 2030, the working-age population ratio is predicted to decline continuously for all economies. Due to this worldwide decline in the working-age population ratio (Carvalho et al. 2016), natural rates of interest will face downward pressure stemming from both domestic factors and global spillovers from overseas real factors.

If we look carefully at the features, the speed of the decline is slightly different among our three economies, even though it is said to be "slow moving" (Powell 2024). Compared

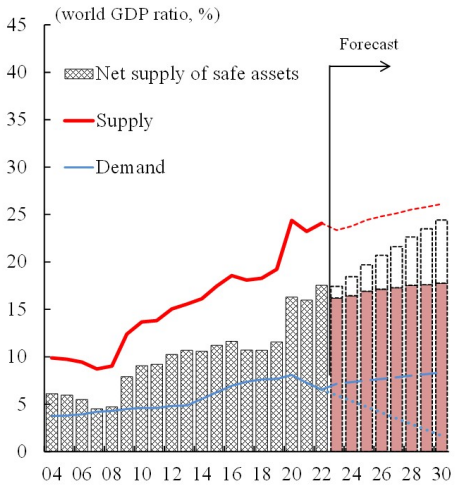
with Japan, which has already seen a significant decline, and the US, which is experiencing a gradual decline, the euro area is forecast to decline at a relatively high speed.

Figure 15. Working-age Population



Note: Forecast is based on "World Population Prospects 2022" published by the United Nations. Working-age is from 20-60 years-old.
Source: United Nations

Figure 16. Net Supply of Safe Assets



Note: Forecast of supply is based on the outlook of the US public gross debt provided by the CBO, as of February 2024, as a percentage of world GDP using the weight of the US (the average from 2004 to 2022) compared with world GDP. Forecast of demand consists of two scenarios: in the upside demand scenario, demand will increase in line with the 1980-2019 trend; in the downside demand scenario, demand will decrease gradually until 2030, reaching the 1995 level.
Source: CBO; IMF; HAVER

As for the supply of safe assets, we estimate this based on the forecast for the US public debt balance by the Congressional Budget Office (CBO). According to Figure 16, the supply of the US Treasury is assumed to continue increasing until 2030, due to the increase in social security expenditure led by the aging population.[20]

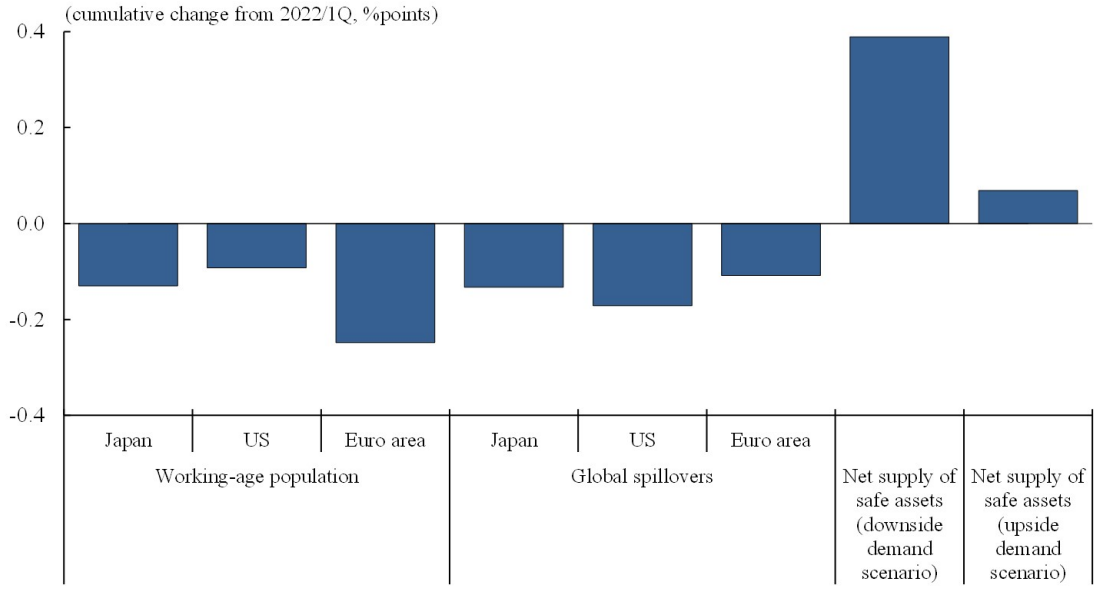
Lastly, as for demand for safe assets, since there is no forecast available, we assume two scenarios: an upside demand scenario – where demand will converge and increase along with the trend of 1980-2019, and a downside demand scenario – where demand will decrease

