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Abstract

In this paper, I extend the business cycle accounting method a la Chari, Kehoe and McGrattan (2007) to a two-country international business cycle model and quantify the effect of the disturbances in relevant markets on the business cycle correlation between Japan and the US over the 1980-2008 period. This paper finds that disturbances in the labor market and production efficiency are important in accounting for the recent increase in the cross-country output correlation. If international financial market integration is important for considering the recent increase in cross-country output correlation, it must operate through an increase in the cross-country correlation of disturbances in the labor market and production efficiency, and not in the domestic investment market.

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1 Introduction

In this paper, I extend the business cycle accounting method a la Chari, Kehoe, and McGrattan (2007) to a two country international business cycle model and quantify the effect of disturbances in relevant markets on the business cycle correlation between Japan and the US over the 1980–2008 period. The main findings are as follows: (i) disturbances in the labor market and production efficiency are important in accounting for the recent increase in the cross-country output correlation; (ii) disturbances in the international financial market are necessary for considering the low cross-country correlation of consumption; and (iii) the main role of the disturbances in the investment market is to prevent resources from flowing into the relatively efficient country. If financial market integration is important for considering the recent increase in cross-country output correlation, it must operate through an increase in the cross-country correlation of disturbances in the labor market and production efficiency, not in the domestic investment market.

The quarterly correlation of the US and Japanese business cycles during the 1980–2008 period is surprisingly low. The correlation of output is approximately zero during the 1980s and negative during the 1990s. Nonetheless, the famous quantity anomaly shown by Backus, Kehoe, and Kydland (1992) still holds because the cross-country correlation of consumption is even lower than the cross-country correlation of output during the period. While the overall cross-country output correlation is low, it dramatically increased during the 2000s. In this paper, I apply the business cycle accounting method to a two-country model and quantitatively account for the Japanese and US business cycle correlation.

The model's foundation is one-good two-country model a la Baxter and Crucini (1995), which consists of final good firms, households, and governments in both countries. The final good firms in both countries produce an identical final good from capital and labor using constant returns to scale production technology. The final good firms face Hicks-neutral disturbances in production efficiency. The infinitely-lived representative households in both countries gain utility from consumption and leisure. The households in each country earn income from capital stock and labor supplied to the final good firms with which they purchase consumption and investment. Moreover, they trade state contingent international claims whose returns are affected by international financial disturbances. The governments in each country collect distortionary labor income and investment taxes from the household, purchase final goods, and rebate the remainder as a lump-sum transfer.

Chari et al (2007) show that distortions created by various frictions can be mapped into a prototype model with distortionary taxes. Following that study, I assess where the important distortions in accounting for the business cycle correlation between Japan and the US are located, instead of analyzing the effects of actual distortionary taxes on the business cycles, as in Braun (1994) and McGrattan (1994). The disturbances in resource, labor, investment, production efficiency, and international financial markets are computed as "wedges" from equilibrium conditions using data of output, consumption, labor, investment, and government purchases. Resource, labor, investment, and production efficiency wedges are identical to those introduced in the original literature. Resource wedges are disturbances in the resource constraints that correspond to government purchases in the data. Labor wedges are disturbances in the labor first order condition that capture the discrepancy between the intratemporal marginal rate of substitution of leisure to consumption and the marginal product of labor. Investment wedges are disturbances in the capital Euler equation that capture the discrepancy between the intertemporal marginal rate of substitution and the return on investment. Production efficiency wedges are equivalent to total factor productivity, i.e., Solow residuals. Wedges in the international financial market are natural additions that I made to the original literature as I extended the business cycle accounting model to a two-country framework. International price wedges are disturbances in the cross-country arbitrage condition that drives wedges between the marginal utility of consumption across countries. International resource wedges are disturbances in the international resource constraint that captures the residual in the aggregate trade balance evaluated at international prices.

This paper is consistent with existing business cycle accounting literature on the US and Japanese economies. The original business cycle accounting paper by Chari et al (2007) concludes that labor and efficiency wedges are important in accounting for the US output fluctuation during the Great Depression and the 1982 recession. Kobayashi and Inaba (2006) show that labor and efficiency wedges are important in accounting for the lost decade in the 1990s. Otsu and Pyo (2009) and Chakraborty (2009) show that not only efficiency wedges but also investment wedges contributed to the build-up of the bubble economy in the late 1980s. While all of these studies use a closed economy models and linearly detrended data, the present study uses an open economy model with HP-filtered data. Nonetheless, I find that labor and efficiency wedges are important in accounting for the HP-filtered fluctuation in US output, while efficiency wedges are important in accounting for that in Japan over the 1980–2008 period.

This paper is also related to international real business cycle models such as Baxter and Crucini (1995), Backus, Kydland, and Kehoe (1994), and Stockman and Tesar (1995). Considering productivity shocks to be given, the simulated cross-country output correlation generated from the model is low and cross-country consumption correlation generated from the model is extremely high relative to data respectively. This paper quantifies the sources of this well-known quantity anomaly by the wedges in each market. Cross-country output correlation is very low in a canonical model since production factors shift toward the relatively productive country. Therefore, production factors have negative cross-country correlations even if productivity shocks are positively correlated across countries. The international business cycle accounting results show that labor and investment wedges are indeed important in increasing the cross-country correlation of output. The international state-contingent claim enables international risk sharing that leads to the high cross-country consumption correlation. International price wedges are needed in order to lower the cross-country correlation of consumption. A successful model for explaining business cycle patterns in a two-country setting must account for the movements in these key wedges.

Furthermore, the business cycle accounting framework enables the assessment for identifying the wedges that are important for considering the recent increase in the cross-country US-Japan business cycle correlation. While the cross-country correlation of all of the domestic wedges increased in the 2000s, the increase in the cross-country correlation of the labor and efficiency wedges are quantitatively important in accounting for the increase in the cross-country output correlation. Therefore, if international financial market integration is the driving force of the recent increase in cross-country output correlation, it must manifest itself as an increase in cross-country correlation of labor and/or efficiency wedges, not investment wedges.

Moreover, I provide simple observational equivalence mapping from international real business cycle models to the prototype international business cycle accounting model with wedges. Backus, Kehoe, and Kydland (1994) and Stockman and Tesar (1995) extend the one-good two-country model to two-good two-country models. I show that such extensions can be interpreted as attempts to endogenously consider the movements of international price wedges. The incomplete capital markets model can also be interpreted to be endogenously accounting for changes in international price wedges by limiting international risk sharing. Therefore, these models can be mapped into the prototype model with wedges. In addition, models with alternative preferences can be mapped into the prototype model with wedges. Therefore, the prototype model serves as a benchmark to investigate the effectiveness of additional assumptions not only on the model structure, but also on household preferences.

The remainder of the paper is organized as follows. In section 2, I assess the business cycle fluctuation facts in Japan and the US In section 3, I describe the prototype international business cycle accounting model. In section 4, I explain the quantitative method and present the simulation results. In section 5, I discuss simple observational equivalence results between international business cycle models with additional structure or alternative preferences, and the prototype model with wedges. Section 6 concludes the paper. Sensitivity analysis results are presented in the appendix.

2 Data

In this section, I present data of the recent business cycle correlation pattern between Japan and the US that focuses on output, consumption, labor, and investment. Output is defined as GDP plus the flow income from durable goods and government capital stock; consumption is defined as the sum of expenditures on nondurable goods and services and the service flow from durable goods and government capital stock; investment is defined as the sum of gross capital formation, government fixed investment, and expenditure of durable goods; and labor refers to the total hours worked. The data source is the BEA website for the US and the ESRI website for Japan.

Table 1 shows the cross-country correlations of quarterly data for 1980–2008 after being detrended by the Hoddrick-Prescott (HP) filter[1]. Japanese and US data show positive but low cross-country correlation of output and labor. In fact, output correlation is almost zero during the 1980s and negative during the 1990s. Ambler et al (2004) show that the cross-country correlation of output between developed countries has fallen during the 1990s, as compared to that for the time-frame used by Backus et al (1994). Surprisingly, the cross-country correlations of consumption and investment are negative

[1] Correlations of linearly detrended data are presented in the appendix table 1. The major results do not change whether we use HP filtered data or linearly detrended data.

on average over the entire period. Therefore, the so-called quantity anomaly such that the cross-country correlation between output is higher than that of consumption still holds. The entire period is sub divided into decades because spnas of ten years seemed as natural divisions given the output fluctuation patterns shown below in Figure 1. The business cycle correlation of the Euro area with Japan and the US also increased during the 2000s. The cross-country output correlations of the Euro area[2] with Japan and the US for 1991–1999 are 0.11 and 0.25, while those for 2000–2008 are 0.72 and 0.55 respectively. I have not included the Euro area in the analysis because of the limited data period covered by reliable data sources[3].

Figure 1 shows the HP-filtered output series in Japan and the US. During the early 1980s, the US experienced a recession, whereas Japan was relatively stable. In the late 1980s, Japan experienced a large expansion, referred to as the bubble economy, while the US was relatively stable. The business cycle correlation was negative in the 1990s because the US underwent steady growth, whereas Japan experienced a decade-long recession, known as the lost decade. The business cycle correlation was stronger for the 2000s. Both countries faced a mild recession in 2000. After a boom during the early to mid-2000s, both economies went into a recession in 2007. The dramatic increase in cross-country output correlation is not solely because of the recent global recession. Excluding 2007 and 2008 from the sample does not dampen the strong cross-country correlation.

Figures 2a and 2b show the HP-filtered fluctuations in key macroeconomic variables in both countries. The correlation of each variable with output follow the stylized facts of the real business cycle literature. Consumption, labor, and investment are all procyclical in each country over the 1980–

[2]Due to data availability issues, real GDP per capita is used as output for the Euro area, and the countries included are Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Norway, the UK, and Switzerland.

[3]For instance, GDP data is available for Germany from 1991, while the data on the average weekly hours worked is available from 1998 for most countries. The data source is the Eurostat website.

2008 period. Consumption and labor are less volatile than output, whereas investment is much more volatile than output.

3 The Prototype Model

The model is a competitive market version of a standard two-country model a la Baxter and Crucini (1995) wherein both countries produce a single tradable final good. Each country $i = JP, US$ consists of a representative household, firm, and government. Following Chari, Kehoe and McGrattan (2007), I introduce wedges in relevant markets, represented as distortionary shocks. The full description of the model is as follows.

3.1 Final Good Firms

The final good firms in each country produce aggregate output Y_t from capital stock K_t and labor supply L_t[4] using Cobb-Douglas production technology that is affected by aggregate TFP, A_t:

$$Y_t^i = A_t^i (K_t^i)^{\theta^i} (l_t^i)^{1-\theta^i}, \tag{1}$$

where θ represents the capital share. I decompose the aggregate TFP into the trend component, $\Gamma_t = (1+\gamma)\Gamma_{t-1}$, also known as the labor augmenting technical progress, and the stationary component z_t:

$$A_t^i = \exp(z_t^i)(\Gamma_t^i)^{1-\theta^i}.$$

[4] Output and capital stock are divided by the adult population. Labor supply consists of average hours worked per worker and the number of workers per adult population. The average hours worked per worker are defined as the average weekly hours worked per worker divided by 14×7, assuming that 14 hours is the maximum that each worker can work per day.

Then, dividing both sides of (1) by Γ_t, the production function can be rewritten as

$$y_t^i = \exp(z_t^i)(k_t^i)^{\theta^i}(l_t^i)^{1-\theta^i}, \tag{2}$$

where y_t^i and k_t^i are output and capital detrended by Γ_t respectively. Finally, the detrended profit maximization problem for the final good firm can be written as

$$\max\left[\exp(z_t^i)(k_t^i)^{\theta^i}(l_t^i)^{1-\theta^i} - w_t^i l_t^i - r_t^i k_t^i\right],$$

where w_t and r_t are real wages and real return on capital respectively[5].

