The International Finance Multiplier in Business Cycle Fluctuations*

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Abstract

In the wake of the "Great Recession" of 2007–09, recent studies have emphasized the importance of the international finance multiplier mechanism—whose idea was originally proposed by Calvo (2000) and formulated by Krugman (2008)—for international business cycles, using calibrated two-country models with financial frictions. This paper empirically investigates the business cycle implications of the mechanism by estimating a two-country financial accelerator model with 23 quarterly time series from the Euro Area (EA) and United States. The estimation results show that financial shocks originating in the US were transmitted to the EA through the international finance multiplier mechanism—which induces pressure for the equalization of external finance premiums across economies—and had an impact on both the EA and US business cycle fluctuations through the financial accelerator mechanism during the past two decades. Moreover, adverse US financial shocks and an adverse EA neutral technology shock explained more than half of the fall in EA and US output growth during the Great Recession and EA neutral technology growth is highly correlated with the net tightening of credit standards by EA banks.

Keywords: International finance multiplier mechanism; Financial accelerator mechanism; External finance premium; Financial shock; Business cycle fluctuation

JEL Classification: F3; F4

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1 Introduction

The "Great Recession" of 2007–09 highlighted the critical role of investors and financial institutions in the international propagation of shocks originating in one country. Allegedly their global investment activities brought about macroeconomic interdependence among countries through financial markets and gave rise to synchronization of business cycle fluctuations in these countries. Krugman (2008) refers to this mechanism as the "international finance multiplier," an idea originally proposed by Calvo (2000) in regard to the Russian crisis in the late 1990s.[1] Recent studies have thus emphasized the importance of this mechanism for international business cycles, using calibrated two-country models with financial frictions.[2] Devereux and Yetman (2010) show that the presence of Kiyotaki and Moore (1997)-type leverage-constrained investors, in combination with their internationally diversified portfolios, introduces a powerful financial transmission channel that results in comovement of output in two countries, independently of the size of international trade linkages. Dedola and Lombardo (2012), using a calibrated two-country model augmented with the financial accelerator mechanism of Bernanke, Gertler, and Gilchrist (1999), indicate that in the presence of investors who search for the same expected return across internationally traded assets, an adverse shock to the investors' net worth in one country raises external finance (EF) premiums in both countries and induces simultaneous contraction in these countries.

This paper empirically investigates the implications of the international finance multiplier mechanism for business cycle fluctuations. Specifically, the paper incorporates the financial accelerator mechanism of Bernanke, Gertler, and Gilchrist (1999)—through

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[1] Krugman (2008) names international business cycle linkages through financial markets the *international finance multiplier* after Robinson (1952), who calls international business cycle linkages through trade of goods and services the *foreign trade multiplier*.

[2] Perri and Quadrini (2011) develop a two-country model with financial frictions and show that a credit contraction can emerge as a self-fulfilling equilibrium caused by pessimistic but fully rational expectations and that, as a consequence of such a credit contraction, countries in a financially integrated world experience large and endogenously synchronized declines in asset prices and economic activity.

which variations in the EF premium amplify business cycle fluctuations—and the international finance multiplier mechanism modeled by Dedola and Lombardo (2012)—which induces pressure for the equalization of EF premiums across countries—in a variant of the two-country model of Ireland (2013), and estimates this model with 23 quarterly time series from the Euro Area (EA) and United States (US): output, consumption, investment, labor, wages, consumption prices, relative prices of investment, monetary policy rates, loans, net worth, EF premiums, and the exchange rate.

The main results of this analysis are twofold. First, financial shocks—shocks to investors' net worth and the EF premium—originating in the US were transmitted to the EA through the international finance multiplier mechanism and had an impact on both the EA and US business cycle fluctuations through the financial accelerator mechanism during the past two decades. US financial shocks explained about 11% and 4% of the variances of US investment and output growth during the sample period of 1985:1Q–2009:4Q and around 6% and 1% of the EA counterparts. Second, adverse US financial shocks and an adverse EA neutral technology shock accounted for more than half of the fall in EA and US output growth during the Great Recession of 2007:4Q–2009:2Q. The estimated series of EA neutral technology growth is (negatively) highly correlated with the series of the net tightening of credit standards by EA banks in The Euro Area Bank Lending Survey. Therefore, the estimated EA neutral technology shock is likely to represent a fundamental disturbance to the functioning of the EA banking sector.

In the literature, the most closely related, complementary study has been done by Kollmann (2012). He estimates the two-country real business cycle model with a global bank developed by Kollmann, Enders, and Müller (2011), using 12 quarterly time series: output, consumption, investment, labor, and loans of the EA and US and the loan rate spread and capital ratio of US commercial banks. His estimation results show that "banking shocks"—shocks to loan losses in the EA and US and the required capital ratio—explained about 6% and 3% of the variances of HP-filtered investment and output in the US during the sample period of 1990:1Q–2010:3Q and around 23% and 4% of the EA counterparts. Moreover, banking shocks accounted for about 12% and 16% of the fall in EA and US HP-filtered output during the Great Recession of 2007:4Q–2009:2Q.

Our study differs markedly from Kollmann's, mainly along two dimensions. First, our study uses non-detrended data to estimate not only parameters but also trends in a model for non-stationary variables that grow at rates of neutral and investment-specific (IS) technological changes, whereas his study employs HP-filtered data to estimate a model for stationary variables. This difference may yield the differing implications for EA and US business cycle fluctuations. Our strategy of modeling and estimation is of crucial importance in examining business cycle implications, since estimates of trends in technological changes determine those of trends in data for estimation and hence the magnitude and direction of the business cycle component of the data. Second and more importantly, Kollmann's financial frictions focus on the supply side of loans (i.e., global banks), whereas ours arise from the financial accelerator mechanism of Bernanke, Gertler, and Gilchrist (1999) and thus draw attention to the demand side of loans (i.e., investors). Taking into consideration the fact that the financial system is bank-based in the EA, while it is market-based in the US,[3] the difference in the source of financial frictions may cause the gap between his and our empirical results: his banking shocks affect EA business cycle fluctuations more than US ones, whereas our financial shocks affect US business cycle fluctuations more than EA ones. Our EA neutral technology shock that is likely to represent a disturbance to the EA banking sector, however, fills this gap or more.

The remainder of the paper proceeds as follows. Section 2 describes a two-country model with an international finance multiplier mechanism. Section 3 presents strategy and data for estimating the model. Section 4 explains results of empirical analysis.

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[3] In the EA, the shares of financial assets of depository corporations, insurance and pension funds, and other financial intermediaries in the total financial assets of financial intermediaries are around 60%, 15%, and 25%, while the US counterparts are about 25%, 30%, and 45%.

Section 5 concludes.

2 The two-country model with the international finance multiplier mechanism

In a variant of the two-country model of Ireland (2013), the present paper incorporates the financial accelerator mechanism of Bernanke, Gertler, and Gilchrist (1999) and the international finance multiplier mechanism modeled by Dedola and Lombardo (2012). The main feature of this model is the presence of investors who search for the same expected return on capital across two countries.

The model consists of home and foreign countries. In each country there are a representative household that consists of worker and investor members, financial intermediaries, intermediate-good firms, consumption-good firms, investment-good firms, capital-good firms, and a central bank. Each country has the same structure and thus the following exposition focuses on the home country. Foreign variables are denoted by an asterisk.

2.1 The representative household

In the representative household, there is a continuum of members. Some members are workers $m \in [0,1]$ and others are investors, but it is assumed as in Andolfatto (1996) and Merz (1995) that all members pool consumption and make joint consumption-saving decisions to avoid distributional issues. The household derives utility from purchasing consumption goods C_t and disutility from supplying differentiated labor services $\{h_t(m)\} = \{\int_0^1 h_t(m,f)df\}$ to intermediate-good firms $f \in [0,1]$. This household's preferences are then represented by the utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t \exp(z_{b,t}) \left[\log\left(C_t - bH_t\right) - \exp(\tilde{z}_{h,t}) \int_0^1 \frac{\left(h_t(m)\right)^{1+\chi}}{1+\chi} dm \right],$$

where E_t is the expectation operator conditional on information available in period t, H_t is equal to home aggregate consumption in the previous period $t-1$, $\beta \in (0,1)$ is the subjective discount factor, $b \in [0,1]$ is the degree of external habit persistence in consumption preferences, $\chi > 0$ is the inverse of the elasticity of labor supply, and $z_{b,t}$ and $\tilde{z}_{h,t}$ represent an intertemporal preference shock and a labor shock, respectively. The household's budget constraint is given by

$$\begin{aligned}&P_t C_t + D_{H,t} + e_t^n B_{H,t}^* \\ &= \int_0^1 P_t W_t(m) h_t(m) dm + r_{t-1} D_{H,t-1} + e_t^n r_{t-1}^* \exp\left(-\phi_e \frac{e_{t-1}^n R_{t-1}}{P_{t-1} Y_{t-1}} + z_{e,t-1}\right) B_{H,t-1}^* + T_t,\end{aligned}$$

where P_t is the price of consumption goods; $D_{H,t}$ is the sum of deposits in financial intermediaries and holdings of home currency denominated one-period bonds; their (gross) interest rates are assumed to be the same, denoted by r_t, which is also assumed to equal the home monetary policy rate; $B_{H,t}^*$ is holdings of foreign currency denominated one-period bonds; its (gross) interest rate is denoted by r_t^*, which is assumed to equal the foreign monetary policy rate; e_t^n is the exchange rate; $W_t(m)$ is worker m's real wage; and T_t consists of profits received from firms and a lump-sum public transfer. The international bond markets are incomplete. Thus, to eliminate non-stationarity induced by this incompleteness, the present paper follows Schmitt-Grohé and Uribe (2003) to introduce a cost of holding foreign currency denominated bonds represented by $\exp\left(-\phi_e e_{t-1}^n R_{t-1}/(P_{t-1} Y_{t-1}) + z_{e,t-1}\right)$, where R_t is equal to home aggregate holdings of foreign currency denominated bonds, Y_t is home output, and $z_{e,t}$ is a disturbance to the cost and represents an uncovered interest rate parity (UIP) shock as explained later.

The first-order conditions for optimal decisions on consumption, home deposits and bond holdings, and foreign bond holdings are given by

$$\Lambda_t = \frac{\exp(z_{b,t})}{C_t - b C_{t-1}}, \tag{1}$$

$$1 = E_t \, \beta \frac{\Lambda_{t+1}}{\Lambda_t} \frac{r_t}{\pi_{t+1}}, \tag{2}$$

$$1 = E_t \, \beta \frac{\Lambda_{t+1}}{\Lambda_t} \frac{r_t^*}{\pi_{t+1}^*} \frac{e_{t+1}}{e_t} \exp\left(-\phi_e \frac{e_t B_{H,t}^*}{P_t^* Y_t} + z_{e,t}\right), \tag{3}$$

where Λ_t is the marginal utility of consumption, $\pi_t = P_t / P_{t-1}$ is the (gross) price inflation rate of home consumption goods, and e_t denotes the real exchange rate given by $e_t = e_t^n P_t^* / P_t$, where P_t^* is the price of foreign consumption goods.