[20] In addition, Obstfeld (2023) mentions the increase in investments related to green transformation and defense as also contributing to the US public debt balance.

gradually until 2030, reaching the 1995 level.[21] Please note that the net supply of safe assets will increase because of the increase in the supply of safe assets, in both of the two scenarios (Williams 2018a).

Based on the forecasts explained above, Figure 17 shows the estimation of how each variable, namely, working-age population ratio, global spillovers from overseas real factors,[22] and the net supply of safe assets, will cumulatively affect the natural rate of interest in the future for the period from the first quarter of 2022 to the fourth quarter of 2030.

Figure 17. Forecast upward and downward pressure on the natural rate of interest



Firstly, the decline in domestic working-age population ratios will put downward pressure on the natural rate of interest in all three economies. Comparing the size of the pressure, the euro area will see a bigger effect than Japan and the US, more than −0.2% points greater,

[21] The 1995 level assumed to be reached in 2030 in the downside demand scenario is the level of demand for safe assets the US saw before the Asian currency crisis and before globalization had progressed as far as it now has.

[22] In estimating the forecast of global spillovers from overseas real factors, productivity for each economy is set to be constant at the values for the first quarter of 2022, and the working-age population ratio will change along with the forecast by the United Nations. Hence, the global spillovers from overseas real factors mentioned herein is limited to spillovers from the change in the foreign working-age population ratio.

reflecting the speed of future population aging.[23]

Secondly, the decline in the working-age population ratio can work as an additional downward pressure because it will be contained in the global spillovers from overseas real factors. The downward pressure led by the global spillovers from overseas real factors will be greatest in the US, since the decline due to population aging in the euro area will spillover to the US through the strength of trade linkages.

Lastly, the net supply of safe assets will push the natural rate of interest upward since both the two scenarios assume supply will exceed demand. However, the size of the upward pressure will be different to some extent, depending on the demand scenario. For the downside demand scenario – the upside scenario for the net supply of safe assets – it will be cumulatively +0.4% points, whereas for the upside demand scenario – the downside scenario for the net supply of safe assets – it will be cumulatively just less than +0.1% points.

Based on the outlook provided above, it is estimated that the cumulative pressures on future natural rates of interest will be nearly balanced in Japan and the US, while the pressures are leaning more towards the downside in the euro area (cumulatively −0.2 to +0.1% points in Japan and the US, and −0.3 to +0.0% points in the euro area).

There are several points that should be noted regarding the estimates in this section. First, we account only for the variables that can be assumed with relatively probable forecasts, even though there are thought to be many other factors affecting the natural rate of interest. To look closely at the forecast for future natural rates of interest, uncertainties regarding long-term productivity for each economy (e.g. the penetration of AI and digital transformation) need to be taken into account. Additionally, as globalization progresses, the impact from convenience yield on the natural rate of interest is increasing, and consideration of further fluctuations in convenience yield is crucial in studying the natural rate of interest. If productivity and

[23] The result that the natural rate of interest in the euro area will decline due to demographics at least until 2030 is in alignment with the results in Brand et al. (2022).

convenience yields fluctuate greatly, then the natural rate of interest may follow a dynamic movement deviating from the estimation result of this section. One final caveat is that there are still many undetermined factors, not least uncertainty about the estimated value of the natural rate of interest itself, and it is possible that the relationship between the natural rate of interest and the various factors might be transformed due to further regime changes.

6 Conclusion

This paper examines the effect of globalization on the natural rate of interest by introducing the concept of non-linear regime change, which previous literature has not taken into account. Specifically, using the global financial integration index as a transition variable, we employ the ST model to estimate changes in the impact and sensitivity of global factors on the natural rate of interest. As a result, global factors including global spillover from overseas real factors, net supply of safe assets, and convenience yield have become non-linearly more influential on the natural rate of interest since around 2000, and they have played a major role in driving the common decline trend seen worldwide. In addition, the results provided in this paper suggest three further issues: First, through stronger linkages in trade transactions and financial markets due to the progress of globalization, foreign real factors are more easily imported; second, international arbitrage in interest rates among financial markets is functioning; and third, the degree of global co-movement regarding the natural rate of interest has increased through these mechanisms.