3.2 Households

The households in each country maximize lifetime utility:

$$U = \sum_{t=0}^{\infty}\sum_{s^t}\beta^t\pi(s^t)u(c_t^i(s^t), l_t^i(s^t)),$$

where c_t and l_t denote detrended consumption and labor supply respectively. The current state is defined as s^t, while the unconditional probability of that state to occur is denoted as $\pi(s^t)$. I assume the following conventional periodical preference function:

$$u(c_t^i(s^t), l_t^i(s^t)) = \Psi^i \ln c_t^i(s^t) + (1-\Psi^i)\ln(1-l_t^i(s^t)). \tag{3}$$

The maximization problem is subject to a budget constraint:

$$\begin{aligned} & (1-\tau_{lt}^i(s^t))w_t^i(s^t)l_t^i(s^t) + r_t^i(s^t)k_t^i(s^t) + p_t^i(s^t)d_t^i(s^t) + tr_t^i(s^t) \\ = \; & c_t^i(s^t) + (1+\tau_{xt}^i(s^t))x_t^i(s^t) + p_t^i(s^t)\sum_{s_t^{t+1}|s^t} q_t(s^{t+1}|s^t)d_{t+1}^i(s^{t+1}|s^t) + \Phi_t(s^t)k_t^i(s^t), \end{aligned}$$

[5] According to the Kaldor growth facts, real wages grow as the labor augmenting technical progress Γ_t increases. Thus, they are detrended by Γ_t. On the other hand, real interest rates do not follow any particular trend.

where x_t is investment, d_t is the state contingent international claim, q_t is the price of the claim, τ_{lt} and τ_{xt} represent distortionary taxes on labor income and investment respectively, and tr_t is the lump-sum transfer from the government. I assume that the international claim is denominated in Japanese final goods so that $p_t^{JP} = 1$ and $p_t^{US} = p_t$. Future variables depend on the future state conditional on the current state $s^{t+1}|s^t$.

Investment is assumed to follow the capital law of motion:

$$\Gamma^i k_{t+1}^i(s^t) = x_t^i(s^t) + (1 - \delta^i)k_t^i(s^{t-1}). \tag{4}$$

The investment adjustment cost Φ_t is assumed to take the form of

$$\Phi_t(s^t) = \frac{\phi^i}{2}\left(\frac{x_t^i(s^t)}{k_t^i(s^{t-1})} - d^i\right)^2,$$

where $d^i = \Gamma^i - (1 - \delta^i)$[6]. Following Christiano and Davis (2006), I set the parameter of capital adjustment cost ϕ^i so that the marginal Tobin's q is equal to one.

3.3 International Financial Market

The state contingent international claims are traded at the international price q_t. The assumption that the claim is denominated in Japanese final goods means that the effective price of the claim is q_t for Japan and $p_t q_t$ for the US. This disturbance p_t can be considered to be a disturbance in the conversion rate of resources in Japan to that in the US.

The international financial constraint can be written as

$$[q_t d_{t+1}^{JP} - d_t^{JP}] + [q_t d_{t+1}^{US} - d_t^{US}] = \tau_t.$$

The residual term τ_t captures the flow of goods from Japan or the US to other

[6]This guarantees that the adjustment cost is equal to zero in the steady state.

countries in the world and vice versa; this is not captured in the model. This term is important because we need both domestic and international resource constraints to hold in order to operate the accounting procedure. This condition can be rewritten into an international trade balance constraint

$$tb_t^{JP} + tb_t^{US}/p_t = \tau_t, \tag{5}$$

where tb is the trade balance.

3.4 Government

The government collects taxes from households, purchases goods and services, and rebates the remaining to the household as a lump-sum transfer in order to satisfy the government budget constraint:

$$\tau_{lt}^i w_t^i l_t^i + \tau_{xt}^i x_t^i = tr_t^i + g_t^i. \tag{6}$$

Braun (1994) and McGrattan (1994) show that distortionary taxes are important in accounting for the postwar US business cycles. However, the main focus of this paper is not to analyze the effect of distortionary taxes, but to identify the wedge that is important in accounting for the business cycle correlation in Japan and the US. Chari, Kehoe and McGrattan (2007) show that several sophisticated models can be mapped into the prototype model with distortions. For instance, monetary shocks with sticky nominal wages manifest themselves as distortions in the labor market. On the other hand, financial frictions such as in Bernanke, Gertler, and Gilchrist (1998) and Carlstrom and Fuerst (1997) manifest themselves as distortions in the investment market. Focusing only on distortionary taxes will overlook the effect of these channels. Therefore, I do not use actual data of distortionary taxes in this paper.

3.5 Shocks

The 10 exogenous state variables are $s = \{g^i, \tau_l^i, \tau_x^i, z^i, p, \tau\}$. I assume that they follow a VAR process, as follows:

$$s_t = P_0 + P * s_{t-1} + \varepsilon_t, \tag{7}$$

where $\varepsilon = \{\varepsilon_g^i, \varepsilon_l^i, \varepsilon_x^i, \varepsilon_z^i, \varepsilon_p, \varepsilon_\tau\}$. I assume that the error terms ε are normally distributed with a mean zero, while there are no restrictions on its variance-covariance matrix V. Agents form rational expectations on future levels of exogenous variables according to this process.

3.6 Equilibrium

The competitive equilibrium is characterized by the prices and quantities $\{y^i, c^i, l^i, x^i, tb^i, k^i, w^i, r^i, tr^i, g^i, \tau_l^i, \tau_x^i, z^i, q, p, \tau\}$, such that (i) households optimize given prices and wedges $\{w^i, r^i, q, p, \tau^i, \tau_l^i, \tau_x^i\}$; (ii) final goods firms optimize given prices and wedges $\{w^i, r^i, z^i\}$; (iii) government budget constraint (6) holds; (iv) the domestic resource constraints,

$$y_t^i = c_t^i + x_t^i + g_t^i + tb_t^i + \Phi_t k_t^i, \tag{8}$$

hold; and (v) wedges follow the stochastic process (7).

The equilibrium can be summarized by the following 10 equations[7]. The Euler equation in both countries

$$\Gamma^i(1+\tau_{xt}^i+\Phi_t')u_{ct}^i = \beta^i E_t\left[u_{ct+1}^i\left(\theta^i\frac{y_{t+1}^i}{k_{t+1}^i} + (1-\delta^i)(1+\tau_{xt+1}^i) + \Phi_{t+1}'\frac{k_{t+2}}{k_{t+1}} + \Phi_{t+1}\right)\right], \tag{9}$$

[7]For simplicity, I abbreviate the state notations and use conventional expectation operator instead.

the labor first order condition in both countries

$$-\frac{u_{lt}^i}{u_{ct}^i} = (1-\tau_{lt}^i)(1-\theta^i)\frac{y_t^i}{l_t^i}, \tag{10}$$

the international first order condition

$$p_t = \frac{u_{ct}^{JP}}{u_{ct}^{US}}\kappa, \tag{11}$$

the domestic resource constraints in both countries (8), the production function in both countries (2), the capital law of motion in both countries (4), and the international resource constraint (5), where $u_{ct}^i = \Psi^i/c_t^i$ and $u_{lt}^i = -(1-\Psi^i)/(1-l_t^i)$. The constant term κ in the international first order condition (11) depends on the initial conditions of the economy. Without loss of generality, if we assume a symmetric initial state, we get $\kappa = 1$[8]. These 12 equations characterize the equilibrium of the following 12 endogenous variables $\{y^i, c^i, l^i, x^i, tb^i, k^i\}$, given 10 exogenous variables $\{g^i, \tau_l^i, \tau_x^i, z^i, p, \tau\}$, and the initial value of capital stock, the endogenous state variable, in both countries.

[8] The international first order condition

$$p_t\frac{u_{ct}^{US}}{u_{ct}^{JP}} = p_{t+1}\frac{\beta^{US}u_{ct+1}^{US}}{\beta^{JP}u_{ct+1}^{JP}}$$

must hold for every possible state owing to the complete markets assumption. This condition can be iterated backwards, which yields

$$p_t\frac{u_{ct}^{US}}{u_{ct}^{JP}} = p_0\frac{(\beta^{US})^{-t}u_{c0}^{US}}{(\beta^{JP})^{-t}u_{c0}^{JP}} = \kappa.$$

If $\beta^{US} = \beta^{JP}$, $p_0 = 1$ and $u_{c0}^{US} = u_{c0}^{JP}$, then $\kappa = 1$.

4 Quantitative Analysis

The business cycle accounting procedure is conducted as follows. First, I use the equilibrium conditions and data of output, consumption, labor, investment, and government purchases for 1980–2008 to calibrate and estimate the parameter values. Second, I obtain linear decision rules for endogenous variables using the method of undetermined coefficients. Third, I compute the wedges using data and linear decision rules. Finally, I simulate the model using the computed wedges and linear decision rules. In this section, I explain the quantitative method in detail and present the simulation results.

4.1 Parameter Values

I assume that there is symmetry in the structural parameters in Japan and the US for simplicity. I use the average of the separately calibrated parameter values as the common parameter values in both countries. The values of structural parameters are listed in Table 2. The detailed calibration procedure is as follows.

The capital share parameter θ is calibrated as follows for each country. First, the capital income share

$$\theta_p = \frac{\text{unambiguous capital income + fixed capital consumption}}{GDP \text{ - ambiguous capital income}}$$

is directly calculated from national income and product accounts[9]. The values are 0.36 for Japan and 0.29 for the US[10]. Since output is defined as GDP plus the flow income from durable and government capital stock ($FLOW$), the capital share is computed as

$$\theta = \frac{\theta_p \times GDP + FLOW}{GDP + FLOW}.$$

[9] For details, see Cooley and Prescott (1995).

[10] I use the Hayashi and Prescott (2002) data set for 1980–2002 for Japan, and BEA data for 1980–2006 for the US.

The depreciation rate is computed directly from the data using the capital law of motion (4)[11]. The average growth rate of per capita output is used for the growth trend Γ. The subjective discount rate β is calibrated to the data of the average capital-output ratio using the steady state version of capital Euler equation (9)

$$\Gamma^i(1+\tau_x^i) = \beta^i \left(\theta^i \frac{y^i}{k^i} + (1-\delta^i)(1+\tau_x^i)\right).$$

The utility parameter Ψ is calibrated to match the data of average labor and consumption-output ratio with the steady state version of the labor first order condition (10)

$$\frac{1-\Psi^i}{1-l^i} = (1-\tau_l^i)(1-\theta^i)\frac{y^i}{l^i}\frac{\Psi^i}{c^i}.$$

I assume that the steady state values of wedges $\{\tau_l^i, \tau_x^i, z^i\}$ are zero for simplification. The steady state levels of government wedges g are computed directly from the data. The steady state levels of international prices p and trade shocks τ are computed from the steady state versions of (11) and (5) respectively.

The persistence parameters of the shock process (7) is obtained using maximum likelihood estimation[12]. For the estimation, I use linearly detrended data of output, consumption, labor, investment, and government purchases for both countries as observable variables. Since there are 10 shocks and 10 observable variables, the system is just identified. Since there are no restrictions on the variance-covariance matrix of the error terms, they are contemporaneously correlated. Unlike the structural parameters, I do not assume symmetry across countries in the stochastic process.

[11] The capital stock series is constructed by the perpetual inventory method.

[12] Resource wedges, labor wedges, production efficiency wedges, and international wedges can all be directly computed from the equilibrium conditions. However, computing investment wedges involves expectational terms. Hence, they cannot be directly computed. Therefore, the entire system must be estimated.

4.2 Wedges

Once the parameter values are obtained, the model can be numerically solved for decision rules. I use the linear solution method a la Uhlig (1999) to solve the model. Following Chari et al (2007), I compute the wedges using the obtained linear decision rules and the data of the observable variables used for the estimation.