2.1.1 Workers

Under monopolistic competition, intermediate-good firms' demand for worker m's labor services is given by $h_t(m) = h_t(W_t(m)/W_t)^{-(1+\lambda_w)/\lambda_w}$, where $h_t = [\int_0^1 (h_t(m))^{1/(1+\lambda_w)}\, dm]^{1+\lambda_w}$ is an aggregate of differentiated labor services with the substitution elasticity $(1 + \lambda_w)/\lambda_w > 1$ and

$$W_t = \left[\int_0^1 (W_t(m))^{-1/\lambda_w}\, dm \right]^{-\lambda_w} \tag{4}$$

is the corresponding aggregate real wage. Each wage $P_t W_t(m)$ is set on a staggered basis à la Calvo (1983). In each period, a fraction $1-\xi_w \in (0,1)$ of wages is reoptimized, while the remaining fraction ξ_w is set by indexation to both the (gross) steady-state balanced growth rate (explained later), z, and a weighted average of past and steady-state inflation rates, $\pi_{t-1}^{\gamma_w} \pi^{1-\gamma_w}$, where $\gamma_w \in [0,1]$ is a weight on the recent past inflation rate. Then, each wage reoptimized in period t is chosen to maximize

$$E_t \sum_{j=0}^{\infty} (\beta \xi_w)^j \left[\Lambda_{t+j} h_{t+j|t}(m) \frac{P_t W_t(m)}{P_{t+j}} \prod_{k=1}^{j} z (\pi_{t+k-1})^{\gamma_w} (\pi)^{1-\gamma_w} - \exp(z_{b,t+j}) \exp(\tilde{z}_{h,t+j}) \frac{\left(h_{t+j|t}(m)\right)^{1+\chi}}{1+\chi} \right]$$

subject to

$$h_{t+j|t}(m) = h_{t+j} \left[\frac{P_t W_t(m)}{P_{t+j} W_{t+j}} \prod_{k=1}^{j} z (\pi_{t+k-1})^{\gamma_w} (\pi)^{1-\gamma_w} \right]^{-\frac{1+\lambda_w}{\lambda_w}}.$$

The first-order condition for the reoptimized real wage $\bar{W}_t$ is given by

$$\bar{W}_t^{1+\frac{\chi(1+\lambda_w)}{\lambda_w}} = (1+\lambda_w) \frac{E_t \sum_{j=0}^{\infty} (\beta \xi_w)^j \exp(z_{b,t+j}) \exp(\tilde{z}_{h,t+j}) \left\{ \left[\frac{1}{W_{t+j}} \prod_{k=1}^{j} z \left(\frac{\pi_{t+k-1}}{\pi} \right)^{\gamma_w} \frac{\pi}{\pi_{t+k}} \right]^{-\frac{1+\lambda_w}{\lambda_w}} h_{t+j} \right\}^{1+\chi}}{E_t \sum_{j=0}^{\infty} (\beta \xi_w)^j \Lambda_{t+j} \left(\frac{1}{W_{t+j}} \right)^{-\frac{1+\lambda_w}{\lambda_w}} \left[\prod_{k=1}^{j} z \left(\frac{\pi_{t+k-1}}{\pi} \right)^{\gamma_w} \frac{\pi}{\pi_{t+k}} \right]^{-\frac{1}{\lambda_w}} h_{t+j}}. \tag{5}$$

The aggregate wage equation (4) can be reduced to

$$W_t^{-\frac{1}{\lambda_w}} = (1-\xi_w) \bar{W}_t^{-\frac{1}{\lambda_w}} + \xi_w \left[W_{t-1} z \left(\frac{\pi_{t-1}}{\pi} \right)^{\gamma_w} \frac{\pi}{\pi_t} \right]^{-\frac{1}{\lambda_w}}. \tag{6}$$

2.1.2 Investors and financial intermediaries

Investors purchase capital goods $K_{H,t-1}$, $K^*_{H,t-1}$ at real prices Q_{t-1}, $e_{t-1}Q^*_{t-1}$ from home and foreign capital-good firms at the end of the previous period $t-1$, and adjust capital utilization rates u_t, u^*_t to provide capital services $u_t K_{H,t-1}$, $u^*_t K^*_{H,t-1}$ at real rental rates $R_{k,t}$, $e_t R^*_{k,t}$ for home and foreign intermediate-good firms in period t. Capital is depreciated after intermediate-good firms' production, and $\delta(u_t)$, $\delta_*(u^*_t)$ are depreciation rates of capital $K_{H,t-1}$, $K^*_{H,t-1}$. As in Greenwood, Hercowitz, and Huffman (1988), it is assumed that a higher utilization rate of capital leads to a higher depreciation rate of capital. The depreciation rate function $\delta(\cdot)$ ($\delta_*(\cdot)$) thus has properties of $\delta' > 0$, $\delta'' > 0$, $\delta(1) = \delta \in (0,1)$, and $\delta'(1)/\delta''(1) = \tau > 0$ ($\delta'_* > 0$, $\delta''_* > 0$, $\delta_*(1) = \delta_* \in (0,1)$, and $\delta'_*(1)/\delta''_*(1) = \tau_* > 0$). Then, investors sell the resulting capital $(1-\delta(u_t))K_{H,t-1}$, $(1-\delta_*(u^*_t))K^*_{H,t-1}$ to home and foreign capital-good firms at real prices Q_t, $e_t Q^*_t$.

The first-order conditions for optimal decisions on the capital utilization rates are given by[4]

$$R_{k,t} = Q_t \delta'(u_t), \tag{7}$$

$$R^*_{k,t} = Q^*_t \delta'_*(u^*_t). \tag{8}$$

Investors' purchase of capital at the end of each period is financed by their real net worth N_t and by their real loan

$$L_t = Q_t K_{H,t} + e_t Q^*_t K^*_{H,t} - N_t \tag{9}$$

from financial intermediaries at the (gross nominal) loan rate $r_{l,t}$. The first-order conditions for optimal decisions on the purchase of home and foreign capital goods are given

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[4] Since the capital depreciation rate functions do not depend on whether investors are domestic or foreign, so do the capital utilization rates.

by

$$E_t \Lambda_{t+1} x_{t+1} = E_t \Lambda_{t+1} \frac{r_{l,t}}{\pi_{t+1}}, \tag{10}$$

$$E_t \Lambda_{t+1} x^*_{t+1} \frac{e_{t+1}}{e_t} = E_t \Lambda_{t+1} \frac{r_{l,t}}{\pi_{t+1}}, \tag{11}$$

where x_t, x_t^* are ex-post marginal returns on home and foreign capital given by

$$x_t = \frac{u_t R_{k,t} + Q_t \left(1 - \delta(u_t)\right)}{Q_{t-1}}, \tag{12}$$

$$x_t^* = \frac{u_t^* R_{k,t}^* + Q_t^* \left(1 - \delta_*(u_t^*)\right)}{Q_{t-1}^*}. \tag{13}$$

Equation (11) is the key condition for the international finance multiplier mechanism. This equation and (10) indicate that investors search for the same expected marginal return on capital across countries (i.e., $E_t \Lambda_{t+1} x_{t+1} = E_t \Lambda_{t+1} x^*_{t+1} e_{t+1}/e_t$).

The loan rate $r_{l,t}$ consists of the deposit rate r_t and the EF premium efp_t,

$$r_{l,t} = r_t efp_t = r_t F\big(l_{H,t} + l^*_{H,t}\big) \exp(z_{\mu,t}). \tag{14}$$

Here,

$$l_{H,t} = \frac{Q_t K_{H,t}}{N_t}, \quad l^*_{H,t} = \frac{e_t Q^*_t K^*_{H,t}}{N_t} \tag{15}$$

are investors' home and foreign leverage ratios. The EF premium function $F(\cdot)$ depends on investors' total leverage ratio $l_{H,t} + l^*_{H,t}$ and satisfies $F' > 0$ and $\mu = (l_H + l^*_H)F'(l_H + l^*_H)/F(l_H + l^*_H) \geq 0$ as in previous studies with open-economy financial accelerator models, such as Gilchrist (2004), Faia (2007), Gertler, Gilchrist, and Natalucci (2007), and Dedola and Lombardo (2012). The disturbance $z_{\mu,t}$ denotes a shock to the EF premium. This shock represents a disturbance to the financial sector that boosts the EF premium beyond the level warranted by currently available information about the state of the economy.

After selling capital to capital-good firms and paying back $r_{l,t-1}L_{t-1}$ to financial intermediaries, a fraction $1 - \gamma_t \in (0, 1)$ of investors becomes workers, while the remaining fraction γ_t survives until the next period.[5] Investors' real net worth then evolves accord-

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[5] This assumption ensures that investors' net worth will never be sufficient to entirely finance their purchase of capital.

ing to

$$N_t = \gamma_t \left[x_t l_{H,t-1} + x_t^* \frac{e_t}{e_{t-1}} l_{H,t-1}^* - \frac{r_{l,t-1}}{\pi_t} \left(l_{H,t-1} + l_{H,t-1}^* - 1 \right) \right] N_{t-1} + (1-\gamma_t)\, t_n Z_t, \quad (16)$$

where t_n is a positive constant and Z_t is the composite technological level (explained later). The term $t_n Z_t$ denotes the transfer that surviving investors receive from investors who become workers. The probability of surviving until the next period is given by $\gamma_t = \gamma \exp(\tilde{z}_{\gamma,t}) / \left(1 - \gamma + \gamma \exp(\tilde{z}_{\gamma,t})\right)$, where $\tilde{z}_{\gamma,t}$ represents a net worth shock.

2.2 Intermediate-good firms

Each intermediate-good firm $f \in [0,1]$ produces output $Y_t(f)$ by choosing a combination of labor and capital inputs $\{h_t(f), K_t(f)\}$ at real rental rates $\{W_t, R_{k,t}\}$ according to the production function

$$Y_t(f) = \left(A_t h_t(f)\right)^{1-\alpha} \left(K_t(f)\right)^{\alpha}. \quad (17)$$

Here, A_t represents the level of neutral technology and it is assumed as in Ireland (2013) that its growth rate follows the stochastic process

$$\log \frac{A_t}{A_{t-1}} = (1-\rho_a) \log a + \rho_a \log \frac{A_{t-1}}{A_{t-2}} + \rho_{ad} \log \frac{A_{t-1}^*}{A_{t-1}} + \varepsilon_{a,t}, \quad (18)$$

where $\rho_a \in [0,1)$ is the persistence parameter; $\rho_{ad} \geq 0$ is the error-correction parameter; $a > 1$ denotes the (gross) steady-state rate of neutral technological change, which is assumed to be the same across countries; and $\varepsilon_{a,t}$ represents a (non-stationary) neutral technology shock. The labor input is given by $h_t(f) = [\int_0^1 \left(h_t(m,f)\right)^{1/(1+\lambda_w)} dm]^{1+\lambda_w}$. The parameter $\alpha \in (0,1)$ represents the capital elasticity of output, which is assumed to be the same across countries.

Combining the first-order conditions for optimal decisions on capital and labor inputs leads to

$$\frac{u_t \left(K_{H,t-1} + K_{F,t-1}\right)}{h_t} = \frac{\alpha W_t}{(1-\alpha) R_{k,t}}, \quad (19)$$

where $h_t = \int_0^1 h_t(f)df$, $u_t K_{H,t-1} = \int_0^1 K_{H,t}(f)df$, and $u_t K_{F,t-1} = \int_0^1 K_{F,t}(f)df$, and the real marginal cost is given by

$$mc_t = \left(\frac{W_t}{(1-\alpha)A_t}\right)^{1-\alpha} \left(\frac{R_{k,t}}{\alpha}\right)^{\alpha}. \tag{20}$$

Under monopolistic competition, intermediate-good firm f faces home and foreign consumption-good firms' demand $Y_{H,t}(f) = Y_{H,t}(P_{H,t}(f)/P_{H,t})^{-(1+\lambda_H)/\lambda_H}$ and $Y^*_{H,t}(f) = Y^*_{H,t}(P^*_{H,t}(f)/P^*_{H,t})^{-(1+\lambda^*_H)/\lambda^*_H}$, where $P_{H,t}(f)$ and $P^*_{H,t}(f)$ are home and foreign prices of differentiated goods produced by intermediate-good firm f, $Y_{H,t}$ and $Y^*_{H,t}$ are home and foreign aggregates of intermediate goods with the substitution elasticities $(1+\lambda_H)/\lambda_H, (1+\lambda^*_H)/\lambda^*_H > 1$, and $P_{H,t}$ and $P^*_{H,t}$ are the corresponding aggregate prices. Then, it is assumed as in Rabanal and Tuesta (2010) that intermediate-good firms adopt local currency pricing of their differentiated products on a staggered basis à la Calvo (1983). In each period, a fraction $1 - \xi_H \in (0, 1)$ of intermediate-good firms reoptimizes prices of their products purchased by home consumption-good firms, while the remaining fraction ξ_H indexes prices of the products to a weighted average of past and steady-state inflation rates of the aggregate price $P_{H,t}$, $(\pi_{H,t-1})^{\gamma_H}(\pi_H)^{1-\gamma_H}$, where $\pi_{H,t} = P_{H,t}/P_{H,t-1}$ and $\gamma_H \in [0, 1]$. Similarly, a fraction $1 - \xi^*_H \in (0, 1)$ of intermediate-good firms reoptimizes prices of their products purchased by foreign consumption-good firms, while the remaining fraction ξ^*_H indexes prices of the products to a weighted average of past and steady-state inflation rates of the aggregate price $P^*_{H,t}$, $(\pi^*_{H,t+k-1})^{\gamma^*_H}(\pi^*_H)^{1-\gamma^*_H}$, where $\pi^*_H = P^*_{H,t}/P^*_{H,t-1}$ and $\gamma^*_H \in [0, 1]$. Hence, intermediate-good firms that reoptimize current-period prices of their products purchased by home consumption-good firms choose the prices to maximize

$$E_t \sum_{j=0}^{\infty} (\xi_H)^j \left(\beta^j \frac{\Lambda_{t+j}}{\Lambda_t}\right) \left[\frac{P_{H,t}(f)}{P_{t+j}} \prod_{k=1}^{j} (\pi_{H,t+k-1})^{\gamma_H} (\pi_H)^{1-\gamma_H} - mc_{t+j}\right] Y_{H,t+j|t}(f)$$

subject to

$$Y_{H,t+j|t}(f) = Y_{H,t+j} \left[\frac{P_{H,t}(f)}{P_{H,t+j}} \prod_{k=1}^{j} (\pi_{H,t+k-1})^{\gamma_H} (\pi_H)^{1-\gamma_H}\right]^{-\frac{1+\lambda_H}{\lambda_H}},$$

where $\beta^j \Lambda_{t+j}/\Lambda_t$ shows the stochastic discount factor between period t and period $t+j$. Similarly, intermediate-good firms that reoptimize current-period prices of their products purchased by foreign consumption-good firms choose the prices to maximize

$$E_t \sum_{j=0}^{\infty} (\xi_H^*)^j \left(\beta^j \frac{\Lambda_{t+j}}{\Lambda_t}\right) \left[\frac{e_{t+j}^n P_{H,t}^*(f)}{P_{t+j}} \prod_{k=1}^{j} \left(\pi_{H,t+k-1}^*\right)^{\gamma_H^*} \left(\pi_H^*\right)^{1-\gamma_H^*} - mc_{t+j}\right] Y_{H,t+j|t}^*(f)$$

subject to

$$Y_{H,t+j|t}^*(f) = Y_{H,t+j}^* \left[\frac{P_{H,t}^*(f)}{P_{H,t+j}^*} \prod_{k=1}^{j} \left(\pi_{H,t+k-1}^*\right)^{\gamma_H^*} \left(\pi_H^*\right)^{1-\gamma_H^*}\right]^{-\frac{1+\lambda_H^*}{\lambda_H^*}}.$$