Based on these results, the spillover mechanism of global real factors, and their increasing impact, should be taken into account when analyzing the natural rate of interest, by, for example, using an open-economy model rather than a closed-economy model. Particularly, when the estimation includes periods of significant globalization in trade and financial markets, as exemplified by China joining the WTO, there could be a risk of misunderstanding the correct paths unless we model the relationship between the natural rate of interest and global factors

appropriately by incorporating regime change.

We conclude here with some caveats and further research ideas. Recently, several studies point out the possibility that the short-term natural rate of interest is rising, reflecting worldwide high inflation in the post-COVID era, speedy rate hikes with the intention of fighting inflation, economies remaining resilient despite the hikes, and the increase in investment in reshoring due to higher geopolitical risks (Baker et al. 2023, Schnabel 2024, Benigno et al. 2024). Since we focus on the long-term natural rate of interest, this paper has few implications for this kind of discussion. In addition, because of data limitations, our estimation period is until the first quarter of 2022. It is therefore beyond the scope of this paper to examine the effect on the natural rate of interest of the rate hike by the Federal Reserve in March 2022, and higher geopolitical risks triggered by Russia's invasion of Ukraine in February 2022.

Additionally, uncertainties regarding the estimated value and the contributing factors are so great that they cannot be ignored, regardless of the countries being considered. It should be noted that differences in estimation methods, such as assumptions about economic structure and methods for measuring the degree of globalization, can produce a considerable range of estimation results. Besides, the reason the estimation in this paper starts from 1985 is to take into consideration the Plaza Accord, which was agreed in that year, being one of the most significant events in the context of international finance. If the regime changed around the Plaza Agreement, it is quite difficult to capture at the same time its non-linear effect and the regime change that happened around 2000. Taking this into consideration and analyzing much longer time periods would be one way to further investigate what we have found in this paper. Moreover, in incorporating the global spillover from overseas real factors, this paper assumes that changes in real factors affect other economies, and we do not directly account for its level. However, if we consider that globalization leads to co-movement of economies and financial markets, then it would also be reasonable to assume that the levels of real factors will converge globally. It is also something we leave for future research.

Appendix A Data Description

We use 5 economies for our estimation: Japan, the US, the euro area, the UK, and Canada. The estimation period is from the second quarter of 1985 to the first quarter of 2022, which is when the data for productivity is available. We use the values estimated in Ferreira and Shousha (2023) for the natural rate of interest, with interpolating data to make them quarterly variables by spline method. For productivity, we use year-on-year growth of GDP per working hour for each economy. Specifically, we use HP-filtered (λ=2,500) trend values after interpolating data of GDP growth per working hour provided by the Long-Term Productivity Database (Bergeaud et al. 2016). For data on demographics, we use yearly data provided by the United Nations' "World Population Prospects 2022" and interpolate them to quarterly data by spline method. The trade weights needed for calculating the global spillovers from overseas real factors are based on weights of effective exchange rates provided by BIS (broad-based, 2017-2019). As for convenience yield, we use the median value of the spread calculated by subtracting the yield of US Treasuries with the same maturity (5 years pitch) from the effective rate of IG bonds, following most of the previous literature (Krishnamurthy and Vissing-Jorgensen 2012, Del Negro et al. 2017, Del Negro et al. 2019, Ferreira and Shousha 2023, etc.). For the missing values, we interpolate them with the spread of Moody's AAA bond yield and the yield of 20-year maturity US Treasury. To obtain the trend, we use an HP filter with a smoothing parameter of 10,000.[24] For the net supply of safe assets, we use the ratio of the difference between the supply and demand of safe assets to world GDP. Here, the supply of safe assets is the value of the US public debt balance subtracted from the non-marketable balance (such

[24]The fluctuation of this variable can contain the effect of fluctuation in the private sector's credibility risk. However, by considering the possibility that the credibility spread moves together with the business cycle, and by extracting the HP trended factor, the short-term volatility of credibility spread is removed to some extent. Also, Del Negro et al. (2017) judge that the average probability of default does not have a clear trend and ignore the default risk, then use nearly the same convenience yield data as ours for estimation.