The linear decision rules DR of endogenous variables are functions of state variables $\{k^i, g^i, \tau_l^i, \tau_x^i, z^i, p, \tau\}$. Initial capital stock in each country is assumed to be at the steady state level. Once the initial capital stock level is given, the entire series of wedges can be computed. The detailed procedure is as follows.

1. Solve the model for linear decision rules:

$$\{k_{t+1}^i, y_t^i, c_t^i, l_t^i, x_t^i, g_t^i\} = DR_{\{k^i,y^i,c^i,l^i,x^i,g^i\}}(k_t^i, g_t^i, \tau_{lt}^i, \tau_{xt}^i, z_t^i, p_t, \tau_t).$$

2. Assuming $k_0^i = k_{ss}^i$, compute $\{g_0^i, \tau_{l0}^i, \tau_{x0}^i, z_0^i, p_0, \tau_0\}$ from

$$\{y_0^i, c_0^i, l_0^i, x_0^i, g_0^i\} = DR_{\{y^i,c^i,l^i,x^i,g^i\}}(k_0^i, g_0^i, \tau_{l0}^i, \tau_{x0}^i, z_0^i, p_0, \tau_0).$$

3. Compute k_1^i from

$$k_1^i = DR_{\{k^i\}}(k_0^i, g_0^i, \tau_{l0}^i, \tau_{x0}^i, z_0^i, p_0, \tau_0).$$

4. Solve for $\{g_1^i, \tau_{l1}^i, \tau_{x1}^i, z_1^i, p_1, \tau_1\}$ from

$$\{y_1^i, c_1^i, l_1^i, x_1^i, g_1^i\} = DR_{\{y^i,c^i,l^i,x^i,g^i\}}(k_1^i, g_1^i, \tau_{l1}^i, \tau_{x1}^i, z_1^i, p_1, \tau_1).$$

5. Repeat 4 and 5 for the whole period.

Figures 3a and 3b plot the domestic wedges in each country along with detrended output, while Figure 3c plots the international wedges. All wedges are detrended by the HP filter. Investment wedges are at least twice more volatile than the other wedges in each country. However, this does not immediately imply that investment wedges are important in accounting for business cycles. In order to evaluate the importance of each wedge, we have to simulate the model. One notable fact is that the model predicts a fall in relative prices of Japanese goods during the late 1980s and mid-1990s, which is when the yen actually appreciated in real terms against US dollars to a historical level. The fact that international price wedges cannot replicate real exchange rates is related to the international price anomaly a la Backus and Smith (1993). In this paper, I will not discuss the price issues and focus on the fluctuations of quantities.

The key economic effects of the changes in each wedge are as follows. A rise in domestic and international resource wedges will generate a negative income effect for the household that tends to reduce consumption and leisure leading to an increase in labor and output. An increase in labor wedges increases the relative price of leisure to consumption, which causes a substitution effect that leads the household to reduce consumption and increase leisure. A decrease in labor leads to an output decline. An increase in current investment wedges increases the relative price of investment to consumption, which leads to an increase in consumption and a reduction in investment. An increase in production efficiency wedges causes a real business cycle effect that increases output, consumption, labor, and investment. An improvement in production efficiency directly increases production. Labor increases because a rise in the marginal product of labor drives up labor demand. Investment increases because the expected future marginal product of capital is high because of an expectation of high efficiency to persist. An increase in wages leads to an increase in consumption. Finally, a rise in the international price wedges raises the price of Japanese resources relative to US resources should lead to a fall in Japanese consumption and a rise in US consumption.

Table 3 presents the correlation of domestic wedges with output in each country as well as the cross-country correlation of wedges. In both countries, government wedges have low correlation, investment wedges have strong negative correlations, and efficiency wedges have strong positive correlations with domestic output. Furthermore, the cross-country correlations of government, labor, investment, and efficiency wedges all increased during the 2000–2008 period. Therefore, the fact that output correlation increased during 2000–2008 can be attributed to the rise in cross-country correlation of wedges. In the following section, I simulate the model in order to investigate the quantitative impact of each wedge.

4.3 Simulation

Simulation is done by plugging the computed (non-HP filtered) wedges into the linear decision rules. All simulation results are detrended by the HP filter. Table 4 presents the results in terms of the fit of simulated series to the data and the cross-country correlation generated from the model. The fit of simulated series to the data of output, consumption, labor, and investment is measured by

$$corr(model, data) \times \frac{std(model)}{std(data)}.$$

This measure indicates whether the simulated variable is moving to the correct direction as well as whether its generated fluctuation is large enough[13]. If the simulation perfectly reproduces the data series, the measure of fit will be equal to one[14]. However, technically speaking, the measure is not bounded.

[13] The measure can be rewritten as

$$\frac{cov(Model, Data)}{var(Data)}$$

by definition. Measuring the fit using mean squared errors between the model and the data leads to similar results to those presented below.

[14] Notice that the data can be perfectly replicated once all of the wedges are plugged into the decision rules.

The table shows that in Japan, efficiency wedges are important in accounting for fluctuations in output; efficiency and international price wedges are important in accounting for fluctuations in consumption; labor wedges are important in accounting for fluctuations in labor; and investment wedges are important in accounting for fluctuations in investment. In the US, labor and efficiency wedges are important in accounting for fluctuations in output; international price wedges are important in accounting for fluctuations in consumption; labor wedges are important in accounting for fluctuations in labor; and investment wedges are important in accounting for fluctuations in investment. As Chari et al (2007), I find that investment wedges are not important in accounting for output fluctuations in both countries. Further, I simulate the model with efficiency wedges in both countries, which is equivalent to a canonical international real business cycle model a la Baxter and Crucini (1995)[15]. The results listed in the bottom row show that while the fit of output is high in both Japan and the US, those for consumption, labor, and investment are all low in a canonical real business cycle model.

The cross-country correlation of variables are useful to break down the sources of the quantity anomaly. First, without international price wedges, the cross-country correlation of consumption is always equal to one. This is obvious from the international risk sharing condition (11), which guarantees that consumption across countries is perfectly correlated without international price wedges. Therefore, international price wedges are necessary to account for the low cross-country correlation of consumption. Next, output, labor, and investment are all negatively correlated across countries only with efficiency wedges in either country. When efficiency is high in one country, the other country is better off borrowing from that country and postponing investment in order to increase consumption. The additional resources shifted from abroad through the international claim generates positive wealth effects;

[15] The only difference is that there are spillover effects from efficiency wedges onto other wedges.

this reduces labor in the borrowing country. Thus, production factors and output should rise in the country that experienced a positive productivity shock and should fall in the other. This intratemporal risk sharing operates even when both countries experience positive productivity shocks[16]. Therefore, canonical models with only productivity shocks fail to explain the order of cross-country correlations of output and consumption. The result in the bottom row shows that the cross-country correlation of output is far below that of consumption, i.e., the quantity anomaly.

Table 5 presents the cross-country correlation of simulated output by decade. For instance, the first column corresponds to the simulation of the model with all wedges except for domestic resource wedges in both countries. The difference between the data and the simulated correlation indicates the importance of the wedges. The model is effective without resource wedges. Labor and efficiency wedges are particularly important in accounting for the rise in output correlation in the 2000s. Investment wedges increase the cross-country correlation of output throughout the whole period by preventing resources to flow into the relatively efficient country. However, they do not explain the rise in output correlation during the 2000s. Therefore, if global financial market integration is the source of increased output correlation between Japan and the US, it must operate through the increased correlation of efficiency and labor wedges.

4.4 The Role of Capital Adjustment Costs

International real business cycle models typically assume capital adjustment costs since the fluctuation of simulated investment is extremely sensitive to productivity shocks. Since the international business cycle accounting model is based on a canonical two-country model, the prototype model includes adjustment costs. The role of capital adjustment costs have been under debate

[16] Yahkin (2007) shows that there must be distortions in labor and investment markets in order to solve the puzzle.

in the closed economy business cycle literature. Chari et al (2007) show that investment wedges without capital adjustment costs are not important in accounting for the US output drop during the Great Depression. Christiano and Davis (2006) show that capital adjustment costs increase the importance of investment wedges. In this section, I investigate the role of capital adjustment costs by simulating the model without them.

Table 6 presents the simulation results of the model without capital adjustment costs, which corresponds to Table 4. Obviously, the quantitative importance of investment wedges falls without capital adjustment costs. The results that efficiency wedges are important in Japan, while efficiency and labor wedges are important in the US in accounting for output fluctuation are emphasized. One interesting result is that the fluctuation of simulated investment is reasonable even without adjustment costs. This is because the estimated stochastic process has spill-over effects across all wedges[17].

Table 7 presents the cross-country output correlation, which corresponds to Table 5. The results show that the model with all wedges except for investment wedges is effective in replicating the cross-country output correlation when capital adjustment costs are ignored. This means that the quantitative impact of investment wedges on output correlation is even weaker than the prototype model when adjustment costs are ignored. Otherwise, there is very little difference in the patterns of correlation with and without capital adjustment costs.

5 Observational Equivalence

Early studies on international business cycles such as Backus et al (1994) and Stockman and Tesar (1995) can be considered as models that improve the quantity anomaly by connecting international price wedges to domes-

[17] A sensitivity analysis forcing the shock persistence matrix to be orthogonal shows that investment is extremely sensitive to efficiency wedges when there are no capital adjustment costs.

tic wedges. Moreover, the incomplete capital market setting improves the quantity anomaly by affecting the international first order condition. In this section, I show how these models can be mapped into the prototype international business cycle accounting model with wedges[18]. In addition, I show that models with alternative preferences can be mapped into the prototype model with wedges. I further discuss a potentially useful way to narrow down successful models.

5.1 The Backus, Kehoe, and Kydland Model

In Backus et al (1994), two countries produce intermediate goods. The intermediate goods are combined in both countries to form final goods according to an Armington aggregator

$$G_t^i = \left(\eta^i (a_t^i)^{\frac{\varepsilon-1}{\varepsilon}} + (1-\eta^i)(b_t^i)^{\frac{\varepsilon-1}{\varepsilon}}\right)^{\frac{\varepsilon}{\varepsilon-1}} = c_t^i + x_t^i,$$

where a and b are intermediate goods produced in each country. The international first order condition is

$$\frac{u_{ct}^{JP}}{u_{ct}^{US}} = \frac{G_{at}^{US}}{G_{at}^{JP}} = \frac{G_{bt}^{US}}{G_{bt}^{JP}}. \tag{12}$$

In this setting, productivity shocks to intermediate goods firms in both countries endogenously shift the international relative prices $\frac{G_{at}^{US}}{G_{at}^{JP}} = \frac{G_{bt}^{US}}{G_{bt}^{JP}}$. That is, comparing (12) with (11), if $\frac{G_{at}^{US}}{G_{at}^{JP}} = \frac{G_{bt}^{US}}{G_{bt}^{JP}} = p_t$, then the model with intermediate goods is observationally equivalent to the prototype model with international price wedges. The extent to which the productivity shocks in each country affect international price wedges depends on the elasticity of substitution between home goods and foreign goods ε, and the home bias η.

[18] The simple mapping presented in this section only focuses on the resource allocations in the prototype model and the alternative model. I do not provide formal proofs because they are obvious. Inaba and Nutahara (2009) show equivalence conditions not only for resource allocation, but also for the stochastic process in the two models.

With their parameter setting, an increase in productivity in Japan and/or a decrease in the US productivity will lead to a reduction in the international relative price of Japanese goods[19]. Although productivity shocks endogenously generate fluctuations in international price wedges, the quantity anomaly is not solved using the Backus, Kehoe, and Kydland model. This implies that there still is a need for other wedges in this setting.