The first-order conditions for reoptimized real prices $\bar{p}_{H,t}$, $\bar{p}_{H,t}^*$ are given by

$$\bar{p}_{H,t} = (1+\lambda_H) \frac{E_t \sum_{j=0}^{\infty} (\beta\xi_H)^j \Lambda_{t+j} Y_{H,t+j} mc_{t+j} \left[\prod_{k=1}^{j} \left(\frac{\pi_{H,t+k-1}}{\pi_H}\right)^{\gamma_H} \frac{\pi_H}{\pi_{H,t+k}}\right]^{-\frac{1+\lambda_H}{\lambda_H}}}{E_t \sum_{j=0}^{\infty} (\beta\xi_H)^j \Lambda_{t+j} Y_{t+j} p_{H,t+j} \left[\prod_{k=1}^{j} \left(\frac{\pi_{H,t+k-1}}{\pi_H}\right)^{\gamma_H} \frac{\pi_H}{\pi_{H,t+k}}\right]^{-\frac{1}{\lambda_H}}}, \tag{21}$$

$$\bar{p}_{H,t}^* = (1+\lambda_H^*) \frac{E_t \sum_{j=0}^{\infty} (\beta\xi_H^*)^j \Lambda_{t+j} Y_{H,t+j}^* mc_{t+j} \left[\prod_{k=1}^{j} \left(\frac{\pi_{H,t+k-1}^*}{\pi_H^*}\right)^{\gamma_H^*} \frac{\pi_H^*}{\pi_{H,t+k}^*}\right]^{-\frac{1+\lambda_H^*}{\lambda_H^*}}}{E_t \sum_{j=0}^{\infty} (\beta\xi_H)^j \Lambda_{t+j} Y_{t+j}^* p_{H,t+j}^* e_{t+j} \left[\prod_{k=1}^{j} \left(\frac{\pi_{H,t+k-1}^*}{\pi_H^*}\right)^{\gamma_H^*} \frac{\pi_H^*}{\pi_{H,t+k}^*}\right]^{-\frac{1}{\lambda_H^*}}}. \tag{22}$$

Aggregating the production function (17) over intermediate-good firms and using the market clearing conditions for intermediate goods yields

$$Y_{H,t} d_{H,t} + Y_{H,t}^* d_{H,t}^* = (A_t h_t)^{1-\alpha} \left[u_t \left(K_{H,t-1} + K_{F,t-1}\right)\right]^{\alpha}, \tag{23}$$

where $d_{H,t} = \int_0^1 (P_{H,t}(f)/P_{H,t})^{-(1+\lambda_H)/\lambda_H} df$ and $d_{H,t}^* = \int_0^1 (P_{H,t}^*(f)/P_{H,t}^*)^{-(1+\lambda_H^*)/\lambda_H^*} df$ are price distortions of intermediate goods purchased by home and foreign consumption-good firms. Note that these distortions are of second order under the staggered pricing and that their steady-state values are unity.

2.3 Consumption-good firms

Consumption-good firms produce output Y_t in two steps to introduce a price markup shock. First, they produce differentiated inputs $\{Y_t(f_c)\}$ by choosing a combination of home and foreign intermediate goods $\{\{Y_{H,t}(f)\},\{Y_{F,t}(f^*)\}\}$ at prices $\{\{P_{H,t}(f)\},\{P_{F,t}(f^*)\}\}$ according to the production function $Y_t(f_c)=[(\omega)^{1/\theta}(Y_{H,t})^{(\theta-1)/\theta}+(1-\omega)^{1/\theta}(Y_{F,t})^{(\theta-1)/\theta}]^{\theta/(\theta-1)}$, where $Y_{H,t}=[\int_0^1(Y_{H,t}(f))^{1/(1+\lambda_H)}df]^{1+\lambda_H}$ and $Y_{F,t}=[\int_0^1(Y_{F,t}(f^*))^{1/(1+\lambda_F)}df^*]^{1+\lambda_F}$ are aggregates of home and foreign intermediate goods. In the second step, they combine differentiated inputs to produce consumption goods $Y_t=[\int_0^1(Y_t(f_c))^{1/(1+\lambda_{c,t})}df_c]^{1+\lambda_{c,t}}$. Consequently, output is given by

$$Y_t=\left[(\omega)^{\frac{1}{\theta}}\left(Y_{H,t}\right)^{\frac{\theta-1}{\theta}}+(1-\omega)^{\frac{1}{\theta}}\left(Y_{F,t}\right)^{\frac{\theta-1}{\theta}}\right]^{\frac{\theta}{\theta-1}}. \tag{24}$$

The first-order conditions for cost minimization yield consumption-good firms' demand for home intermediate good f and foreign intermediate good f^* given by

$$\begin{aligned}
Y_{H,t}(f)=Y_{H,t}\left(\frac{P_{H,t}(f)}{P_{H,t}}\right)^{-\frac{1+\lambda_H}{\lambda_H}}&=\omega\left(\frac{P_{H,t}}{MC_{c,t}}\right)^{-\theta}\left(\frac{P_{H,t}(f)}{P_{H,t}}\right)^{-\frac{1+\lambda_H}{\lambda_H}}Y_t,\\
Y_{F,t}(f^*)=Y_{F,t}\left(\frac{P_{F,t}(f^*)}{P_{F,t}}\right)^{-\frac{1+\lambda_F}{\lambda_F}}&=(1-\omega)\left(\frac{P_{F,t}}{MC_{c,t}}\right)^{-\theta}\left(\frac{P_{F,t}(f^*)}{P_{F,t}}\right)^{-\frac{1+\lambda_F}{\lambda_F}}Y_t,
\end{aligned}$$

and their marginal cost given by

$$MC_{c,t}=[\omega(P_{H,t})^{1-\theta}+(1-\omega)(P_{F,t})^{1-\theta}]^{\frac{1}{1-\theta}},$$

where $P_{H,t}=[\int_0^1(P_{H,t}(f))^{-\frac{1}{\lambda_H}}df]^{-\lambda_H}$ and $P_{F,t}=[\int_0^1(P_{F,t}(f^*))^{-\frac{1}{\lambda_F}}df^*]^{-\lambda_F}$ are aggregate prices of home and foreign intermediate goods. These demand equations yield

$$\frac{Y_{F,t}}{Y_{H,t}}=\frac{1-\omega}{\omega}\left(\frac{p_{F,t}}{p_{H,t}}\right)^{-\theta}. \tag{25}$$

From the staggered pricing of home and foreign intermediate-good firms, the aggregate price equations for $P_{H,t}$, $P_{F,t}$ can be reduced to

$$1=(1-\xi_H)\left(\bar{p}_{H,t}\right)^{-\frac{1}{\lambda_H}}+\xi_H\left[\frac{\pi_H}{\pi_{H,t}}\left(\frac{\pi_{H,t-1}}{\pi_H}\right)^{\gamma_H}\right]^{-\frac{1}{\lambda_H}}, \tag{26}$$

$$1=(1-\xi_F)\left(\bar{p}_{F,t}\right)^{-\frac{1}{\lambda_F}}+\xi_F\left[\frac{\pi_F}{\pi_{F,t}}\left(\frac{\pi_{F,t-1}}{\pi_F}\right)^{\gamma_F}\right]^{-\frac{1}{\lambda_F}}. \tag{27}$$

The price of consumption goods is given by $P_t=(1+\lambda_{c,t})MC_{c,t}$, which can be reduced to

$$1=(1+\lambda_{c,t})\left[\omega\left(p_{H,t}\right)^{1-\theta}+(1-\omega)\left(p_{F,t}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}}, \tag{28}$$

where $p_{H,t} = P_{H,t}/P_t$ and $p_{F,t} = P_{F,t}/P_t$.

2.4 Investment-good firms

Each investment-good firm $f_i \in [0,1]$ uses the production technology that converts one unit of consumption goods into Ψ_t units of differentiated investment goods. Thus, Ψ_t represents the level of IS technology.[6] It is assumed as in Ireland (2013) that its growth rate follows the stochastic process

$$\log \frac{\Psi_t}{\Psi_{t-1}} = (1-\rho_\psi)\log\psi + \rho_\psi \log\frac{\Psi_{t-1}}{\Psi_{t-2}} + \rho_{\psi d}\log\frac{\Psi^*_{t-1}}{\Psi_{t-1}} + \varepsilon_{\psi,t}, \tag{29}$$

where $\rho_\psi \in [0,1)$ is the persistence parameter; $\rho_{\psi d} \geq 0$ is the error-correction parameter; $\psi > 1$ denotes the (gross) steady-state rate of IS technological change, which is assumed to be the same across countries; and $\varepsilon_{\psi,t}$ represents a (non-stationary) IS technology shock. The cost minimization of investment-good firms shows that their real marginal cost equals the inverse of the IS technological level, $1/\Psi_t$.

Under monopolistic competition, investment-good firm f_i faces capital-good firms' demand

$$I_t(f_i) = I_t\left(\frac{P_{i,t}(f_i)}{P_{i,t}}\right)^{-\frac{1+\lambda_{i,t}}{\lambda_{i,t}}}, \tag{30}$$

where $P_{i,t}(f_i)$ is the price of investment goods produced by firm f_i, $I_t = [\int_0^1 (I_t(f_i))^{1/(1+\lambda_{i,t})} df_i]^{1+\lambda_{i,t}}$ is the aggregate of differentiated investment goods with the substitution elasticity $(1+\lambda_{i,t})/\lambda_{i,t} > 1$, and $P_{i,t} = [\int_0^1 (P_{i,t}(f_i))^{-1/\lambda_{i,t}} df_i]^{-\lambda_{i,t}}$ is the corresponding aggregate price of investment goods.

The price of investment good f_i is given by $P_{i,t}(f_i) = (1+\lambda_{i,t})P_t/\Psi_t$. The aggregate

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[6] The presence of IS technological change is based on the observed downward trends in the data on the relative price of investment to consumption in the EA and US. Greenwood, Hercowitz, and Krusell (1997) indicate the importance of IS technological change for US economic growth. Moreover, Greenwood, Hercowitz, and Krusell (2000) indicate that an IS technology shock plays a crucial role for US business cycle fluctuations, using a calibrated closed-economy model. Fisher (2006) estimates a structural vector autoregression model and shows the importance of a non-stationary IS technology shock for US business cycle fluctuations.

price equation for $P_{i,t}$ then yields

$$P_{i,t} = (1+\lambda_{i,t})\frac{P_t}{\Psi_t}, \tag{31}$$

and hence (30) implies that $I_t(f_i) = I_t$. From (31), the (gross) rate of change in the relative price of investment goods to consumption goods is given by

$$r_{i,t} = \frac{P_{i,t}/P_t}{P_{i,t-1}/P_{t-1}} = \frac{1+\lambda_{i,t}}{1+\lambda_{i,t-1}}\frac{\Psi_{t-1}}{\Psi_t}. \tag{32}$$

The market clearing condition for consumption goods is now given by

$$Y_t = C_t + \int_0^1 \frac{I_t(f_i)}{\Psi_t}df_i + gZ_t \exp(\tilde{z}_t^g) = C_t + \frac{I_t}{\Psi_t} + gZ_t \exp(\tilde{z}_t^g), \tag{33}$$

where the last term $gZ_t \exp(\tilde{z}_t^g)$ denotes demand for consumption goods other than the household's consumption demand and investment-good firms' demand, $\tilde{z}_t^g$ represents a shock to this exogenous consumption-good demand, and Z_t is the composite technological level given by $Z_t = A_t(\Psi_t)^{\alpha/(1-\alpha)}$. This composite technological level can be derived using intermediate-good firms' Cobb-Douglas production function (17). Then, the composite technological change $z_t = Z_t/Z_{t-1}$ turns out to be the (gross) rate of home-country balanced growth and its steady-state rate is given by $z = a\psi^{\alpha/(1-\alpha)}$.