as government holdings).[25] For the demand of safe assets, out of many possible alternatives, we narrow down the scope to the balance of foreign reserves.[26]

Appendix B Robustness Checks

B.1 Using Both Demand and Supply of Safe Assets as Explanatory Variables

First, to check the robustness of measurement of the demand and supply of safe assets, we re-estimate the model with the demand and supply of safe assets separately as explanatory variables. According to Table B.1, we obtain nearly the same as in the baseline results. The signs of coefficients are the same as we expect from economic theories, and the result implying that the sensitivities of global factors rise as regime changes is the same as we discussed. Also, the period of regime change is the same as in the baseline result, which is from the late 1990s to the early 2000s as shown in Figure B.1. We reconfirm that global factors went through a rise in sensitivity along with regime change and put downward pressure on the natural rate of interest, as shown in Figure B.2, Figure B.3, and Figure B.4.[27]

[25] We obtained data of the US Treasury from HAVER.

[26] We obtained data regarding the US dollar-based foreign reserves compiled by the IMF from HAVER.

[27] As in the baseline results, the natural rate of interest depicted by the red line in (a) and (b) are actual values. Decomposition is depicted without error terms, therefore, the sum of the stacked bar graphs and the line graph are not the same. This is also the case below.

Table B.1. Estimation Results

		ST model		Regression model
		Regime 1	Regime 2	(Supplementary)
Domestic variables	Productivity	0.301		0.327
		(0.022)		(0.040)
	Working-age population	0.095		0.080
		(0.019)		(0.017)
Global variables	Convenience yield	-0.752	-1.979	-1.393
		(0.082)	(0.242)	(0.090)
	Supply of safe assets	0.014	0.054	0.041
		(0.005)	(0.003)	(0.003)
	Demand of safe assets	-0.005	-0.108	-0.073
		(0.027)	(0.088)	(0.008)
	Global spillovers	0.000	0.786	0.633
		–	(0.088)	(0.240)
Parameters of transition function	Threshold of regime change	0.678		–
		(0.007)		
	Speed of regime change	67.667		–
		(29.744)		

Notes: Standard errors are in brackets. "ST model" is the result of Equation (4) and "Regression model" is the result of Equation (2). "Global spillovers" in "ST model" is restricted between 0 and 1 following Ferreira and Shousha (2023) and the value for "Regime 1" is 0 as a result of this treatment. Therefore, the standard error for "Global spillovers" of "Regime 1" is not written.

Figure B.1. Transition Function

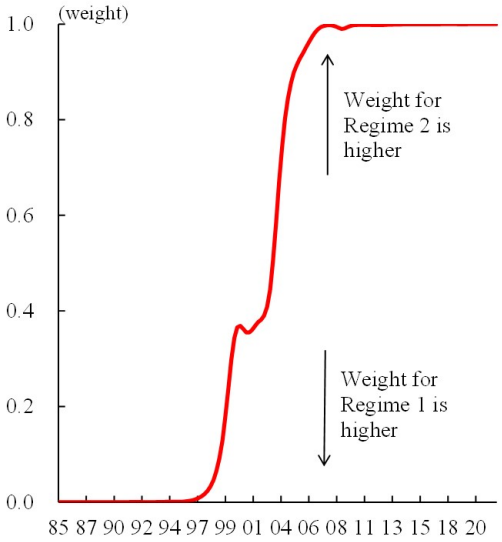
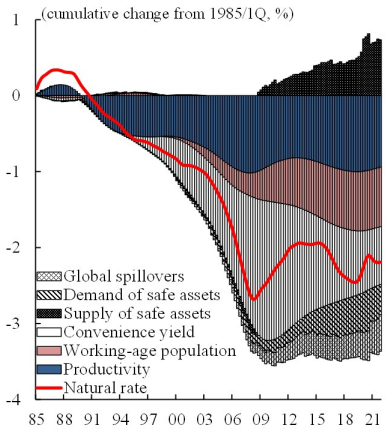


Figure B.2. Decomposition of the Natural Rate of Interest (Japan)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant

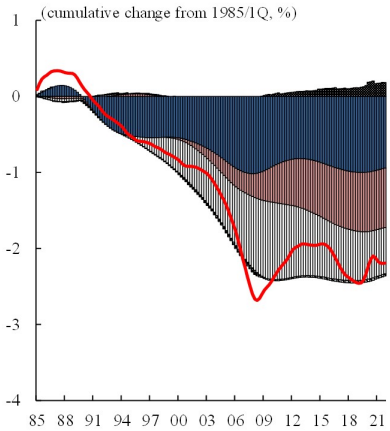
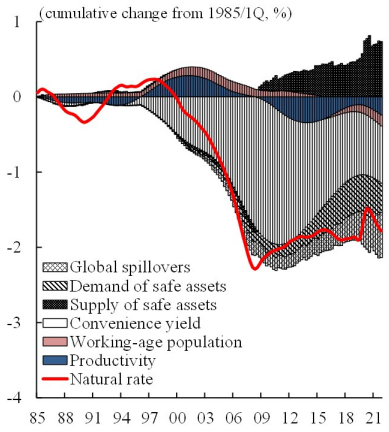


Figure B.3. Decomposition of the Natural Rate of Interest (US)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant

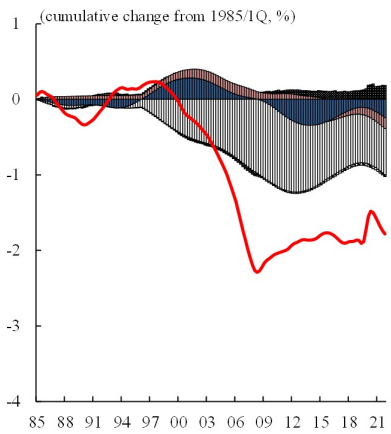
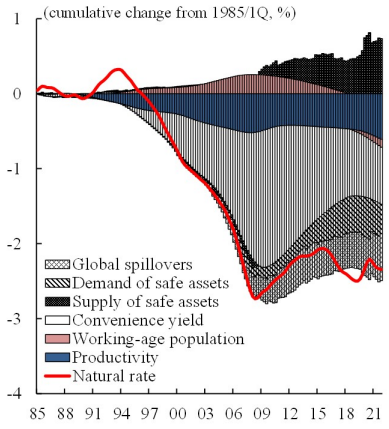
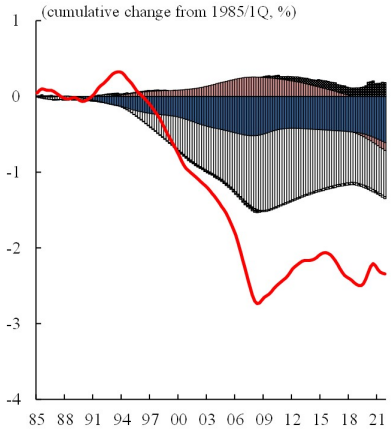


Figure B.4. Decomposition of the Natural Rate of Interest (euro area)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant



B.2 Changing the Variable for Demographics to Life Expectancy

Demographic change has long been considered an important factor contributing to fluctuations in the natural rate of interest, but there is no consensus regarding which variable can proxy demographics in the actual estimation. In addition, as we discussed in Section 2.2.2, there is much debate regarding the sign of the effect of longevity on the natural rate of interest. From the baseline results, it was suggested that the decline in the working-age population ratio, which is equivalent to the progress of population aging, has been lowering the natural rate of interest. For the following, we will use life expectancy instead of working-age population ratio for the robustness check and reconfirm the implications we obtained in the baseline model. Table B.2 provides the estimation result. It shows that the sign of coefficient of life expectancy is negative, therefore implying that, as population aging progresses, the natural rate of interest is reduced. For other variables, we could reconfirm that the signs of coefficients align with economic theories, and the absolute values of coefficients of global factors become greater as regime changes, as we have observed in the baseline results. Also, for the transition function, Figure B.5 implies that the regime change was non-linear from the late 1990s to the early 2000s, as we have seen in the baseline result. In addition, the results of historical decompositions for Japan, the US, and the euro area shown in Figures B.6, B.7, and B.8, are basically the same as in the baseline results. Compared with the baseline results, the degree of influence of life expectancy is rather smaller than that of working-age population ratio, and this feature is also mentioned in some of the previous literature (Lunsford and West 2019 and Carvalho et al. 2023).