5.2 The Stockman and Tesar Model

The Stockman and Tesar (1995) model has two key features: the distinction of tradable and nontradable sectors and the introduction of taste shocks. First, I discuss the effect of the two-sector setting on the equilibrium. Next, I discuss the channels through which the taste shocks operate. Both extensions can be mapped into a prototype model with wedges.

In the case of tradable and nontradable goods, the international relative prices depend on the changes in the nontradable good price. The essence of the two-good model can be described using a simple consumption composite index

$$c^i = (c^i_T)^\gamma (c^i_{NT})^{1-\gamma},$$

where c_T and c_{NT} are consumption of tradable and nontradable goods respectively. The equilibrium international relative price is

$$\frac{P^{JP}}{P^{US}} = \left(\frac{p^{JP}_{NT}}{p^{US}_{NT}}\right)^{1-\gamma},$$

where p^i_{NT} is the price of nontradables relative to the tradables[20]. Therefore, the model with tradable and nontradable goods is observationally equivalent

[19]In this model, productivity shocks are not equivalent to Solow residuals. Since they appear in the intermediate good production function, the Solow residuals include changes in intermediate good productivity and changes in the relative price of intermediate goods to final goods. Therefore, there is feedback from p_t to efficiency wedges in the Backus et al (1994, 1995) model.

[20]See Obstfeld and Rogoff (1991) for the full setting and derivations.

to the prototype model with international price wedges if $\left(\frac{p_{NT}^{JP}}{p_{NT}^{US}}\right)^{1-\gamma} = p_t$. Productivity shocks in the nontradable sector affect the international relative price through typical Balassa-Samuelson effects. That is, an increase in Japanese nontradable productivity endogenously leads to a reduction in the international price wedges. Although this helps in reducing the discrepancy between the cross-country correlations of output and consumption, it is found that this additional channel alone does not solve the quantity anomaly.

In addition, Stockman and Tesar (1995) introduce taste shocks that directly affect the relative importance of goods within the household's preference function. In a simplified one-sector version of their model, the preference function with taste shocks can be written as

$$u(c_t^i, l_t^i) = \Psi_t^i \log c_t^i + (1 - \Psi_t^i) \log(1 - l_t^i),$$

where Ψ_t is the stochastic taste shock. This setting is equivalent to the one-good demand shock model introduced by Wen (2007). With this modification, the marginal utilities become $u_{ct}^i = \Psi_t^i / c_t^i$ and $u_{lt}^i = -(1-\Psi_t^i)/(1-l_t^i)$. Therefore, the capital Euler equation (9), the labor first order condition (10), and the international financial equation (11) are all affected by fluctuations in taste shocks. Intuitively, taste shocks will work as investment wedges by affecting the relative value of today's consumption to tomorrow's consumption. However, the mapping of the model with taste shocks to a model with investment wedges requires linearization. The model with taste shocks can be mapped into the prototype model with labor wedges if

$$\frac{\Psi_t^i}{1 - \Psi_t^i} = \frac{\Psi^i}{1 - \Psi^i}(1 - \tau_{lt}^i). \tag{13}$$

The model with taste shocks can be mapped into the prototype model with international price wedges if

$$\Psi_t^{US} / \Psi_t^{JP} = p_t. \tag{14}$$

Since taste shocks are not related to efficiency wedges, taste shocks alone cannot fully account for the fluctuation in output. Moreover, it is unlikely that taste shocks alone can account for investment, labor, and international price wedges all together by coincidence[21]. Nonetheless, the introduction of taste shocks improves the quantity anomaly by reducing the correlation of consumption.

5.3 The Incomplete Asset Market Model

Baxter and Crucini (1995) investigate the importance of the asset structure of the international financial market on the cross-country business cycle comovement among developed countries. They find that if shocks are trend-stationary and there are cross-country spillovers of productivity shocks, complete markets and incomplete markets yield very similar allocations. The incomplete asset market model can also be mapped into the prototype model with international price wedges.

When only a risk free bond b_t is traded in the international financial market instead of the state-contingent claim d_t, the household cannot diversify country-specific risks because the return on the bond is predetermined. The international first order condition without international price wedges becomes

$$\frac{u_{ct}^{JP}}{u_{ct}^{US}} = \frac{\beta^{JP} E_t \left[u_{ct+1}^{JP}\right]}{\beta^{US} E_t \left[u_{ct+1}^{US}\right]}. \tag{15}$$

Therefore, the expected cross-country marginal rate of substitution of future consumption operates as the international price wedge. If $\frac{\beta^{JP} E_t\left[u_{ct+1}^{JP}\right]}{\beta^{US} E_t\left[u_{ct+1}^{US}\right]} = p_t$, then the incomplete asset market model is observationally equivalent to the prototype model with international price wedges. The result of Baxter and Crucini (1995) can be interpreted as a statement on how productivity shocks

[21] In other words, the value of taste shocks can be different, depending on whether they were computed from the capital Euler equation, the labor first order condition (13) or the international first order condition (14).

affect the right-hand side of (15). When productivity shocks are permanent, consumption will jump up in the country hit by a positive productivity shock, while it will jump down in the other due to the large wealth effects. However, when productivity shocks are transitory, consumption in both countries will rise in response to either country's positive productivity shock due to the lack of strong wealth effects. Therefore, the incomplete market model can endogenously account for p_t when the productivity shocks are persistent, whereas it cannot when they are trend-stationary.

5.4 Models with Alternative Preferences

The business cycle accounting results are affected by alternative preference assumptions. I show that the model with alternative forms of preferences can also be mapped into the prototype model with wedges. In this section, I present simple equivalence results of models with non-separable preferences, habit formation preferences, and GHH preferences to the prototype model with wedges. Quantitative results are presented in the appendix.

5.4.1 Non-Separable Utility

First, I consider a preference function that is non-separable between consumption and leisure

$$u(c,l) = \frac{(c_t^{\Psi}(1-l_t)^{1-\Psi})^{1-\sigma}}{1-\sigma}.$$

The curvature parameter represents the degree of risk aversion of the household. The preference in (3) is a special case of this preference function in which $\sigma = 1$. With non-separable preferences, $\sigma \neq 1$, marginal utilities of consumption in each countries are not only functions of consumption, but also labor.

The marginal utilities for non-separable preferences are $u_{ct}^i = \Psi^i(c_t^i)^{\Psi^i(1-\sigma)-1}(1-l_t^i)^{(1-\Psi^i)(1-\sigma)}$ and $u_{lt}^i = (1-\Psi^i)(c_t^i)^{\Psi^i(1-\sigma)}(1-l_t^i)^{(1-\Psi^i)(1-\sigma)-1}$. The labor first order condition does not change. The capital Euler equation (9) and the international first order condition is affected by the additional leisure term that enters the marginal utility. Therefore, the leisure term can be considered as partially endogenizing investment wedges and international price wedges. Sensitivity analysis provided in the appendix shows that a model with $\sigma = 5$ produces results very similar to those of the prototype model.

5.4.2 Habit Formation Utility

Next, I consider a case in which the household consumption forms habit persistence

$$u(c, l) = \Psi \log(c_t - b\widehat{c}_{t-1}) + (1 - \Psi) \log(1 - l_t).$$

The habit persistence parameter b is assumed to be equal to 0.65, following the estimation of Christiano, Eichenbaum, and Evans (2005). For simplicity, I assume that the habit is formed upon the lagged aggregate consumption $\widehat{c}$, which is not affected by individual decisions. This preference helps inducing persistence in consumption. Since both countries want to gradually increase consumption when one of the countries experiences high efficiency, they have a motive to accumulate wealth for the future. Dmitriev and Krznar (2009) find that this channel is strong enough to generate positive cross-country investment correlations when the adjustment cost for capital is sufficiently high.

With habit persistence, the marginal utility of consumption will become $u^i_{ct} = \Psi^i/(c^i_t - b\widehat{c}^i_{t-1})$, which is a function of consumption growth rather than the level of consumption. The marginal utility of labor is the same as in the prototype model. This affects the capital Euler equation (9), labor first order condition (10), and international first order condition (11). However, the international first order condition still guarantees that consumption is perfectly correlated across countries without international price wedges since the growth of consumption is perfectly correlated across countries. Sensitivity analysis shows that the quantity anomaly still exists because this alternative preference has little impact on the responses of labor.

5.4.3 GHH Preferences

Finally, I consider the GHH preferences a la Greenwood, Hercowitz, and Huffman (1988):

$$u(c, l) = \log(c_t - \chi l_t^{\nu}).$$

GHH preferences are widely used in the small open economy literature because of their ability to generate high volatility in consumption and countercyclical trade balance through the lack of income effects on labor supply. The GHH preferences can be considered to be a reduced form of preferences with home production. The implicit home production term operates as taste shocks.

The marginal utilities become $u_{ct}^i = 1/(c_t^i - \chi(l_t^i)^{\nu})$ and $u_{lt}^i = \chi\nu(l_t^i)^{\nu-1}/(c_t^i - \chi(l_t^i)^{\nu})$. This affects the capital Euler equation (9), labor first order condition (10), and international first order condition (11). Raffo (2008) shows that the GHH preference can generate a countercyclical trade balance in the Backus et al (1994, 1995) two-country model through countercyclical fluctuation of goods rather than counter cyclical international prices. The logic is as follows. With the lack of income effects on labor, productivity shocks generate larger fluctuations in consumption. If the fluctuation of domestic absorption in response to productivity shock is greater than that of output, productivity shocks can generate a counter-cyclical trade balance.

This finding is closely related to the quantity anomaly. The more the consumption reacts to the fluctuation of the domestic productivity shocks, the lower is the cross-country consumption correlation. Furthermore, since labor reacts less to foreign productivity shocks because of the lack of income effects, labor supply becomes more volatile[22]. Therefore, this helps solving the quantity anomaly even in a single good setting such as Baxter and Crucini (1995) wherein consumption and labor becomes more volatile, which leads to higher cross-country output correlation and a lower cross-country consumption correlation. I find that the simulated cross-country correlation of output and consumption using only efficiency wedges in both countries are -0.13 and 0.14 respectively, as opposed to -0.66 and 1.00 in the prototype model. Therefore, the GHH preference assumption improves the quantity anomaly, but does not solve it.

5.5 A Hint for Successful Models

Since the stochastic process (7) does not restrict the contemporaneous correlation of the error term, the errors are inter-related with each other. Table 10 shows the correlation between the error terms. International price wedges are negatively correlated to the Japanese efficiency wedges while they are positively correlated to the US efficiency wedges. Efficiency wedges are negatively correlated to investment wedges and positively correlated to labor wedges in both countries. This information is useful in narrowing down the potentially successful models.

The challenge to build a sophisticated model based on the business cycle accounting results is that we do not know the causality relationship among the wedges. Christiano and Davis (2006) show that in order to understand the nature of shocks to the economy, one has to orthogonalize the error terms. Only by doing so can we define fundamental economic shocks and understand how they form wedges. That is, the error terms can be expressed as

$$\varepsilon_t = Ce_t,$$

[22] From the international first order condition (11), marginal utilities of consumption across countries can be equalized by movements not only in consumption but also in labor. The link between consumption and leisure across countries weakens since an increase in both consumption and leisure nullifies any movement in the marginal utility.

where $ee' = I$. However, this involves an identification process of the matrix C, which is usually problematic since there is not enough information.

Sophisticated international business cycle models, such as those mentioned above, identify the contemporaneous relationship of error terms by assuming a certain structure of the economy. As long as this identification is consistent with the statistical correlation of the computed wedges, the model should be successful. In order to solve the quantity anomaly, a model should introduce additional shocks that manifest themselves as important wedges or generate a sufficiently large spill-over from one wedge to another. As discussed above, Backus et al (1994) and Stockman and Tesar (1995) have the endogenous spill-over of productivity shocks, i.e., efficiency wedges onto the international price wedges. Since the error terms of efficiency wedges and international price wedges are negatively correlated in Japan and positively correlated in the US, both of these models are supported by the data. Further, the correlation of the error terms of labor wedges and international price wedges are positive in Japan and negative in the US. This is consistent with the Stockman and Tesar (1995) model with taste shocks.