2.5 Capital-good firms

Capital-good firms purchase capital goods $(1-\delta(u_t))K_{H,t-1}$, $(1-\delta(u_t))K_{F,t-1}$ back from home and foreign investors and make an investment I_t. This investment is subject to not only adjustment costs $S((I_t/I_{t-1})/(z\psi)) = (\zeta/2)[(I_t/I_{t-1})/(z\psi)-1]^2$, $\zeta > 0$, advocated by Christiano, Eichenbaum, and Evans (2005), but also a shock to the marginal efficiency of investment (MEI) proposed by Greenwood, Hercowitz, and Huffman (1988) and denoted by $z_{\nu,t}$.[7] This shock represents a technology shock that affects the transformation of investment goods into capital goods. The capital accumulation equation is thus given by

$$K_t = (1-\delta(u_t))K_{t-1} + \exp(z_{\nu,t})\left(1 - S\left(\frac{I_t/I_{t-1}}{z\psi}\right)\right)I_t, \tag{34}$$

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[7] In an estimated closed-economy model with no financial friction, Justiniano, Primiceri, and Tambalotti (2010, 2011) show that a MEI shock is the main source of US business cycle fluctuations.

where

$$K_t = K_{H,t} + K_{F,t}. \tag{35}$$

Then, capital-good firms sell capital $K_{H,t}$, $K_{F,t}$ to home and foreign investors.

Capital-good firms' problem is to choose investment I_t and a combination of investment goods $\{I_t(f_i)\}$ to maximize profit

$$E_t \sum_{j=0}^{\infty} \beta^j \frac{\Lambda_{t+j}}{\Lambda_t} \left\{ Q_{t+j} \left[K_{t+j} - (1 - \delta(u_{t+j}))K_{t+j-1} \right] - \frac{P_{i,t+j}}{P_{t+j}} I_{t+j} \right\}$$

subject to the capital accumulation equation (34). The first-order condition for optimal decisions on investment I_t is given by

$$\begin{aligned} \frac{P_{i,t}}{P_t} = Q_t \exp(z_{\nu,t}) \left[1 - S\left(\frac{I_t/I_{t-1}}{z\psi} \right) - S'\left(\frac{I_t/I_{t-1}}{z\psi} \right) \frac{I_t/I_{t-1}}{z\psi} \right] \\ + E_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} z\psi Q_{t+1} \exp(z_{\nu,t+1}) S'\left(\frac{I_{t+1}/I_t}{z\psi} \right) \left(\frac{I_{t+1}/I_t}{z\psi} \right)^2. \end{aligned} \tag{36}$$

2.6 Central bank

The central bank conducts monetary policy by adjusting the policy rate according to the Taylor (1993)-type rule

$$\log r_t = \phi_r \log r_{t-1} + (1-\phi_r) \left(\log r + \frac{\phi_\pi}{4} \sum_{j=0}^{3} \log \frac{\pi_{t-j}}{\pi} + \phi_y \log \frac{Y_t/Z_t}{y} \right) + \phi_{\Delta y} \log \frac{Y_t/Y_{t-1}}{z} + z_{r,t}, \tag{37}$$

where r is the (gross) steady-state policy rate, y is the steady-state value of detrended output $y_t = Y_t/Z_t$, $\phi_r \in [0, 1)$ represents the degree of policy rate smoothing, $\phi_\pi, \phi_y, \phi_{\Delta y} \geq 0$ represent the degrees of policy responses to inflation, output, and output growth, and the disturbance $z_{r,t}$ represents a monetary policy shock.

2.7 Exchange rate

The exchange rate is determined as follows. The law of motion of foreign currency denominated one-period bonds is given by

$$e_t^n B_{H,t}^* = e_t^n r_{t-1}^* \exp\left(-\phi_e \frac{e_{t-1}^n B_{H,t-1}^*}{P_{t-1} Y_{t-1}} + z_{e,t-1} \right) B_{H,t-1}^* + e_t^n P_{H,t}^* Y_{H,t}^* - P_{F,t} Y_{F,t},$$

which can be reduced to

$$\log d_t = \frac{e_t}{e_{t-1}} \frac{r^*_{t-1}}{\pi^*_t} \frac{Y_{t-1}}{Y_t} \exp\left(-\phi_e \log d_{t-1} + z_{e,t-1}\right) \log d_{t-1} + e_t p^*_{H,t} \frac{Y^*_{H,t}}{Y_t} - p_{F,t} \frac{Y_{F,t}}{Y_t}, \quad (38)$$

where $\log d_t = e_t B^*_{H,t}/(P^*_t Y_t)$ and $p^*_{H,t} = P^*_{H,t}/P^*_t$. Then, from (3) and the foreign counterpart to (2), the real exchange rate e_t is determined according to

$$E_t\left[\frac{1}{\pi^*_{t+1}}\left(\frac{\Lambda^*_{t+1}}{\Lambda^*_t} - \frac{\Lambda_{t+1}}{\Lambda_t}\frac{e_{t+1}}{e_t}\exp\left(-\phi_e \log d_t + z_{e,t}\right)\right)\right] = 0. \quad (39)$$

2.8 Equilibrium conditions

In the model, the equilibrium conditions consist of three parts. First, those for the home country are given by (1), (2), (5)–(16), (19)–(28), (31)–(36), and (37), together with the stochastic processes of neutral and IS technological changes, (18), (29), and those of the other nine exogenous shocks $z_{x,t}$, $x \in \{b, g, h, c, i, r, \nu, \mu, \gamma\}$, where $z_{g,t} = (g/y)\tilde{z}_{g,t}$, $z_{h,t} = (1-\xi_w)(1-\beta\xi_w)/\{\xi_w[1+\chi(1+\lambda_w)/\lambda_w]\}\tilde{z}_{h,t}$, $z_{c,t}$ and $z_{i,t}$ are shocks associated with the consumption-good price markup $\lambda_{c,t}$ and the investment-good price markup $\lambda_{i,t}$, and $z_{\gamma,t} = \gamma[r_l/(z\pi) - 1]\tilde{z}_{\gamma,t}$. Each of the exogenous shocks is assumed to follow the univariate stationary first-order autoregressive process with the persistence parameter ρ_x and the standard deviation of shock innovations σ_x. Second, there are the foreign-country counterparts to these home-country conditions. Last, the exchange rate-related conditions are given by (38) and (39) together with the univariate stationary first-order autoregressive process of the UIP shock (ρ_e, σ_e).

3 The strategy and data for estimation

This section describes strategy and data for estimating the model presented in the preceding section.

3.1 The estimation strategy

The model is estimated using a Bayesian likelihood approach with 23 quarterly time series from the EA and US: EA and US output Y_t, Y_t^*; EA and US consumption C_t, C_t^*; EA and US investment I_t, I_t^*; EA and US labor h_t, h_t^*; EA and US real wages W_t, W_t^*; EA and US prices of consumption goods P_t, P_t^*; EA and US relative prices of investment goods $P_{i,t}/P_t, P_{i,t}^*/P_t^*$; EA and US monetary policy rates r_t, r_t^*; EA and US external finance premiums efp_t, efp_t^*; EA and US real loans L_t, L_t^*; EA and US real net worth N_t, N_t^*; and the Euro per USD exchange rate e_t^n.

For estimation, the equilibrium conditions presented in the preceding section are rewritten in terms of detrended variables: $y_t = Y_t/Z_t$, $c_t = C_t/Z_t$, $w_t = W_t/Z_t$, $n_t = N_t/Z_t$, $l_t = L_t/Z_t$, $\lambda_t = \Lambda_t Z_t$, $i_t = I_t/(Z_t \Psi_t)$, $k_t = K_t/(Z_t \Psi_t)$, $k_{H,t} = K_{H,t}/(Z_t \Psi_t)$, $k_{F,t} = K_{F,t}/(Z_t \Psi_t)$, $r_{k,t} = R_{k,t} \Psi_t$, $q_t = Q_t \Psi_t$, $z_t = Z_t/Z_{t-1}$, $a_t = A_t/A_{t-1}$, $\psi_t = \Psi_t/\Psi_{t-1}$, and the foreign counterparts of these variables, together with $z_t^d = Z_t/Z_t^*$, $a_t^d = A_t/A_t^*$, $\psi_t^d = \Psi_t/\Psi_t^*$. The resulting equilibrium conditions are then log-linearized around a deterministic steady state with balanced trade, home and foreign capital utilization rates of unity, and home and foreign investors' portfolio shares of holdings of claims to domestic capital of $\eta, \eta^* \in [0,1]$, where $\eta = qk_H/(qk_H + eq^* k_H^*/z^d)$ and $\eta^* = q^* k_F^*/(q^* k_F^* + qk_F z^d/e)$.[8]

Like recent studies that estimate dynamic stochastic general equilibrium models by Bayesian methods, such as Smets and Wouters (2003, 2007), the present paper uses the Kalman filter to evaluate the likelihood function for the system of log-linearized equilibrium conditions in terms of detrended variables, and applies the Metropolis-Hastings algorithm to generate draws from the posterior distribution of model parameters.[9] Based

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[8] It is well known that steady-state portfolio choices are indeterminate. As explained in Devereux and Sutherland (2011), the second-order approximation of equilibrium conditions for asset pricing, together with the first-order approximation of other equilibrium conditions, is required to compute optimal steady-state portfolio choices. Applying such techniques in our estimation is beyond the scope of the present paper. Our paper infers steady-state portfolio choices from the data.

[9] Our estimation is done using DYNARE (Adjemian et al., 2011). In each estimation, 200,000 draws

on these draws, our empirical analysis is conducted.

3.2 The data

The data on the Euro per USD exchange rate e_t^n comes from the 10th update of the Area-Wide Model (AWM) database (Fagan, Henry, and Mestre, 2001). The data on EA and US consumption-good prices P_t, P_t^* are the HICP and the PCE price index. The other 20 time series are the same as those in Christiano, Motto, and Rostagno (2010), except that (i) the EA nominal series of GDP, consumption, wages, the relative price of investment, loans, and net worth are deflated with the HICP; (ii) the US series of consumption and investment are PCE and FPI; and (iii) the US nominal series of GDP, consumption, wages, the relative price of investment, loans, and net worth are deflated with the PCE price index. The sample period is from 1985:1Q to 2009:4Q. The

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were generated and the first half of these draws was discarded. The scale factor for the jumping distribution in the Metropolis-Hastings algorithm was adjusted so that an acceptance rate of around 24% was obtained.