Table B.2. Estimation Results

		ST model		Regression model
		Regime 1	Regime 2	(Supplementary)
Domesticl variables	Productivity	0.308		0.338
		(0.032)		(0.026)
	Life expectancy	-0.048		-0.036
		(0.008)		(0.012)
Global variables	Convenience yield	-0.635	-1.652	-1.250
		(0.102)	(0.122)	(0.071)
	Net supply of safe assets	0.015	0.042	0.034
		(0.005)	(0.003)	(0.003)
	Global spillovers	0.000	0.782	0.498
		–	(0.189)	(0.074)
Parameters of transition function	Threshold of regime change	0.678		–
		(0.007)		
	Speed of regime change	76.946		–
		(32.890)		

Notes: Standard errors are in brackets. "ST model" is the result of Equation (4) and "Regression model" is the result of Equation (2). "Global spillovers" in "ST model" is restricted between 0 and 1 following Ferreira and Shousha (2023) and the value for "Regime 1" is 0 as a result of this treatment. Therefore, the standard error for "Global spillovers" of "Regime 1" is not written.

Figure B.5. Transition Function

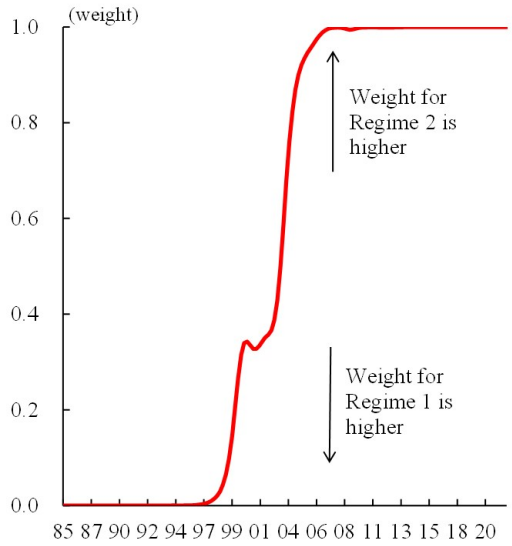
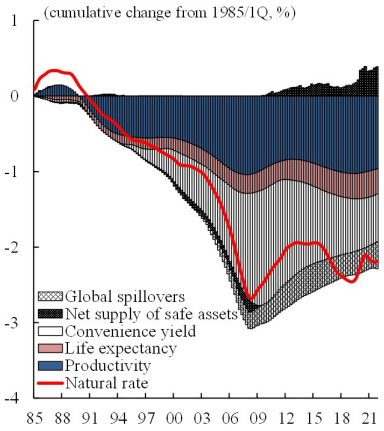


Figure B.6. Decomposition of the Natural Rate of Interest (Japan)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant

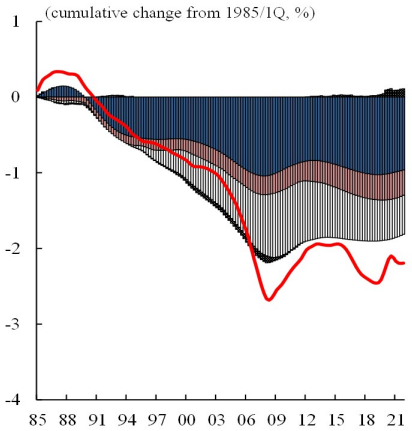
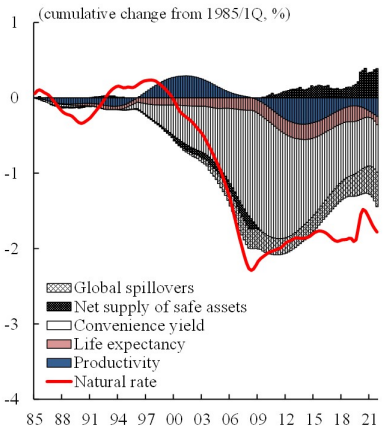


Figure B.7. Decomposition of the Natural Rate of Interest (US)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant

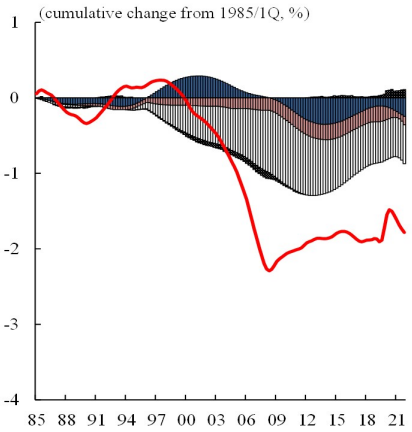
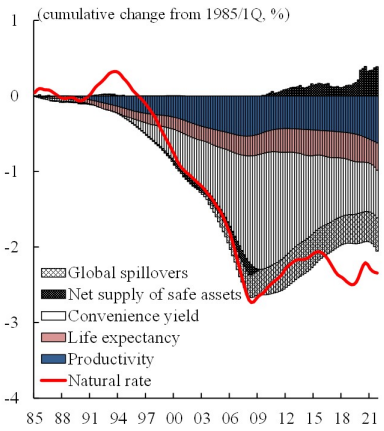
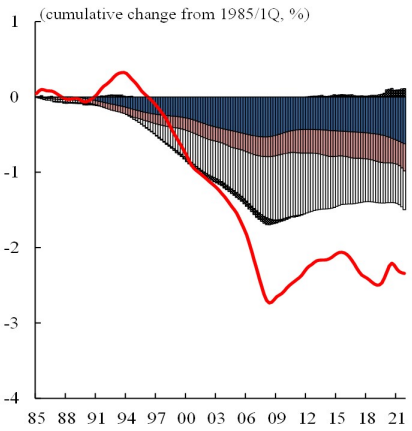


Figure B.8. Decomposition of the Natural Rate of Interest (euro area)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant



B.3 Using Time Trend as Transition Variable

In the baseline model, we have employed the ST framework which uses the global financial integration index as the transition variable and have endogenously obtained the result that in the transition from Regime 1 to Regime 2, the change in the natural rate of interest was both rapid and non-linear. To check the robustness of the existence of structural change, we re-estimate the model using time trend – a series that increases by a constant number each period from the beginning to the end of the estimation period – as the transition variable, which makes the model much simpler to interpret. As a result, we get mostly the same result as shown in Table B.3. In particular, the signs of the coefficients are the same as expected from economic theories, and the sensitivities of global factors increase as regime changes. Moreover, the period when the regime change occurred is from the late 1990s to the early 2000s, as shown in Figure B.9, and this is the same result as in the baseline result. In addition, as shown in the Figures B.10, B.11, and B.12, the factors that cause fluctuations in the natural rate of interest in Japan, the US, and the euro area confirm once again that global factors have pushed down the natural rate of interest, accompanied by an increase in sensitivity due to regime change.

Table B.3. Estimation Results

		ST model		Regression model
		Regime 1	Regime 2	(Supplementary)
Domestic variables	Productivity	0.279		0.319
		(0.028)		(0.039)
	Working-age population	0.109		0.088
		(0.017)		(0.022)
Global variables	Convenience yield	-0.605	-1.957	-1.446
		(0.174)	(0.099)	(0.109)
	Net supply of safe assets	0.016	0.046	0.037
		(0.005)	(0.003)	(0.003)
	Global spillovers	0.000	0.686	0.600
		–	(0.113)	(0.213)
Parameters of transition function	Threshold of regime change	0.420		–
		(0.019)		
	Speed of regime change	25.269		–
		(8.480)		

Notes: Standard errors are in brackets. "ST model" is the result of Equation (4) and "Regression model" is the result of Equation (2). "Global spillovers" in "ST model" is restricted between 0 and 1 following Ferreira and Shousha (2023) and the value for "Regime 1" is 0 as a result of this treatment. Therefore, the standard error for "Global spillovers" of "Regime 1" is not written.