Finally, the business cycle accounting results that investment wedges are not the main source of business cycle fluctuations do not directly imply that shocks in the domestic financial market are unimportant. The negative correlation between investment and efficiency wedges in both Japan and the US gives rise to a possibility that financial frictions lead to drops in production efficiency and vice versa. Therefore, the recent financial market integration, illustrated by the increase in the cross-country investment wedges correlation, may have caused the increase in cross-country efficiency wedge correlation. Hence, the accounting results of this paper supports models linking international financial market integration to the increase in cross-country business cycle correlation.

6 Conclusion

This study extends the business cycle accounting method a la Chari, Kehoe, and McGrattan (2007) to a two-country open economy framework for considering the business cycle correlation patterns between Japan and the U.S. over the 1980-2008 period. In terms of accounting for fluctuations in output, efficiency wedges are important in Japan, while labor and efficiency wedges are important in the US. Furthermore, the increase in the cross-country correlation of the labor and efficiency wedges is important in accounting for the recent increase in the cross-country output correlation. In addition, international price wedges are necessary to account for the low cross-country consumption correlation. The main role of investment wedges is to prevent resources from flowing into the relatively efficient country. A successful model for business cycle correlations between Japan and the US must account for this fact.

A useful way to narrow down successful models is to investigate the correlation between wedges. The relationship between efficiency wedges and international price wedges modeled in order to solve the quantity anomaly in existing studies are supported by data. Furthermore, the relationship between investment wedges and efficiency wedges supports models linking international financial market integration to the increase in cross-country business cycle correlation. Since exploring detailed models is not the main focus of this paper, this will be left as a future research topic.

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A Sensitivity Analysis

In this section, I conduct sensitivity analysis of the quantitative results. I test the robustness of the results using alternative assumptions on the model. For each alternative model, I reestimate the stochastic process and recompute the wedges. Tables A2 to A7 report the sensitivity analysis results which correspond to Tables 4 and 5.

In sensitivity analysis A2, I simulate the model using parameter values separately calibrated in each country, as reported in Table 2. The results are similar to those of the prototype model. Therefore, the common parameter assumption in the prototype model does not affect the quantitative results. Next in sensitivity analysis A3, I simulate the model imposing a restriction on the stochastic process such that there are no spillover effects across wedges. That is, I estimate the matrix P in (7) with an orthogonality restriction. The results are almost identical to those from the prototype model. Therefore, the spillover effects are not quantitatively important in the prototype model. In sensitivity analysis A4, I impose the no spillover assumption on the model without adjustment costs. Comparing the results to Tables 6 and 7, the no spillover assumption affects the results significantly in the model without adjustment costs. The fluctuation of investment explodes in reaction to investment, efficiency, and international price wedges[23]. Therefore, the spillover of wedges is important in the model without adjustment costs. In sensitivity analysis A5, I simulate the model with non-separable preferences assuming $\sigma = 5$. Indeed, the nonseparability on consumption and leisure reduces the cross-country correlation of consumption as expected[24]. However, the quantitative impact of this modification is not large in terms of the fit of the model as well as the impacts of each wedge on output. In

[23] The absolute value of the fit of variables are ridiculously large because the standard deviation of the model simulation relative to that of the data is much larger than one.

[24] The cross-country correlation of consumption with efficiency wedges in both countries improves from 1.00 to 0.66.

sensitivity analysis A6, I simulate the model with habit formation preferences[25]. The fit of the model and the quantitative impacts of each wedge are very similar to those of the prototype model. Habit persistence generates positive investment correlation with efficiency wedges in both countries as shown in Dmitriev and Krznar (2009). However, it cannot account for the low cross-country correlation of consumption, nor the positive cross-country correlation of labor. In sensitivity analysis A7, I simulate the model with GHH preferences. The fit of the model is similar to that of the prototype model, whereas the quantitative importance of investment and international wedges falls. Furthermore, the results with only efficiency wedges in both countries in terms of cross-country correlation of output and consumption is much closer to the data than any other setting.

B Tables and Figures

Table 1. Japan-US Quarterly Business Cycle Correlation
HP Filtered (1980-2008)

	Y	C	L	X
total period	0.06	-0.08	0.24	-0.06
1980-1989	0.09	-0.14	-0.04	-0.01
1990-1999	-0.33	-0.11	-0.08	-0.47
2000-2008	0.70	0.23	0.73	0.63

[25] With habit persistence, consumption in both countries are defined as endogenous state variables. Otherwise, the solution method is the same as the prototype model.

Table 2. Parameter Values

	Japan	US	Common
θ	0.457	0.387	0.422
δ	0.02	0.014	0.017
Γ	1.004	1.005	1.004
β	0.982	0.986	0.984
Ψ	0.269	0.214	0.241
l	0.252	0.202	0.227
c/y	0.592	0.659	0.626
x/y	0.258	0.220	0.239
g/y	0.134	0.145	0.139

Table 3. Correlation of Wedges

Correlation with Japanese Output (total period)					
g^{JP}	τ_l^{JP}	τ_x^{JP}	z^{JP}	p	τ
0.04	0.23	-0.79	0.89	-0.31	0.57
Correlation with US Output (total period)					
g^{US}	τ_l^{US}	τ_x^{US}	z^{US}	p	τ
-0.06	-0.73	-0.89	0.71	0.75	-0.17

Correlation across Countries

	g^{JP}, g^{US}	τ_l^{JP}, τ_l^{US}	τ_x^{JP}, τ_x^{US}	z^{JP}, z^{US}
total period	-0.21	0.14	-0.03	-0.13
1980-1989	-0.42	-0.30	0.03	-0.06
1990-1999	-0.06	0.24	-0.41	-0.36
2000-2008	0.07	0.48	0.50	0.08

Table 4. Simulation Results

	Fit of Simulated Series to Data[26]								Cross-Country Correlation			
	Japan				US							
	Y	C	L	X	Y	C	L	X	Y	C	L	X
g^{JP}	0.00	0.01	0.01	0.00	-0.01	0.02	-0.02	0.01	0.97	1.00	0.99	-1.00
τ_l^{JP}	-0.12	0.05	0.76	-0.06	-0.01	0.06	-0.02	0.00	-1.00	1.00	-1.00	-1.00
τ_x^{JP}	0.14	-0.02	0.15	0.74	0.04	-0.07	0.08	0.00	0.53	1.00	0.88	0.01
z^{JP}	1.04	0.44	0.08	0.37	0.00	-0.04	-0.03	0.00	-1.00	1.00	-1.00	-1.00
g^{US}	-0.01	0.01	-0.02	0.00	0.00	0.00	-0.01	0.00	0.97	1.00	0.99	0.99
τ_l^{US}	-0.04	-0.02	-0.16	-0.02	0.50	0.39	0.97	0.10	-1.00	1.00	-1.00	-1.00
τ_x^{US}	-0.03	0.10	0.04	0.00	0.21	-0.24	0.25	0.76	0.67	1.00	0.92	-0.84
z^{US}	0.04	-0.12	0.02	0.01	0.52	0.26	0.10	0.13	-1.00	1.00	-1.00	-1.00
p	-0.11	0.57	0.06	-0.01	-0.22	0.51	-0.30	-0.02	-1.00	-1.00	-1.00	-1.00
τ	0.08	-0.02	0.07	-0.04	-0.02	0.11	-0.02	0.01	0.99	1.00	1.00	1.00
z^{JP}, z^{US}	1.08	0.32	0.09	0.38	0.51	0.22	0.07	0.13	-0.66	1.00	-1.00	-0.45
Data	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.06	-0.08	0.24	-0.06

Table 5. Simulation Results

Cross-Country Correlation of Simulated Output without						
	g^{JP}, g^{US}	τ_l^{JP}, τ_l^{US}	τ_x^{JP}, τ_x^{US}	z^{JP}, z^{US}	$p\&\tau$	Data
total period	0.08	-0.12	-0.26	-0.12	-0.32	0.06
1980-1989	0.11	0.05	-0.21	-0.28	-0.45	0.09
1990-1999	-0.33	-0.36	-0.64	-0.38	-0.58	-0.33
2000-2008	0.72	-0.12	0.43	0.22	0.48	0.70

[26] The fit of simulated series is defined as

$$corr(model, data) * \frac{std(model)}{std(data)}.$$

Table 6. Simulation Results (no Adjustment Costs)

	Fit of Simulated Series to Data								Cross-Country Correlation			
	Japan				US							
	Y	C	L	X	Y	C	L	X	Y	C	L	X
g^{JP}	0.00	0.01	0.02	0.00	-0.02	0.03	-0.03	-0.01	1.00	1.00	1.00	0.68
τ_l^{JP}	-0.12	0.6	0.74	-0.01	0.00	0.07	-0.01	-0.01	-1.00	1.00	-1.00	0.05
τ_x^{JP}	-0.05	-0.02	-0.04	0.38	0.03	0.04	0.01	0.47	-0.99	1.00	-0.88	-0.98
z^{JP}	1.10	0.38	0.10	0.33	-0.01	-0.06	-0.03	-0.03	-1.00	1.00	-1.00	0.31
g^{US}	-0.01	0.01	-0.03	-0.01	0.00	0.00	-0.02	-0.01	0.99	1.00	1.00	-0.66
τ_l^{US}	0.00	0.00	-0.03	0.11	0.65	0.05	1.24	0.30	-0.79	1.00	-0.77	1.00
τ_x^{US}	0.09	0.06	0.14	0.26	-0.02	0.11	0.00	-0.02	1.00	1.00	1.00	0.89
z^{US}	0.02	-0.07	0.01	-0.05	0.62	0.15	0.15	0.26	-0.99	1.00	-0.98	0.21
p	-0.11	0.58	0.05	0.00	-0.22	0.51	-0.30	0.03	-1.00	-1.00	-1.00	-0.36
τ	0.07	-0.01	0.05	-0.02	-0.01	0.10	-0.02	0.01	0.99	1.00	1.00	-0.13
z^{JP}, z^{US}	1.12	0.31	0.10	0.28	0.60	0.09	0.12	0.23	-0.50	1.00	-0.86	0.09
Data	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.06	-0.08	0.24	-0.06

Table 7. Simulation Results (no Adjustment Costs)

Cross-Country Correlation of Output Simulated without						
	g^{JP}&g^{US}	τ_l^{JP}&τ_l^{US}	τ_x^{JP}&τ_x^{US}	z^{JP}&z^{US}	p&τ	Data
total period	0.09	-0.15	0.03	-0.23	-0.32	0.06
1980-1989	0.13	-0.11	0.20	-0.57	-0.44	0.09
1990-1999	-0.32	-0.27	-0.45	-0.41	-0.58	-0.33
2000-2008	0.72	-0.10	0.61	0.23	0.48	0.70

Table 8. Cross-Correlation of Error Terms

	ε_l^{JP}	ε_x^{JP}	ε_z^{JP}	ε_g^{US}	ε_l^{US}	ε_x^{US}	ε_z^{US}	ε_p	ε_τ
ε_g^{JP}	0.04	0.16	0.03	0.00	0.11	0.11	-0.21	-0.01	0.00
ε_l^{JP}		-0.30	0.56	-0.03	0.21	0.06	-0.13	0.08	0.24
ε_x^{JP}			-0.35	-0.06	-0.09	0.05	-0.12	-0.14	-0.30
ε_z^{JP}				-0.09	-0.03	0.09	-0.12	-0.56	0.27
ε_g^{US}					0.23	0.16	0.23	0.12	-0.03
ε_l^{US}						0.08	0.18	-0.13	0.18
ε_x^{US}							-0.69	-0.24	0.00
ε_z^{US}								0.33	0.12
ε_p									0.10