corresponding observation equations are

$$\begin{bmatrix} 100\Delta\log Y_t \\ 100\Delta\log C_t \\ 100\Delta\log I_t \\ 100\log h_t \\ 100\Delta\log W_t \\ 100\Delta\log P_t \\ 100\Delta\log(P_{i,t}/P_t) \\ 100\log r_t \\ efp_t \\ 100\Delta\log L_t \\ 100\Delta\log N_t \\ 100\Delta\log Y_t^* \\ 100\Delta\log C_t^* \\ 100\Delta\log I_t^* \\ 100\log h_t^* \\ 100\Delta\log W_t^* \\ 100\Delta\log P_t^* \\ 100\Delta\log(P_{i,t}^*/P_t^*) \\ 100\log r_t^* \\ efp_t^* \\ 100\Delta\log L_t^* \\ 100\Delta\log N_t^* \\ 100\Delta\log e_t^n \end{bmatrix} = \begin{bmatrix} \bar{z} \\ \bar{z} \\ \bar{z}+\bar{\psi} \\ \bar{h} \\ \bar{z} \\ \bar{\pi} \\ -\bar{\psi} \\ \bar{r} \\ efp \\ \bar{z} \\ \bar{z} \\ \bar{z} \\ \bar{z} \\ \bar{z}+\bar{\psi} \\ \bar{h}^* \\ \bar{z} \\ \bar{\pi} \\ -\bar{\psi} \\ \bar{r} \\ efp \\ \bar{z} \\ \bar{z} \\ 0 \end{bmatrix} + \begin{bmatrix} \hat{z}_t + \hat{y}_t - \hat{y}_{t-1} \\ \hat{z}_t + \hat{c}_t - \hat{c}_{t-1} \\ \hat{z}_t + \hat{\psi}_t + \hat{\imath}_t - \hat{\imath}_{t-1} \\ \hat{h}_t \\ \hat{z}_t + \hat{w}_t - \hat{w}_{t-1} \\ \hat{\pi}_t \\ -\hat{\psi}_t + z_{i,t} - z_{i,t-1} \\ \hat{r}_t \\ \hat{r}_{l,t} - \hat{r}_t \\ \hat{z}_t + \hat{l}_t - \hat{l}_{t-1} \\ \hat{z}_t + \hat{n}_t - \hat{n}_{t-1} \\ \hat{z}_t^* + \hat{y}_t^* - \hat{y}_{t-1}^* \\ \hat{z}_t^* + \hat{c}_t^* - \hat{c}_{t-1}^* \\ \hat{z}_t^* + \hat{\psi}_t^* + \hat{\imath}_t^* - \hat{\imath}_{t-1}^* \\ \hat{h}_t^* \\ \hat{z}_t^* + \hat{w}_t^* - \hat{w}_{t-1}^* \\ \hat{\pi}_t^* \\ -\hat{\psi}_t^* + z_{i,t}^* - z_{i,t-1}^* \\ \hat{r}_t^* \\ \hat{r}_{l,t}^* - \hat{r}_t^* \\ \hat{z}_t^* + \hat{l}_t^* - \hat{l}_{t-1}^* \\ \hat{z}_t^* + \hat{n}_t^* - \hat{n}_{t-1}^* \\ \hat{e}_t - \hat{e}_{t-1} + \hat{\pi}_t - \hat{\pi}_t^* \end{bmatrix},$$

where $\bar{z} = 100(z-1)$, $\bar{\psi} = 100(\psi-1)$, $\bar{\pi} = 100(\pi-1)$, $\bar{r} = 100(r-1)$, $\bar{h}$ and $\bar{h}^*$ are normalized to be equal to zero as in Smets and Wouters (2007), and hatted variables represent log-deviations from steady-state values.

3.3 Fixed parameters and prior distributions

Most of the model parameters are estimated, while some are fixed to avoid identification issues. The steady-state output ratio of spending other than consumption and investment is set at the sample mean (i.e., EA: $g/y = 0.22$; US: $g^*/y^* = 0.16$). The steady-state depreciation rate and the wage markup are chosen from Christiano, Motto, and Rostagno (2010) (i.e., EA: $\delta = 0.02$, $\lambda_w = 0.05$; US: $\delta^* = 0.025$, $\lambda_w^* = 0.05$) and the price markups of intermediate goods and those of consumption and investment goods at the steady state are all set at 0.2 (i.e., $\lambda_x = \lambda_x^* = 0.2$; $x = H, F, c, i$). Since no data on exports or imports are used in estimation, the share parameter ω, ω^* is chosen from Ireland (2013) (i.e., $\omega = \omega^* = 0.9$) and the elasticity of substitution between EA and US intermediate goods θ, θ^* is chosen from Backus, Kehoe, and Kydland (1994) (i.e., $\theta = \theta^* = 1.5$). It is also assumed that $\xi_H = \xi_H^*$, $\gamma_H = \gamma_H^*$, $\xi_F^* = \xi_F$, and $\gamma_F^* = \gamma_F$.

The prior distributions of parameters are shown in the third to fifth columns of Tables 1–3. Those of the steady-state rates of balanced growth, IS technological change, inflation, and policy and the steady-state EF premium (i.e., $\bar{z}$, $\bar{\psi}$, $\bar{\pi}$, $\bar{r}$, efp) are set to be the Gamma distributions with the standard deviation of 0.1 and the mean given by the EA-US sample mean of the output growth rate, the rate of decline in the relative price of investment, the inflation rate, the policy rate, and the EF premium, respectively. Those of the normalized steady-state labor $\bar{h}$, $\bar{h}^*$ are the same as the one in Smets and Wouters (2007). The prior distribution of the elasticity of cost of foreign bond holdings ϕ_e is the same as that in Rabanal and Tuesta (2010). Those of investors' steady-state portfolio shares of holdings of claims to domestic capital η, η are set to be the Beta distributions with the mean of 0.75 and the standard deviation of 0.1, taking into account a home bias. For the structural parameters that also appear in the model of Smets and Wouters (2007) (i.e., α, b, χ, ζ, γ_w, ξ_w, γ_H, ξ_H, ϕ_r, ϕ_π, ϕ_y, $\phi_{\Delta y}$, b^*, χ^*, ζ^*, γ_w^*, ξ_w^*, γ_F^*, ξ_F^*, ϕ_r^*, ϕ_π^*, ϕ_y^*, $\phi_{\Delta y}^*$), the same prior mean and the same prior standard deviations as theirs are used.[10] The prior distribution for the inverse of the elasticity of adjustment cost of the capital utilization rate μ is set to be the Gamma distribution with the mean of 0.22 and the standard deviation of 0.1, based on Khan and Tsoukalas (2011). As for the parameters related to the financial accelerator mechanism, the prior distributions of the steady-state survival probability γ, γ^*, the steady-state liability share of net worth $n_l (= n/(n+l))$, $n_l^* (= n^*/(n^*+l^*))$, and the elasticity of the

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[10] For the parameters χ, ζ, ϕ_π, ϕ_y, and $\phi_{\Delta y}$, our study employs the Gamma distributions instead of the Normal distributions used in Smets and Wouters (2007), since these parameters are assumed to be positive. The prior distributions of the other parameters (i.e., α, b, γ_w, ξ_w, γ_H, ξ_H, ϕ_r) are the same as those in their studies.

EF premium μ, μ^* are the same as those in Kaihatsu and Kurozumi (2010). For the parameters of shocks, the present paper chooses the Beta distribution with the mean of 0.5 and the standard deviation of 0.2 for the persistence of each shock (i.e., ρ_e, ρ_x, ρ_x^*, $x \in \{b, g, h, c, i, r, a, \psi, \nu, \mu, \gamma\}$), the Gamma distribution with the mean of 0.2 and the standard deviation of 0.1 for the error correction in each technological change (i.e., ρ_x, ρ_x^*, $x \in \{ad, \psi d\}$), and the Inverse Gamma distribution with the mean of 0.5 and the standard deviation of infinity for the standard deviation of each shock innovation (i.e., σ_e, σ_x, σ_x^*, $x \in \{b, g, h, c, i, r, a, \psi, \nu, \mu, \gamma\}$).

4 Results of the empirical analysis

This section presents results of the empirical analysis. First, estimates of model parameters are explained. Then, empirical implications of the international finance multiplier mechanism are examined using impulse responses. Last, variance and historical decompositions of business cycle fluctuations are analyzed.

4.1 Parameter estimates

Each parameter's posterior mean and 90% posterior interval are reported in the last two columns of Tables 1–3. In these tables, three points are worth mentioning. First, both the EA and US estimates of investors' steady-state portfolio share of holdings of claims to domestic capital, $\eta = 0.75$, $\eta^* = 0.55$, are less than unity. This suggests that the international finance multiplier mechanism is effective in that investors in each economy hold claims to both domestic and foreign capital. Second, the EA estimate of the elasticity of the EF premium $\mu = 0.10$ is much larger than the US one $\mu^* = 0.01$, suggesting that the financial accelerator mechanism is much more effective in the EA than in the US. Last, the estimate of the elasticity of cost of foreign bond holdings ϕ_e is positive but very close to zero. As shown in the following subsections, these parameter estimates yield a powerful propagation channel through which financial shocks originating in the

US are transmitted to the EA and have an impact on both the EA and US business cycle fluctuations.

4.2 Empirical implications of the international finance multiplier mechanism

The estimates of parameters have shown that the international finance multiplier mechanism is effective between the EA and US. This subsection investigates empirical implications of this mechanism for international business cycles under the financial accelerator mechanism.

Combining the log-linearization of the first-order conditions for home and foreign investors' optimal decisions on the purchase of capital (i.e., (10) and its foreign counterpart) yields a loan rate version of the UIP condition

$$\hat{r}_{l,t} - E_t\hat{\pi}_{t+1} = E_t\hat{x}_{t+1} = \hat{r}^*_{l,t} - E_t\hat{\pi}^*_{t+1} + E_t\hat{e}_{t+1} - \hat{e}_t. \tag{40}$$

From the log-linearization of the real exchange rate equation (39), the home representative household's consumption Euler equation (2), and its foreign counterpart, it follows that

$$\hat{r}_t - E_t\hat{\pi}_{t+1} = \hat{r}^*_t - E_t\hat{\pi}^*_{t+1} + E_t\hat{e}_{t+1} - \hat{e}_t - \phi_e\hat{d}_t + z_{e,t}. \tag{41}$$

These two equations (40) and (41) then imply

$$\widehat{efp}_t = \hat{r}_{l,t} - \hat{r}_t = \hat{r}^*_{l,t} - \hat{r}^*_t + \phi_e\hat{d}_t - z_{e,t} = \widehat{efp}^*_t + \phi_e\hat{d}_t - z_{e,t}, \tag{42}$$

which suggests that there is pressure for the equalization of the EF premiums across home and foreign countries as long as the effects of incompleteness of international bond markets (i.e., $\phi_e\hat{d}_t - z_{e,t}$) are relatively small.

Since variations in the EF premium amplify business cycle fluctuations through the financial accelerator mechanism, a shock that affects the EF premium in one country has an impact on the country's economy and simultaneously has a similar effect on the other country via the international finance multiplier mechanism. That is, the equalization pressure for the EF premiums in home and foreign countries gives rise to synchronization of business cycle fluctuations in these countries.

Figures 1 and 2 illustrate impulse responses to a one standard deviation innovation to the EF premium shock in the EA and US, respectively. In both figures, the EF premium shock raises the EF premiums and loan rates in both economies and hence dampens investment and output growth in these economies. This effect is sizable for the EF premium shock originating in the US, while it is quite limited for the one originating in the EA, reflecting the difference between the EA and US estimates of the elasticity of the EF premium. This suggests that through the international finance multiplier mechanism financial shocks originating in the US are transmitted to the EA and have an impact on both the EA and US business cycle fluctuations under the financial accelerator mechanism.

4.3 Variance decompositions

This subsection examines variance decompositions of business cycle fluctuations.

Table 4 reports the relative contribution of each shock to the variances of output growth, investment growth, consumption growth, and labor in the EA and US at the business cycle frequency of 8–32 quarters, evaluated at the posterior mean estimates of parameters. In this table, two points are worth mentioning. First, financial shocks originating in the EA (i.e., the EA EF premium shock e_μ and the EA net worth shock e_γ) made a negligible contribution to EA and US business cycle fluctuations during the past two decades. Second, financial shocks originating in the US (i.e., the US EF premium shock e_μ^* and the US net worth shock e_γ^*) accounted for 3.2%, 11.0%, 0.0%, and 4.2% of the variances of output growth, investment growth, consumption growth, and labor in the US during the sample period of 1985:1Q–2009:4Q and 0.2%, 5.4%, 1.3%, and 0.2% of the EA counterparts. These results are consistent with the impulse responses to the EA and US EF premium shocks illustrated above.

The magnitude of the relative contribution of our financial shocks to the EA and US business cycle fluctuations is similar to that of the "banking shocks" in Kollmann (2012). He estimates the two-country real business cycle model with a global bank developed in Kollmann, Enders, and Müller (2011) and shows that banking shocks to loan losses in the EA and US and to the required capital ratio explained 3.1%, 6.1%, 0.6%, and 6.3% of the variances of HP-filtered output, investment, consumption, and labor in the US during the sample period of 1990:1Q–2010:3Q and 4.0%, 22.6%, 2.2%, and 7.8% of the EA counterparts. There is, however, one crucial difference between his and our results for variance decompositions. His banking shocks affect EA business cycle fluctuations more than US ones, whereas our financial shocks affect US business cycle fluctuations more than EA ones. This difference may be caused by the difference in the source of financial frictions between his and our studies. His financial frictions focus on the supply side of loans (i.e., a global bank), while ours arise from the financial accelerator mechanism of Bernanke, Gertler, and Gilchrist (1999) and therefore draw attention to the demand side of loans (i.e., investors). Then, since the financial system is bank-based in the EA, while it is market-based in the US (e.g., in the EA the shares of financial assets of depository corporations, insurance and pension funds, and other financial intermediaries in the total financial assets of financial intermediaries are around 60%, 15%, and 25%, while the US counterparts are about 25%, 30%, and 45%), the difference in the contribution of his banking shocks and our financial shocks to the EA and US business cycle fluctuations may be induced.