Figure B.9. Transition Function

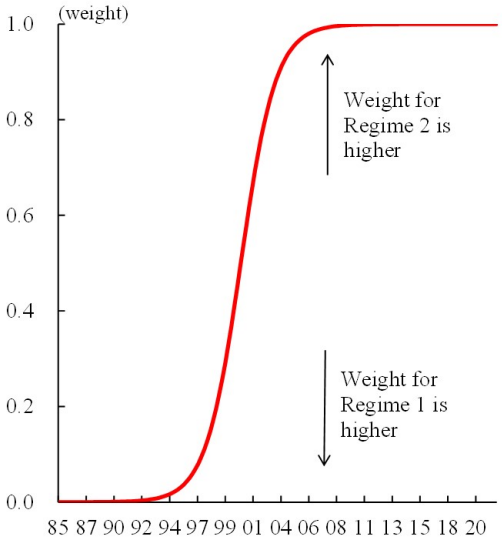
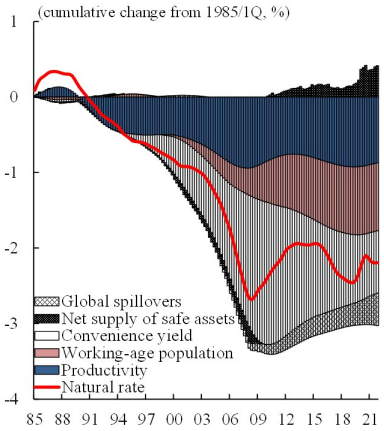


Figure B.10. Decomposition of the Natural Rate of Interest (Japan)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant

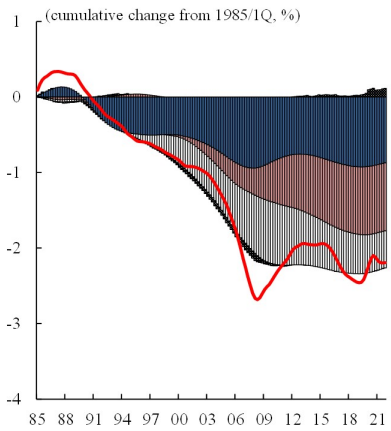
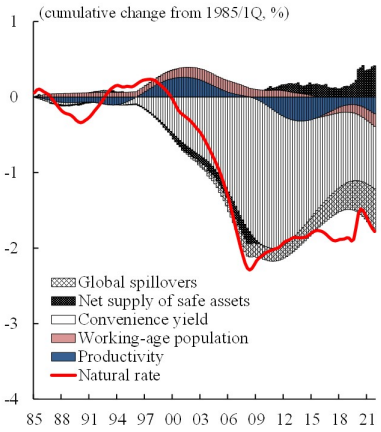


Figure B.11. Decomposition of the Natural Rate of Interest (US)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant

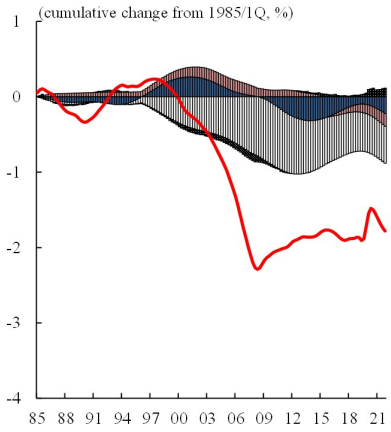
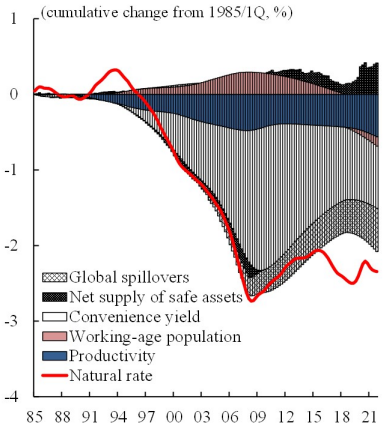
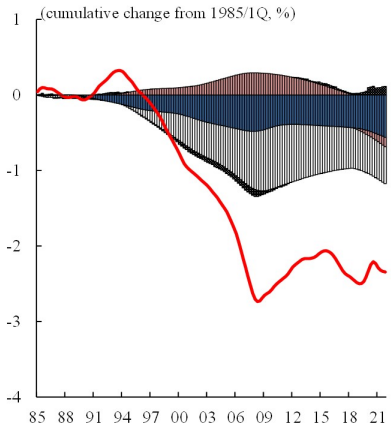


Figure B.12. Decomposition of the Natural Rate of Interest (euro area)

(a) Actual Decomposition



(b) Global Variables Coeffs Constant



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