Table A1. Japan-US Quarterly Business Cycle Correlation
Linearly Detrended (1980-2008)

	Y	C	L	X
total period	0.14	-0.03	-0.54	-0.26
1980-1989	0.75	-0.74	0.16	0.45
1990-1999	-0.85	-0.32	-0.88	-0.87
2000-2008	0.79	-0.57	0.90	0.58

Table A2a. Sensitivity Analysis (separate parameters)

	Fit of Simulated Series to Data								Cross-Country Correlation			
	Japan				US							
	Y	C	L	X	Y	C	L	X	Y	C	L	X
g^{JP}	0.00	0.00	0.01	0.00	-0.01	0.02	-0.02	0.00	0.99	1.00	1.00	1.00
τ_l^{JP}	-0.09	0.06	0.71	-0.02	0.00	0.07	-0.02	0.00	-1.00	1.00	-1.00	1.00
τ_x^{JP}	0.18	-0.05	0.21	0.87	0.08	-0.10	0.13	0.00	0.44	1.00	0.88	-0.99
z^{JP}	0.96	0.51	0.08	0.13	-0.03	-0.03	-0.07	-0.01	-1.00	1.00	-1.00	1.00
g^{US}	0.00	0.01	-0.01	0.00	0.00	0.00	-0.01	0.00	0.99	1.00	1.00	1.00
τ_l^{US}	-0.02	-0.02	-0.13	0.02	0.58	0.36	1.05	0.04	-1.00	1.00	-1.00	1.00
τ_x^{US}	-0.02	0.08	0.02	0.00	0.19	-0.18	0.21	0.83	0.57	1.00	0.88	-1.00
z^{US}	0.03	-0.11	0.02	-0.01	0.51	0.21	0.10	0.05	-1.00	1.00	-1.00	1.00
p	-0.09	0.51	0.04	0.01	-0.31	0.58	-0.38	0.07	-1.00	-1.00	-1.00	-1.00
τ	0.06	0.01	0.06	-0.01	0.00	0.07	0.00	0.00	1.00	1.00	1.00	1.00
z^{JP}, z^{US}	0.99	0.41	0.10	0.12	0.48	0.19	0.03	0.04	-0.70	1.00	-0.99	0.99
Data	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.06	-0.08	0.24	-0.06

Table A2b. Sensitivity Analysis (separate parameters)

Cross-Country Correlation of Output Simulated without						
	g^{JP}&g^{US}	τ_l^{JP}&τ_l^{US}	τ_x^{JP}&τ_x^{US}	z^{JP}&z^{US}	p&τ	Data
total period	0.08	-0.17	-0.26	-0.17	-0.31	0.06
1980-1989	0.12	-0.03	-0.14	-0.43	-0.41	0.09
1990-1999	-0.33	-0.34	-0.68	-0.44	-0.60	-0.33
2000-2008	0.71	-0.17	0.38	0.27	0.48	0.70

Table A3a. Sensitivity Analysis (no spillover)

	Fit of Simulated Series to Data								Cross-Country Correlation			
	Japan				US							
	Y	C	L	X	Y	C	L	X	Y	C	L	X
g^{JP}	0.00	0.00	0.01	0.00	-0.01	0.02	-0.02	0.00	1.00	1.00	1.00	1.00
τ_l^{JP}	-0.12	0.06	0.74	-0.03	0.00	0.07	-0.01	0.00	-1.00	1.00	-1.00	1.00
τ_x^{JP}	0.13	-0.01	0.17	0.71	0.07	-0.10	0.10	-0.01	0.41	1.00	0.85	-1.00
z^{JP}	1.01	0.48	0.07	0.35	0.00	-0.04	-0.04	0.01	-1.00	1.00	-1.00	-1.00
g^{US}	-0.01	0.01	-0.02	0.00	0.00	0.00	-0.01	0.00	1.00	1.00	1.00	1.00
τ_l^{US}	-0.04	-0.02	-0.16	-0.02	0.50	0.39	0.97	0.11	-1.00	1.00	-1.00	-1.00
τ_x^{US}	0.00	0.07	0.04	-0.02	0.19	-0.24	0.24	0.77	0.60	1.00	0.90	-1.00
z^{US}	0.04	-0.12	0.02	0.01	0.52	0.26	0.10	0.13	-1.00	1.00	-1.00	-1.00
p	-0.10	0.55	0.05	-0.01	-0.23	0.53	-0.31	-0.03	-1.00	-1.00	-1.00	-1.00
τ	0.09	-0.02	0.08	-0.01	-0.02	0.12	-0.03	0.00	1.00	1.00	1.00	1.00
z^{JP}, z^{US}	1.05	0.36	0.09	0.37	0.52	0.22	0.06	0.15	-0.69	1.00	-0.98	-0.80
Data	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.06	-0.08	0.24	-0.06

Table A3b. Sensitivity Analysis (no spillover)

Cross-Country Correlation of Output Simulated without						
	g^{JP}&g^{US}	τ_l^{JP}&τ_l^{US}	τ_x^{JP}&τ_x^{US}	z^{JP}&z^{US}	p&τ	Data
total period	0.08	-0.14	-0.29	-0.10	-0.32	0.06
1980-1989	0.12	0.04	-0.28	-0.26	-0.43	0.09
1990-1999	-0.33	-0.39	-0.64	-0.37	-0.58	-0.33
2000-2008	0.72	-0.13	0.43	0.23	0.48	0.70

Table A4a. Sensitivity Analysis (no spillover no adjustment costs)

	Fit of Simulated Series to Data								Cross-Country Correlation			
	Japan				US							
	Y	C	L	X	Y	C	L	X	Y	C	L	X
g^{JP}	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	1.00	1.00	1.00	1.00
τ_l^{JP}	-0.23	0.00	0.97	-2.16	-0.09	0.08	-0.08	1.79	-0.79	1.00	-0.59	-1.00
τ_x^{JP}	-2.45	0.44	-1.05	-20.48	-0.55	-0.09	-0.73	-42.92	-1.00	1.00	-1.00	-1.00
z^{JP}	2.07	0.09	0.51	6.39	0.03	-0.09	0.03	-1.36	-0.88	1.00	-0.88	-1.00
g^{US}	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	1.00	1.00	1.00	1.00
τ_l^{US}	-0.12	0.00	-0.24	0.82	1.12	0.02	1.68	2.51	-0.98	1.00	-0.93	-0.99
τ_x^{US}	-1.00	-0.07	1.57	-32.96	-9.91	0.41	-6.69	-22.86	-1.00	1.00	-1.00	-1.00
z^{US}	0.10	-0.03	0.06	1.34	1.12	0.08	0.38	1.76	-0.91	1.00	-0.90	-1.00
p	2.62	0.55	-0.81	48.18	9.27	0.53	6.43	61.98	-1.00	-1.00	-1.00	-1.00
τ	0.02	0.01	0.00	-0.14	0.01	0.07	-0.02	0..07	1.00	1.00	1.00	1.00
z^{JP}, z^{US}	1.04	0.44	0.08	0.37	0.00	-0.04	-0.03	0.00	-1.00	1.00	-1.00	-1.00
Data	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.06	-0.08	0.24	-0.06

Table A4b. Sensitivity Analysis (no spillover no adjustment cost)

Cross-Country Correlation of Output Simulated without						
	$g^{JP}\&g^{US}$	$\tau_l^{JP}\&\tau_l^{US}$	$\tau_x^{JP}\&\tau_x^{US}$	$z^{JP}\&z^{US}$	$p\&\tau$	Data
total period	0.06	-0.57	-1.00	-0.84	-1.00	0.06
1980-1989	0.10	-0.73	-1.00	-0.92	-1.00	0.09
1990-1999	-0.33	-0.44	-1.00	-0.89	-1.00	-0.33
2000-2008	0.71	-0.55	-0.99	-0.66	-0.99	0.70

Table A5a. Sensitivity Analysis (non-separable preference)

	Fit of Simulated Series to Data								Cross-Country Correlation			
	Japan				US							
	Y	C	L	X	Y	C	L	X	Y	C	L	X
g^{JP}	0.00	0.00	0.01	0.00	-0.01	0.02	-0.01	0.01	0.98	1.00	1.00	0.86
τ_l^{JP}	-0.09	0.10	0.55	-0.02	0.00	0.02	0.00	0.00	-0.99	0.99	-1.00	1.00
τ_x^{JP}	0.12	0.01	0.18	0.71	0.04	-0.05	0.07	0.00	0.54	0.98	0.94	-1.00
z^{JP}	0.95	0.57	0.06	0.35	-0.01	-0.03	-0.02	-0.01	-1.00	1.00	-1.00	1.00
g^{US}	0.00	0.00	-0.01	0.01	0.00	0.00	-0.01	0.01	0.98	1.00	1.00	1.00
τ_l^{US}	-0.01	0.00	-0.04	0.00	0.37	0.69	0.72	0.08	-1.00	1.00	-0.99	-0.98
τ_x^{US}	-0.01	0.11	0.04	0.00	0.17	-0.20	0.22	0.70	0.70	0.99	0.96	-1.00
z^{US}	0.02	-0.06	0.01	-0.01	0.48	0.32	0.07	0.17	-1.00	1.00	-1.00	1.00
p	-0.04	0.27	0.15	0.01	-0.04	0.14	-0.02	0.01	-1.00	-1.00	-1.00	-1.00
τ	0.07	-0.01	0.05	-0.05	-0.01	0.09	-0.02	0.03	1.00	1.00	1.00	1.00
z^{JP}, z^{US}	0.97	0.51	0.06	0.34	0.47	0.29	0.05	0.16	-0.46	0.66	-0.98	0.28
Data	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.06	-0.08	0.24	-0.06

Table A5b. Sensitivity Analysis (non-separable preferences)

Cross-Country Correlation of Output Simulated without						
	g^{JP}&g^{US}	τ_l^{JP}&τ_l^{US}	τ_x^{JP}&τ_x^{US}	z^{JP}&z^{US}	p&τ	Data
total period	0.07	-0.01	-0.20	0.05	-0.09	0.06
1980-1989	0.11	0.12	-0.18	-0.24	-0.10	0.09
1990-1999	-0.33	-0.28	-0.58	-0.14	-0.44	-0.33
2000-2008	0.71	0.16	0.48	0.44	0.57	0.70

Table A6a. Sensitivity Analysis (habit formation preferences)

	Fit of Simulated Series to Data								Cross-Country Correlation			
	Japan				US							
	Y	C	L	X	Y	C	L	X	Y	C	L	X
g^{JP}	0.00	0.00	0.01	0.00	-0.01	0.02	-0.02	-0.02	0.69	1.00	0.93	-1.00
τ_l^{JP}	0.01	0.22	0.67	-0.01	0.01	0.07	-0.01	0.00	-0.97	1.00	-0.98	1.00
τ_x^{JP}	0.17	0.00	0.27	0.74	0.07	-0.14	0.15	0.01	0.84	1.00	0.97	1.00
z^{JP}	0.99	0.24	0.09	0.23	-0.03	-0.10	-0.07	0.00	-0.97	1.00	-0.91	1.00
g^{US}	0.00	0.00	-0.02	0.00	0.00	0.00	-0.01	0.00	0.99	1.00	1.00	1.00
τ_l^{US}	-0.02	-0.02	-0.22	-0.02	0.49	0.40	0.92	0.13	-0.98	1.00	-0.98	-0.97
τ_x^{US}	-0.03	0.07	-0.05	0.02	0.19	-0.13	0.20	0.71	0.75	1.00	0.95	-0.99
z^{US}	0.05	-0.10	0.03	-0.02	0.50	0.23	0.10	0.06	-0.96	1.00	-0.88	1.00
p	-0.23	0.57	0.14	0.03	-0.23	0.55	-0.27	0.05	-1.00	-1.00	-1.00	-1.00
τ	0.08	0.02	0.08	0.03	0.01	0.10	0.00	0.06	0.84	1.00	0.97	-0.99
z^{JP}, z^{US}	1.04	0.14	0.12	0.21	0.47	0.13	0.03	0.05	-0.75	1.00	-0.84	0.92
Data	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.06	-0.08	0.24	-0.06