One point we emphasize here is that our EA neutral technology shock e_a played an important role for both EA and US business cycle fluctuations. This shock accounted for 19.2%, 1.9%, 30.5%, and 23.5% of the variances of output growth, investment growth, consumption growth, and labor in the US during the period of 1985:1Q–2009:4Q and 16.1%, 7.7%, 3.0%, and 0.7% of the EA counterparts. The shock thus fills the gap or more in the contribution of Kollmann's banking shocks and our financial shocks to the

EA and US business cycle fluctuations. As examined in the next subsection, the EA neutral technology shock is closely related to EA banks' lending attitude and hence is likely to represent a disturbance to the EA banking sector.

4.4 Historical decompositions

The variance decompositions have shown that the EA financial shocks made a negligible contribution to EA and US business cycle fluctuations during the past two decades, whereas the US financial shocks and the EA neutral technology shock made a considerable contribution to them. In the present subsection, this result, particularly that for output growth fluctuations in the EA and US, is investigated from a historical perspective.

First, US output growth fluctuations are examined. Figure 3 shows the contribution of EA and US financial shocks and EA and US neutral technology shocks to the US output growth rate in each period. This figure shows, in line with the result of the variance decompositions, that the EA financial shocks made a negligible contribution to US output growth fluctuations and that the US financial shocks and the EA neutral technology shock played an important role for boom-bust cycles of US output growth during the periods from 1988 to 1992, from 1995 to 2002, and from 2004 onward. In addition, the US neutral technology shock made a considerable contribution to the fall in US output growth during the Great Recession of 2007:4Q–2009:2Q.

Next, we turn to EA output growth fluctuations. Figure 4 illustrates the contribution of EA and US financial shocks and EA and US neutral technology shocks to the EA output growth rate in each period. In this figure, the EA financial shocks played a negligible role for EA output growth fluctuations, whereas the US financial shocks—which were transmitted to the EA through the international finance multiplier mechanism—and the EA neutral technology shock made a considerable contribution to the fall in EA output growth during the Great Recession.

Kollmann (2012) shows that during the Great Recession of 2007:4Q–2009:2Q his banking shocks (i.e., shocks to loan losses in the EA and US and the required capital ratio) accounted for 16% of the fall in EA HP-filtered output and for 12% of the US counterpart. These proportions are somewhat larger than those of the fall in EA and US output growth explained by our financial shocks. In the same period, our US financial shocks explained 9.3% of the fall in EA output growth and 10.2% of the US counterpart. This difference may be again caused by the difference in the source of financial frictions between his and our studies. A global bank played a key role for financial frictions in Kollmann, whereas our model contains no such bank.

Our EA neutral technology shock fills this gap or more. This shock explained 55.6% of the fall in EA output growth during the Great Recession of 2007:4Q–2009:2Q and 65.1% of the US counterpart. That is, our adverse US financial shocks and our adverse EA neutral technology shock accounted for more than half of the fall in EA and US output growth during the Great Recession. This result poses the question as to what our EA neutral technology shock really represents. As a source of fluctuations in total factor productivity (i.e., neutral technology), recent studies, such as Buera, Kaboski, and Shin (2011) and Moll (2012), have pointed out financial frictions that induce misallocation of capital.[11] The present paper thus compares the estimated series of EA neutral technology growth $\hat{a}_t$ with the series of the net tightening of credit standards by EA banks on loan to enterprises in The Euro Area Bank Lending Survey. As Figure 5 demonstrates, these two series are highly correlated (the absolute value of the correlation coefficient is 0.73). Therefore, the EA neutral technology shock is likely to represent a fundamental disturbance to the functioning of the EA banking sector. As for US neutral technology growth $\hat{a}_t^*$, Figure 6 shows that its estimated series is weakly correlated with the series of domestic respondents' tightening standards for C&I loans in the Senior Loan Officer

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[11] See also Peek and Rosengren (2005), who show empirical evidence on misallocation of bank credit in Japan after the asset price bust in the 1990s.

Opinion Survey on Bank Lending Practices (the absolute value of the correlation coefficient is 0.20), in line with the fact that the US financial system is market-based but not bank-based.

5 Concluding remarks

This paper has empirically investigated the implications of the international finance multiplier mechanism for business cycle fluctuations. To this end, the paper has incorporated the financial accelerator mechanism of Bernanke, Gertler, and Gilchrist (1999) and the international finance multiplier mechanism modeled by Dedola and Lombardo (2012) in a variant of the two-country model of Ireland (2013) and has estimated this model with 23 quarterly time series from the EA and US. The main results of the empirical analysis are twofold. First, financial shocks originating in the US were transmitted to the EA through the international finance multiplier mechanism and had an impact on both the EA and US business cycle fluctuations through the financial accelerator mechanism during the past two decades. Second, adverse US financial shocks and an adverse EA neutral technology shock accounted for more than half of the fall in EA and US output growth during the Great Recession of 2007–09. The estimated series of EA neutral technology growth is highly correlated with the series of the net tightening of credit standards by EA banks in The Euro Area Bank Lending Survey, and therefore the estimated EA neutral technology shock is likely to represent a disturbance to the EA banking sector.

Our paper has estimated investors' steady-state portfolio choices directly from the data. Devereux and Sutherland (2011) present a computational method for optimal steady-state portfolio choices. Thus, one direction of future research would be to introduce this computational method in estimation of our model. More generally, another paper of theirs (Devereux and Sutherland, 2010) provides a computational method for the first-order approximation of optimal portfolio choices. Applying this method to our model and estimation would be of great interest.

Another research direction is found in recent studies, such as Hirakata, Sudo, and Ueda (2011) and Ueda (2012), which introduce the financial accelerator mechanism in both demand and supply sides of loans (i.e., investors and banks). Thus, developing a two-country model with the international finance multiplier mechanism along the lines of these previous studies and estimating the model would be a fruitful extension of the present analysis. We will investigate these topics in future work.

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Table 1: Prior and posterior distributions of structural parameters.

		Prior			Posterior	
Parameter		Type	Mean	S.D.	Mean	90% interval
ϕ_e	Elasticity of foreign bond holding cost	G	0.020	0.014	0.000	[0.000, 0.000]
α	Capital elasticity of output	B	0.300	0.050	0.313	[0.305, 0.321]
$\bar{z}$	Steady-state rate of balanced growth	G	0.410	0.100	0.382	[0.336, 0.425]
$\bar{\psi}$	Steady-state rate of IS technological change	G	0.160	0.100	0.020	[0.002, 0.037]
$\bar{\pi}$	Steady-state inflation rate	G	0.620	0.100	0.733	[0.710, 0.754]
$\bar{r}$	Steady-state policy rate	G	1.330	0.100	1.242	[1.193, 1.292]
efp	Steady-state EF premium	G	0.720	0.100	0.726	[0.698, 0.753]
η	EA steady-state portfolio share of domestic capital	B	0.750	0.100	0.748	[0.725, 0.766]
b	EA habit persistence	B	0.700	0.100	0.704	[0.684, 0.723]
χ	EA inverse elasticity of labor supply	G	2.000	0.750	4.129	[3.935, 4.320]
ζ	EA elasticity of investment adjustment cost	G	4.000	1.500	6.629	[6.220, 6.982]
τ	EA inverse elasticity of utilization adjustment cost	G	0.220	0.100	0.024	[0.015, 0.035]
γ_w	EA wage indexation	B	0.500	0.150	0.356	[0.300, 0.410]
ξ_w	EA wage stickiness	B	0.500	0.100	0.566	[0.541, 0.589]
γ_H	EA intermediate-good price indexation	B	0.500	0.150	0.439	[0.372, 0.504]
ξ_H	EA intermediate-good price stickiness	B	0.500	0.100	0.294	[0.260, 0.331]
ϕ_r	EA monetary policy rate smoothing	B	0.750	0.100	0.814	[0.800, 0.835]
ϕ_π	EA monetary policy response to inflation	G	1.500	0.250	1.672	[1.601, 1.729]
ϕ_y	EA monetary policy response to output	G	0.125	0.050	0.035	[0.019, 0.048]
$\phi_{\Delta y}$	EA monetary policy response to output growth	G	0.125	0.050	0.129	[0.106, 0.150]
$\bar{h}$	EA normalized steady-state labor	N	0.000	2.000	-1.979	[-2.729, -1.124]
μ	EA elasticity of EF premium	G	0.070	0.020	0.098	[0.094, 0.102]
γ	EA investor survival probability	B	0.973	0.020	0.951	[0.946, 0.957]
n_l	EA steady-state liability share of net worth	B	0.500	0.070	0.644	[0.602, 0.687]
η^*	US steady-state portfolio share of domestic capital	B	0.750	0.100	0.549	[0.536, 0.559]
b^*	US habit persistence	B	0.700	0.100	0.819	[0.797, 0.842]
χ^*	US inverse elasticity of labor supply	G	2.000	0.750	0.334	[0.162, 0.496]
ζ^*	US elasticity of investment adjustment cost	G	4.000	1.500	8.532	[8.300, 8.735]
τ^*	US inverse elasticity of utilization adjustment cost	G	0.220	0.100	0.423	[0.407, 0.441]
γ_w^*	US wage indexation	B	0.500	0.150	0.375	[0.343, 0.413]
ξ_w^*	US wage stickiness	B	0.500	0.100	0.762	[0.728, 0.792]
γ_F^*	US intermediate-good price indexation	B	0.500	0.150	0.601	[0.564, 0.645]
ξ_F^*	US intermediate-good price stickiness	B	0.500	0.100	0.950	[0.946, 0.953]
ϕ_r^*	US monetary policy rate smoothing	B	0.750	0.100	0.818	[0.798, 0.846]
ϕ_π^*	US monetary policy response to inflation	G	1.500	0.250	1.526	[1.464, 1.582]
ϕ_y^*	US monetary policy response to output	G	0.125	0.050	0.026	[0.020, 0.032]
$\phi_{\Delta y}^*$	US monetary policy response to output growth	G	0.125	0.050	0.023	[0.016, 0.030]
$\bar{h}^*$	US normalized steady-state labor	N	0.000	2.000	0.674	[0.279, 1.018]
μ^*	US elasticity of EF premium	G	0.070	0.020	0.006	[0.005, 0.007]
γ^*	US investor survival probability	B	0.973	0.020	0.985	[0.982, 0.989]
n_l^*	US steady-state liability share of net worth	B	0.500	0.070	0.311	[0.300, 0.324]

Note: In the type of prior distributions, B, G, IG, and N stand for Beta, Gamma, Inverse Gamma, and Normal distributions, respectively.

Table 2: Prior and posterior distributions of shock persistence and error-correction parameters.

Parameter		Prior			Posterior	
		Type	Mean	S.D.	Mean	90% interval
ρ_e	UIP shock persistence	B	0.500	0.200	0.900	[0.875, 0.928]
ρ_b	EA preference shock persistence	B	0.500	0.200	0.792	[0.742, 0.837]
ρ_g	EA exogenous demand shock persistence	B	0.500	0.200	0.987	[0.977, 0.997]
ρ_h	EA labor shock persistence	B	0.500	0.200	0.677	[0.612, 0.723]
ρ_c	EA consumption price markup shock persistence	B	0.500	0.200	0.494	[0.448, 0.535]
ρ_i	EA investment price markup shock persistence	B	0.500	0.200	0.920	[0.905, 0.935]
ρ_r	EA monetary policy shock persistence	B	0.500	0.200	0.978	[0.968, 0.991]
ρ_a	EA neutral technology shock persistence	B	0.500	0.200	0.994	[0.989, 0.999]
ρ_{ad}	EA neutral technological change error-correction	G	0.200	0.100	0.008	[0.005, 0.011]
ρ_ψ	EA IS technology shock persistence	B	0.500	0.200	0.775	[0.711, 0.842]
$\rho_{\psi d}$	EA IS technological change error-correction	G	0.200	0.100	0.053	[0.037, 0.069]
ρ_ν	EA MEI shock persistence	B	0.500	0.200	0.944	[0.931, 0.958]
ρ_μ	EA EF premium shock persistence	B	0.500	0.200	0.933	[0.894, 0.971]
ρ_γ	EA net worth shock persistence	B	0.500	0.200	0.258	[0.189, 0.322]
ρ_b^*	US preference shock persistence	B	0.500	0.200	0.997	[0.996, 0.998]
ρ_g^*	US exogenous demand shock persistence	B	0.500	0.200	0.985	[0.972, 0.998]
ρ_h^*	US labor shock persistence	B	0.500	0.200	0.727	[0.687, 0.766]
ρ_c^*	US consumption price markup shock persistence	B	0.500	0.200	0.535	[0.489, 0.569]
ρ_i^*	US investment price markup shock persistence	B	0.500	0.200	0.999	[0.998, 1.000]
ρ_r^*	US monetary policy shock persistence	B	0.500	0.200	0.945	[0.927, 0.962]
ρ_a^*	US neutral technology shock persistence	B	0.500	0.200	0.244	[0.212, 0.277]
ρ_{ad}^*	US neutral technological change error-correction	G	0.200	0.100	0.119	[0.093, 0.143]
ρ_ψ^*	US IS technology shock persistence	B	0.500	0.200	0.995	[0.991, 0.999]
$\rho_{\psi d}^*$	US IS technological change error-correction	G	0.200	0.100	0.002	[0.001, 0.004]
ρ_ν^*	US MEI shock persistence	B	0.500	0.200	0.999	[0.998, 1.000]
ρ_μ^*	US EF premium shock persistence	B	0.500	0.200	0.910	[0.887, 0.933]
ρ_γ^*	US net worth shock persistence	B	0.500	0.200	0.833	[0.797, 0.861]

Note: In the type of prior distributions, B, G, IG, and N stand for Beta, Gamma, Inverse Gamma, and Normal distributions, respectively.