Table A6b. Sensitivity Analysis (habit formation preferences)

Cross-Country Correlation of Output Simulated without						
	$g^{JP}\&g^{US}$	$\tau_l^{JP}\&\tau_l^{US}$	$\tau_x^{JP}\&\tau_x^{US}$	$z^{JP}\&z^{US}$	$p\&\tau$	Data
total period	0.08	-0.25	-0.21	-0.12	-0.50	0.06
1980-1989	0.14	-0.21	-0.22	-0.23	-0.55	0.09
1990-1999	-0.34	-0.40	-0.54	-0.38	-0.72	-0.33
2000-2008	0.71	-0.25	0.51	0.20	0.19	0.70

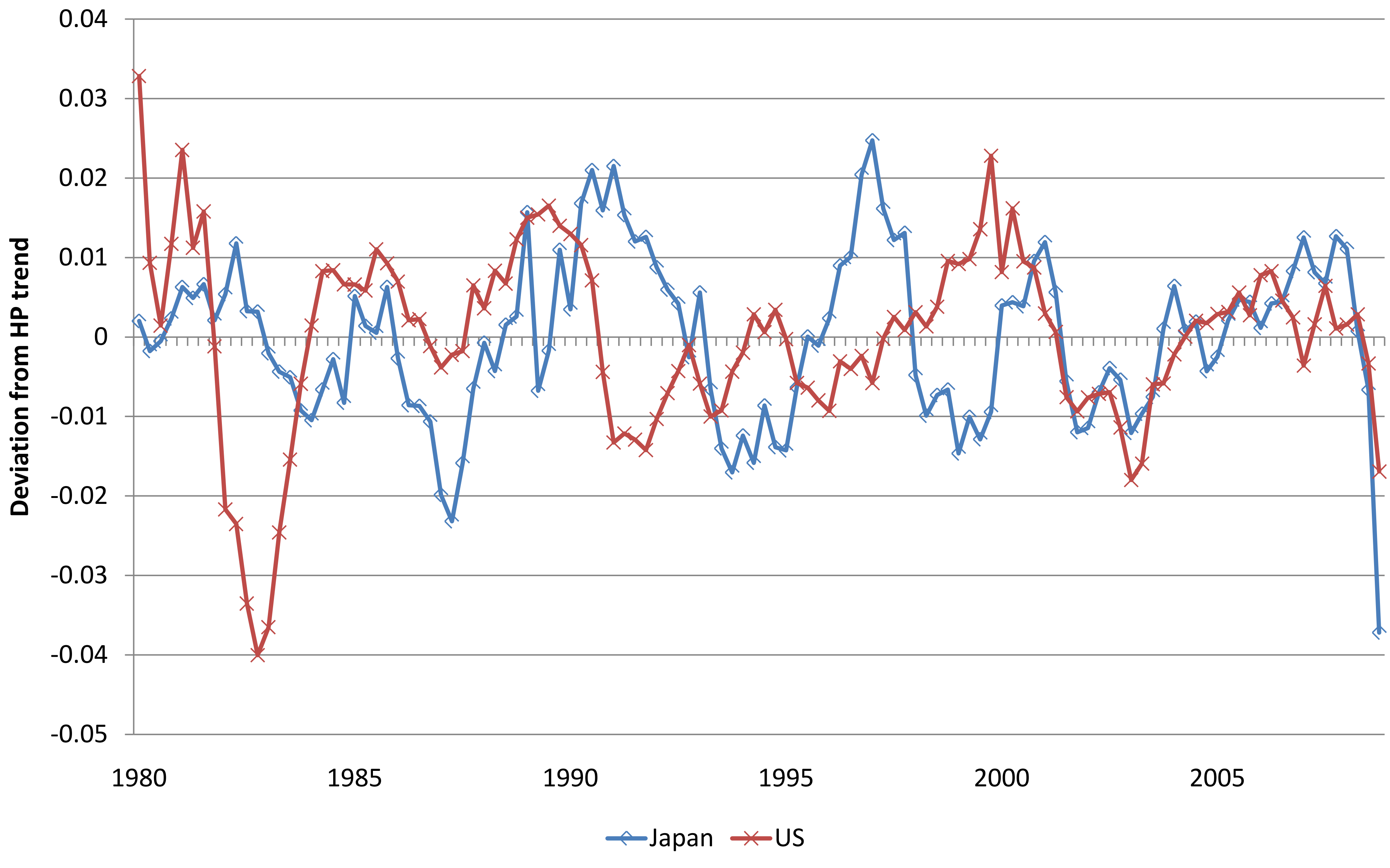
Table A7a Sensitivity Analysis (GHH preference)

	Fit of Simulated Series to Data								Cross-Country Correlation			
	Japan				US							
	Y	C	L	X	Y	C	L	X	Y	C	L	X
g^{JP}	0.00	0.01	0.00	0.00	0.00	0.03	0.00	0.02	-0.33	0.98	0.00	-1.00
τ_l^{JP}	-0.36	-0.89	0.86	-0.17	-0.02	-0.06	-0.01	-0.03	0.06	-0.99	0.13	-1.00
τ_x^{JP}	0.01	0.26	-0.03	0.63	0.02	-0.06	0.01	-0.01	-1.00	0.91	-1.00	-1.00
z^{JP}	1.34	1.30	0.15	0.72	0.00	-0.03	0.00	0.00	-0.07	1.00	-0.08	0.99
g^{US}	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.96	0.99	0.94	1.00
τ_l^{US}	0.00	0.00	0.00	-0.01	0.27	0.67	0.73	0.05	-0.04	-1.00	0.01	-1.00
τ_x^{US}	-0.03	0.03	-0.02	-0.08	-0.01	-0.38	0.01	0.87	-1.00	0.85	-1.00	-1.00
z^{US}	0.00	-0.05	0.00	-0.02	0.69	0.72	0.23	0.25	-0.17	0.98	-0.19	1.00
p	0.01	0.33	0.02	0.01	0.03	-0.04	0.01	-0.21	-1.00	-1.00	-1.00	-1.00
τ	0.03	0.00	0.02	-0.09	0.02	0.15	0.01	0.05	1.00	1.00	1.00	1.00
z^{JP}, z^{US}	1.34	1.26	0.15	0.69	0.69	0.69	0.23	0.25	-0.13	0.14	-0.13	-0.08
Data	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.06	-0.08	0.24	-0.06

Table A7b. Sensitivity Analysis (GHH preferences)

Cross-Country Correlation of Output Simulated without						
	$g^{JP}\&g^{US}$	$\tau_l^{JP}\&\tau_l^{US}$	$\tau_x^{JP}\&\tau_x^{US}$	$z^{JP}\&z^{US}$	$p\&\tau$	Data
total period	0.06	-0.11	0.02	-0.01	0.02	0.06
1980-1989	0.09	-0.09	0.06	-0.40	0.20	0.09
1990-1999	-0.33	-0.24	-0.38	0.04	-0.43	-0.33
2000-2008	0.71	0.08	0.53	0.28	0.62	0.70

Figure 1. Japan and US Output Correlation



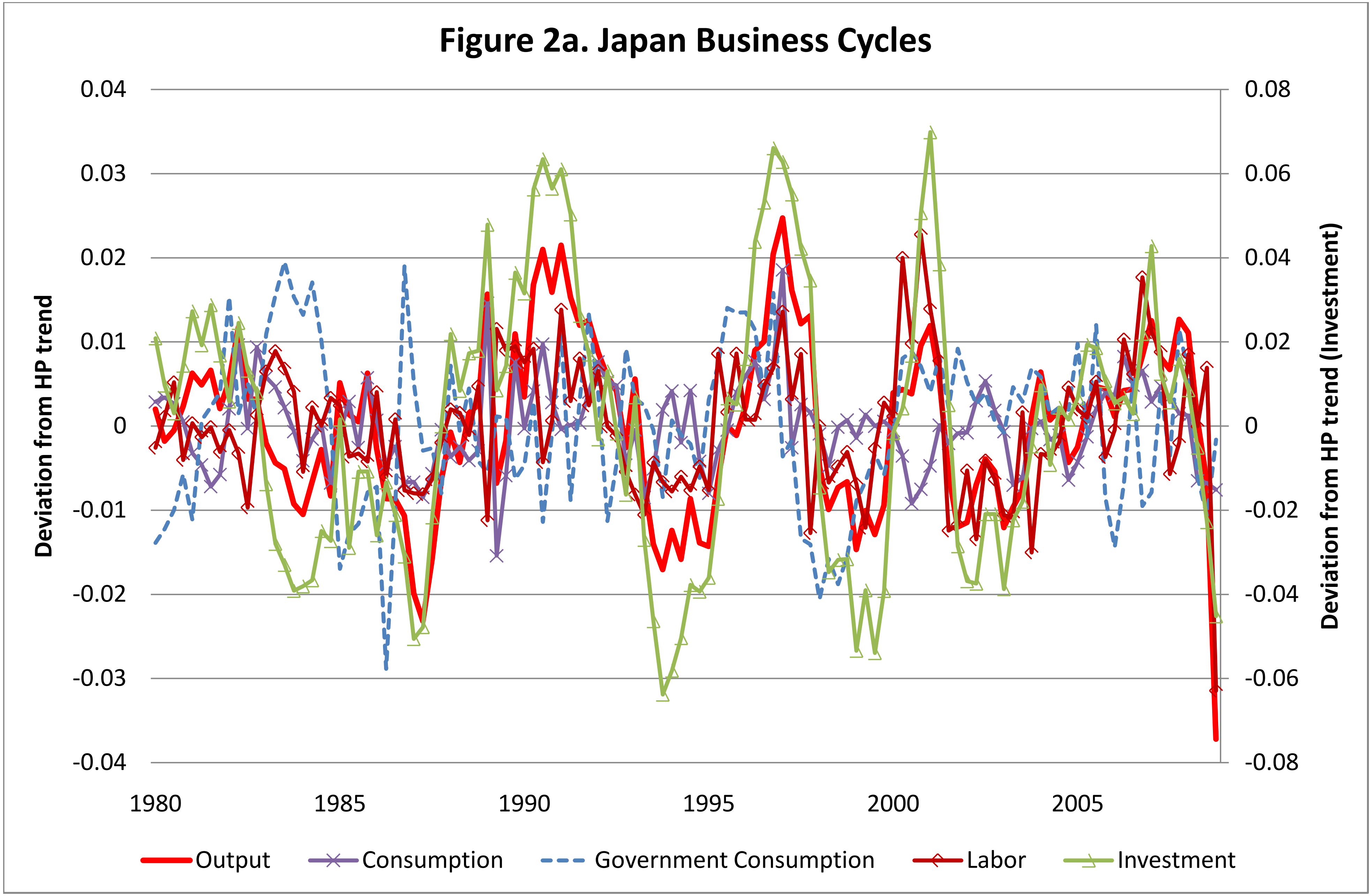
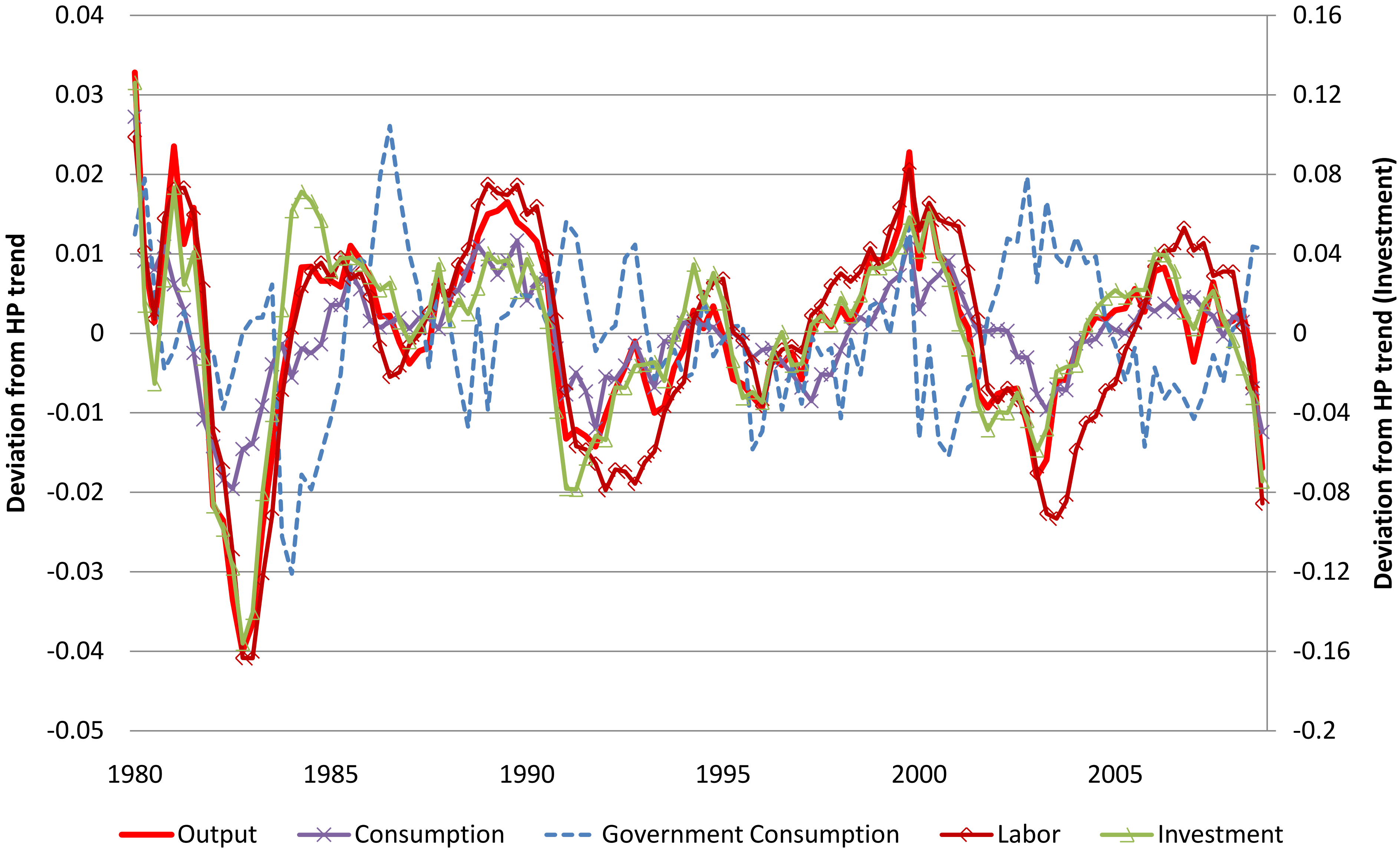