Table 3: Prior and posterior distributions of standard deviations of shock innovations.

		Prior			Posterior	
Parameter		Type	Mean	S.D.	Mean	90% interval
σ_e	UIP shock innovation S.D.	IG	0.500	Inf	0.173	[0.153, 0.193]
σ_b	EA preference shock innovation S.D.	IG	0.500	Inf	2.270	[2.023, 2.501]
σ_g	EA exogenous demand shock innovation S.D.	IG	0.500	Inf	0.365	[0.322, 0.409]
σ_h	EA labor shock innovation S.D.	IG	0.500	Inf	0.269	[0.226, 0.314]
σ_c	EA consumption price markup shock innovation S.D.	IG	0.500	Inf	0.124	[0.108, 0.139]
σ_i	EA investment price markup shock innovation S.D.	IG	0.500	Inf	2.321	[2.041, 2.608]
σ_r	EA monetary policy shock innovation S.D.	IG	0.500	Inf	0.684	[0.599, 0.769]
σ_a	EA neutral technology shock innovation S.D.	IG	0.500	Inf	0.273	[0.224, 0.318]
σ_ψ	EA IS technology shock innovation S.D.	IG	0.500	Inf	0.606	[0.518, 0.690]
σ_ν	EA MEI shock innovation S.D.	IG	0.500	Inf	5.794	[5.022, 6.554]
σ_μ	EA EF premium shock innovation S.D.	IG	0.500	Inf	0.306	[0.246, 0.363]
σ_γ	EA net worth shock innovation S.D.	IG	0.500	Inf	10.909	[10.292, 11.567]
σ_b^*	US preference shock innovation S.D.	IG	0.500	Inf	11.385	[9.653, 12.574]
σ_g^*	US exogenous demand shock innovation S.D.	IG	0.500	Inf	0.414	[0.367, 0.462]
σ_h^*	US labor shock innovation S.D.	IG	0.500	Inf	0.319	[0.257, 0.381]
σ_c^*	US consumption price markup shock innovation S.D.	IG	0.500	Inf	0.100	[0.088, 0.112]
σ_i^*	US investment price markup shock innovation S.D.	IG	0.500	Inf	0.498	[0.432, 0.563]
σ_r^*	US monetary policy shock innovation S.D.	IG	0.500	Inf	0.658	[0.571, 0.743]
σ_a^*	US neutral technology shock innovation S.D.	IG	0.500	Inf	1.261	[1.096, 1.417]
σ_ψ^*	US IS technology shock innovation S.D.	IG	0.500	Inf	0.322	[0.268, 0.378]
σ_ν^*	US MEI shock innovation S.D.	IG	0.500	Inf	4.647	[4.252, 5.043]
σ_μ^*	US EF premium shock innovation S.D.	IG	0.500	Inf	0.146	[0.128, 0.163]
σ_γ^*	US net worth shock innovation S.D.	IG	0.500	Inf	1.316	[1.152, 1.477]

Note: In the type of prior distributions, B, G, IG, and N stand for Beta, Gamma, Inverse Gamma, and Normal distributions, respectively.

Table 4: Variance decomposition.

		Output		Investment		Consumption		Labor	
Shock		EA	US	EA	US	EA	US	EA	US
e_e	UIP	0.2	0.1	2.8	0.0	2.5	0.2	0.7	0.1
e_b	EA preference	12.2	0.0	1.1	0.0	21.4	0.1	3.4	0.5
e_g	EA exogenous demand	1.9	0.0	0.0	0.0	2.9	0.1	0.4	0.1
e_h	EA labor	10.5	0.1	4.6	0.0	5.5	0.1	28.8	0.1
e_c	EA consumption price markup	2.4	0.0	0.5	0.0	1.9	0.0	1.4	0.1
e_i	EA investment price markup	15.1	0.2	19.6	0.2	4.1	0.6	5.9	4.8
e_r	EA monetary policy	0.0	0.0	0.6	0.0	0.1	0.0	0.0	0.0
e_a	EA neutral technology	16.1	19.2	7.7	1.9	3.0	30.5	0.7	23.5
e_ψ	EA IS technology	7.1	0.4	13.2	0.7	20.1	0.1	44.8	0.6
e_ν	EA MEI	8.7	0.1	38.4	0.7	2.6	0.1	4.4	0.1
e_μ	EA EF premium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e_γ	EA net worth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
e_b^*	US preference	23.8	12.3	0.2	2.4	31.1	35.5	4.7	1.4
e_g^*	US exogenous demand	0.1	5.5	0.0	0.0	0.1	0.6	0.0	2.0
e_h^*	US labor	0.2	2.5	0.0	0.8	0.2	2.7	0.1	6.7
e_c^*	US consumption price markup	0.1	9.2	0.1	4.3	0.1	7.7	0.2	9.6
e_i^*	US investment price markup	0.0	8.7	0.0	4.5	0.0	6.8	0.1	7.1
e_r^*	US monetary policy	0.0	0.5	0.0	1.6	0.0	0.0	0.0	0.3
e_a^*	US neutral technology	0.1	9.0	0.1	0.6	0.1	4.5	0.0	10.1
e_ψ^*	US IS technology	0.9	15.2	4.8	55.2	3.0	6.0	4.3	23.8
e_ν^*	US MEI	0.1	13.7	0.7	16.1	0.1	4.4	0.1	4.9
e_μ^*	US EF premium	0.2	2.2	4.3	7.4	0.9	0.0	0.2	3.0
e_γ^*	US net worth	0.0	1.0	1.1	3.6	0.4	0.0	0.0	1.2

Note: This table shows the variance decomposition of output growth, investment growth, consumption growth, and labor corresponding to periodic components with frequency between 8 and 32 quarters, evaluated at the posterior mean estimates of parameters.

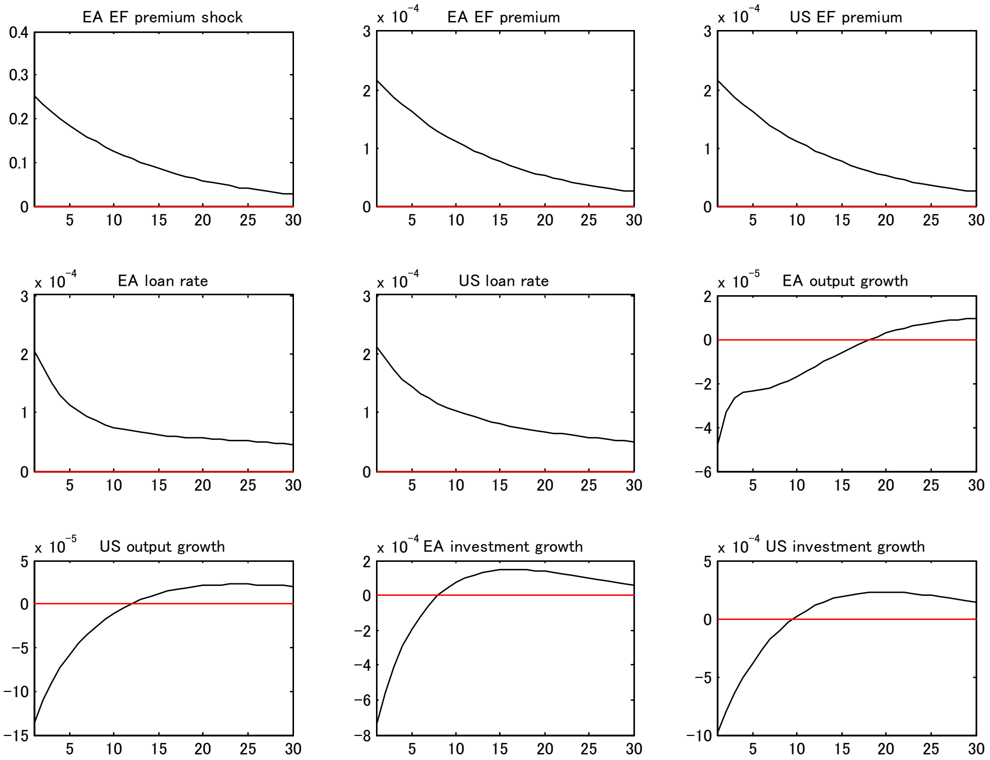

Figure 1: Impulse responses to the external finance premium shock in the Euro Area.

Note: The figures show the impulse responses to a one standard deviation innovation to the EF premium shock in the EA, based on the posterior mean estimates of parameters.

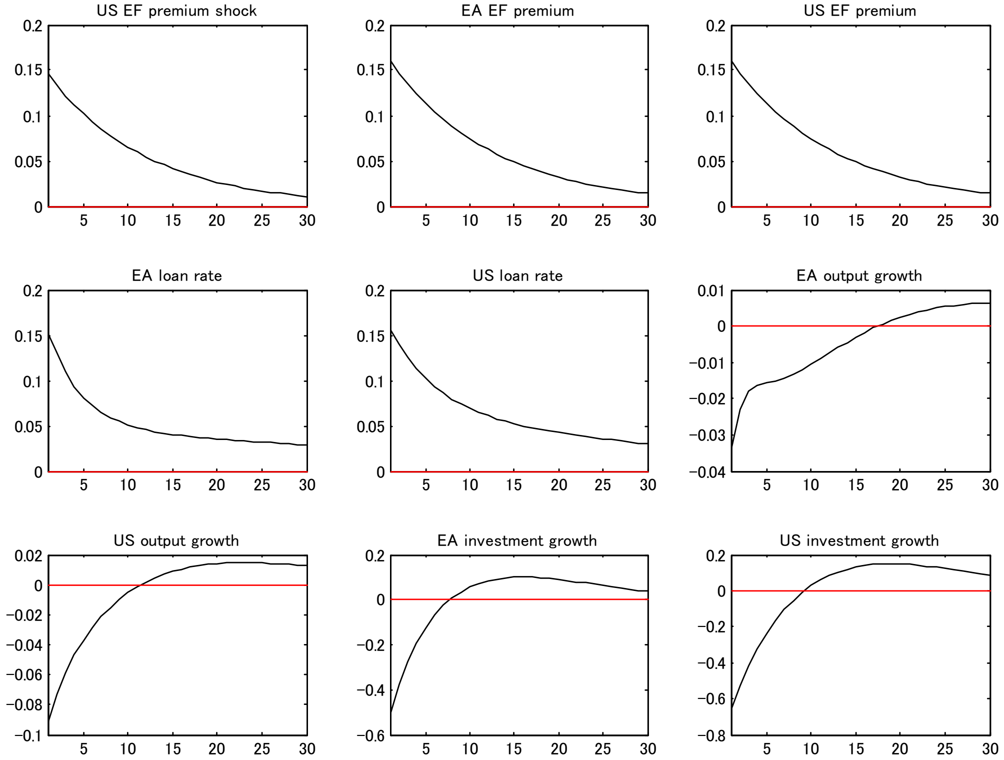

Figure 2: Impulse responses to the external finance premium shock in the United States.

Note: The figures show the impulse responses to a one standard deviation innovation to the EF premium shock in the US, based on the posterior mean estimates of parameters.

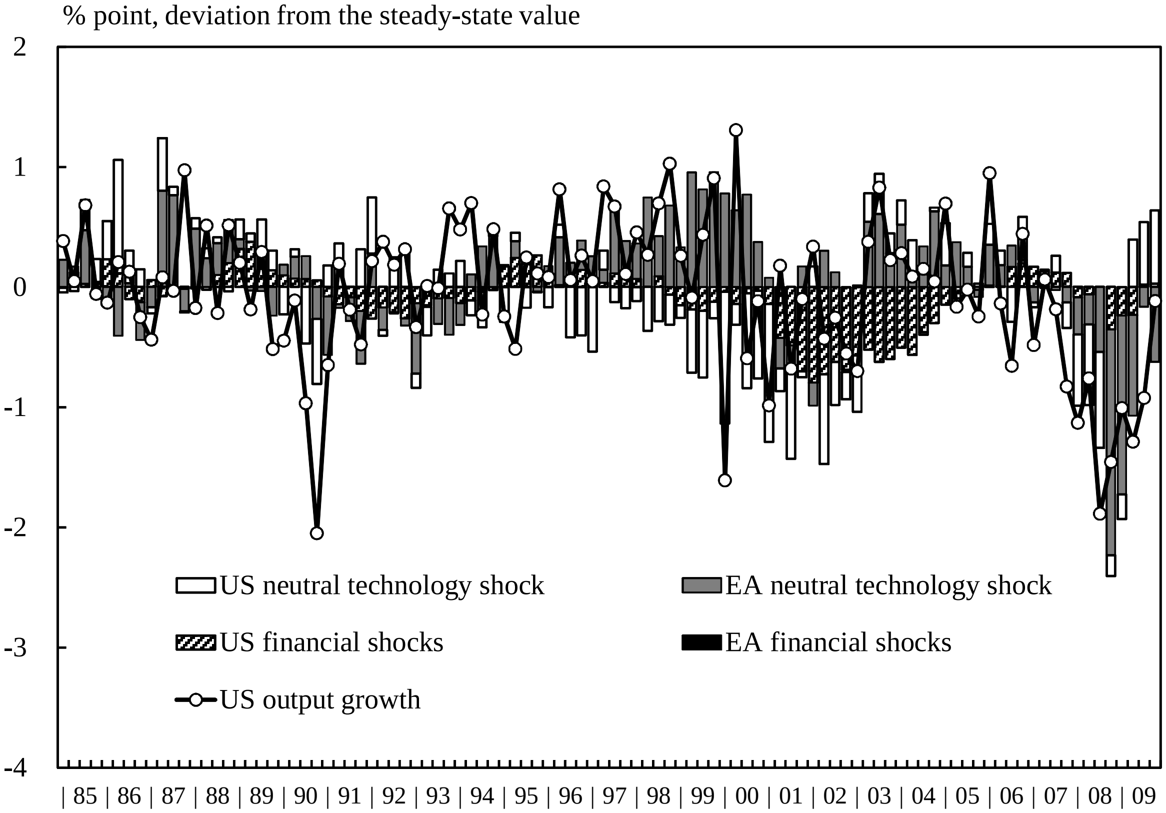

Figure 3: Historical decomposition of the output growth rate in the United States.

Note: This figure shows the historical decomposition of the US output growth rate, based on the posterior mean estimates of parameters and the Kalman smoothed mean estimates of shocks.

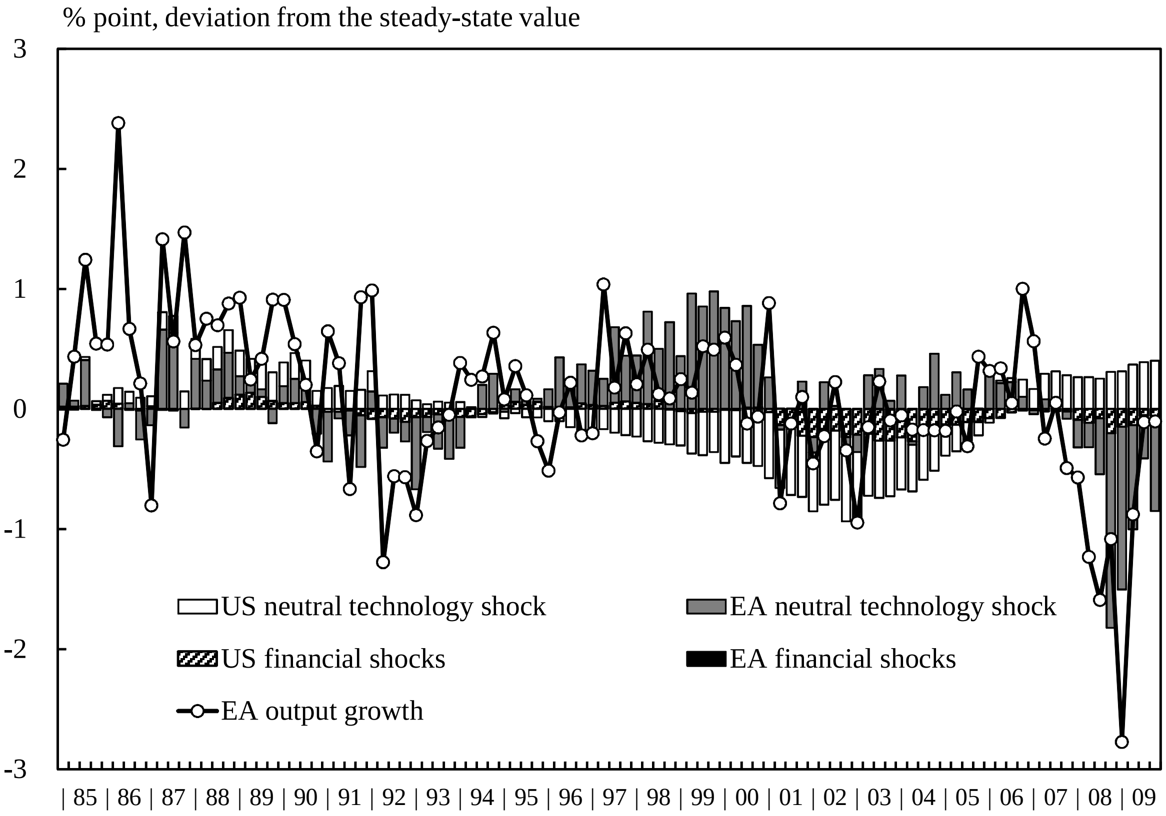

Figure 4: Historical decomposition of the output growth rate in the Euro Area.

Note: This figure shows the historical decomposition of the EA output growth rate, based on the posterior mean estimates of parameters and the Kalman smoothed mean estimates of shocks.

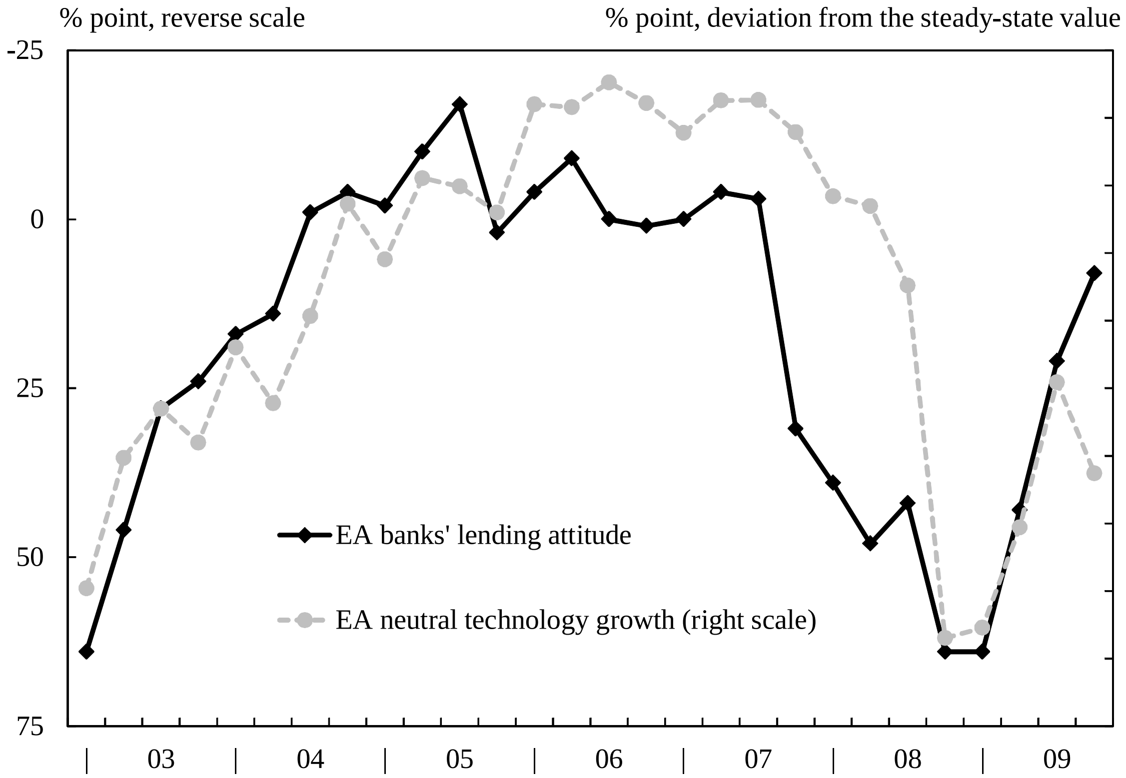

Figure 5: Banks' lending attitude and estimated neutral technology growth in the Euro Area.

Note: This figure compares the estimated series of EA neutral technology growth $\hat{a}_t$ and the series of the net tightening of credit standards for loan to enterprises in The Euro Area Bank Lending Survey by the ECB.

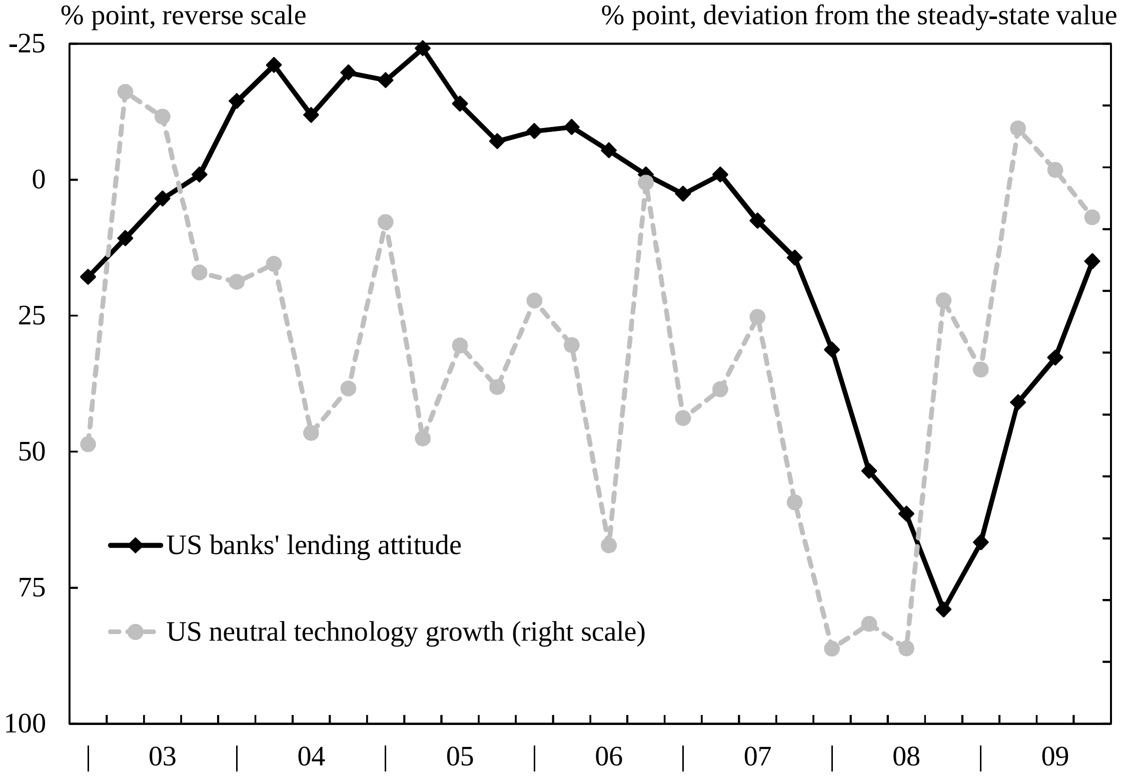

Figure 6: Banks' lending attitude and estimated neutral technology growth in the United States.

Note: This figure compares the estimated series of US neutral technology growth $\hat{a}_t^*$ and the series of domestic respondents' tightening standards for C&I loans in the Senior Loan Officer Opinion Survey on Bank Lending Practices by the FRB.