Figure 2a. Japan Business Cycles
Deviation from HP trend
Deviation from HP trend (Investment)
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
1980
1985
1990
1995
2000
2005
Output
Consumption
Government Consumption
Labor
Investment

Figure 2b. US Business Cycles



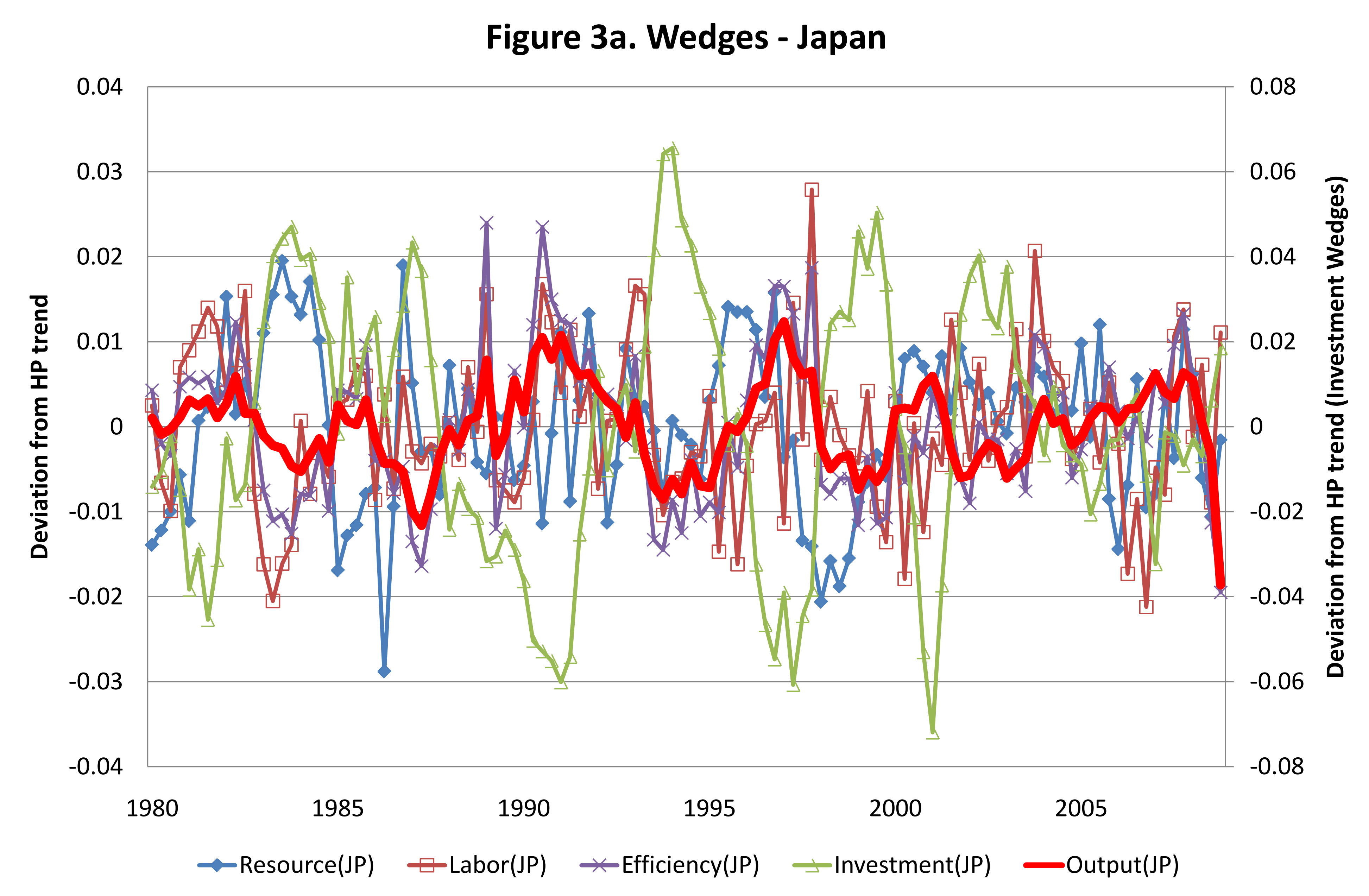


Figure 3a. Wedges - Japan
Deviation from HP trend
Deviation from HP trend (Investment Wedges)
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
1980
1985
1990
1995
2000
2005
Resource(JP)
Labor(JP)
Efficiency(JP)
Investment(JP)
Output(JP)

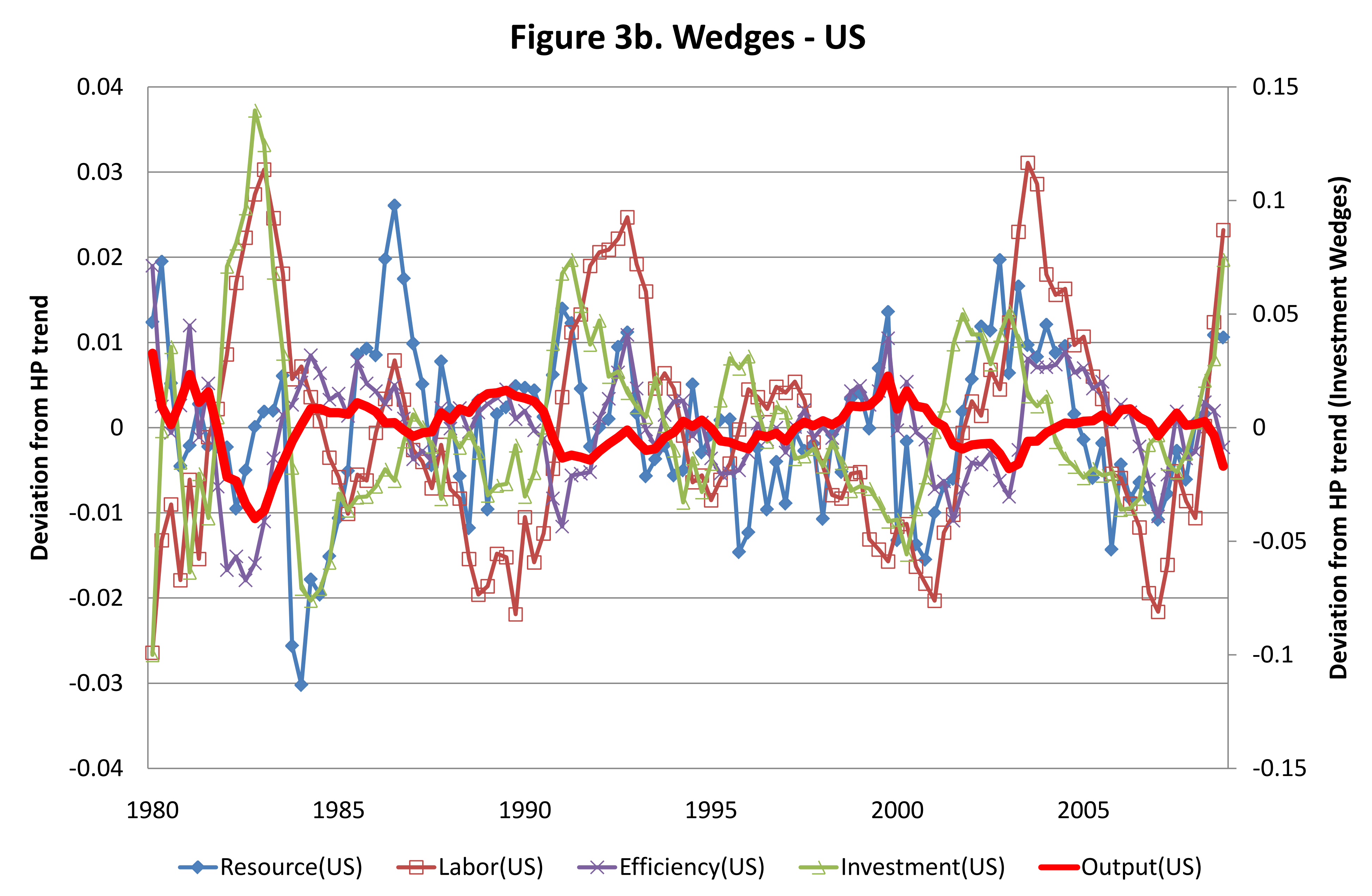


Figure 3b. Wedges - US
Deviation from HP trend
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
Deviation from HP trend (Investment Wedges)
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
1980
1985
1990
1995
2000
2005
Resource(US)
Labor(US)
Efficiency(US)
Investment(US)
Output(US)

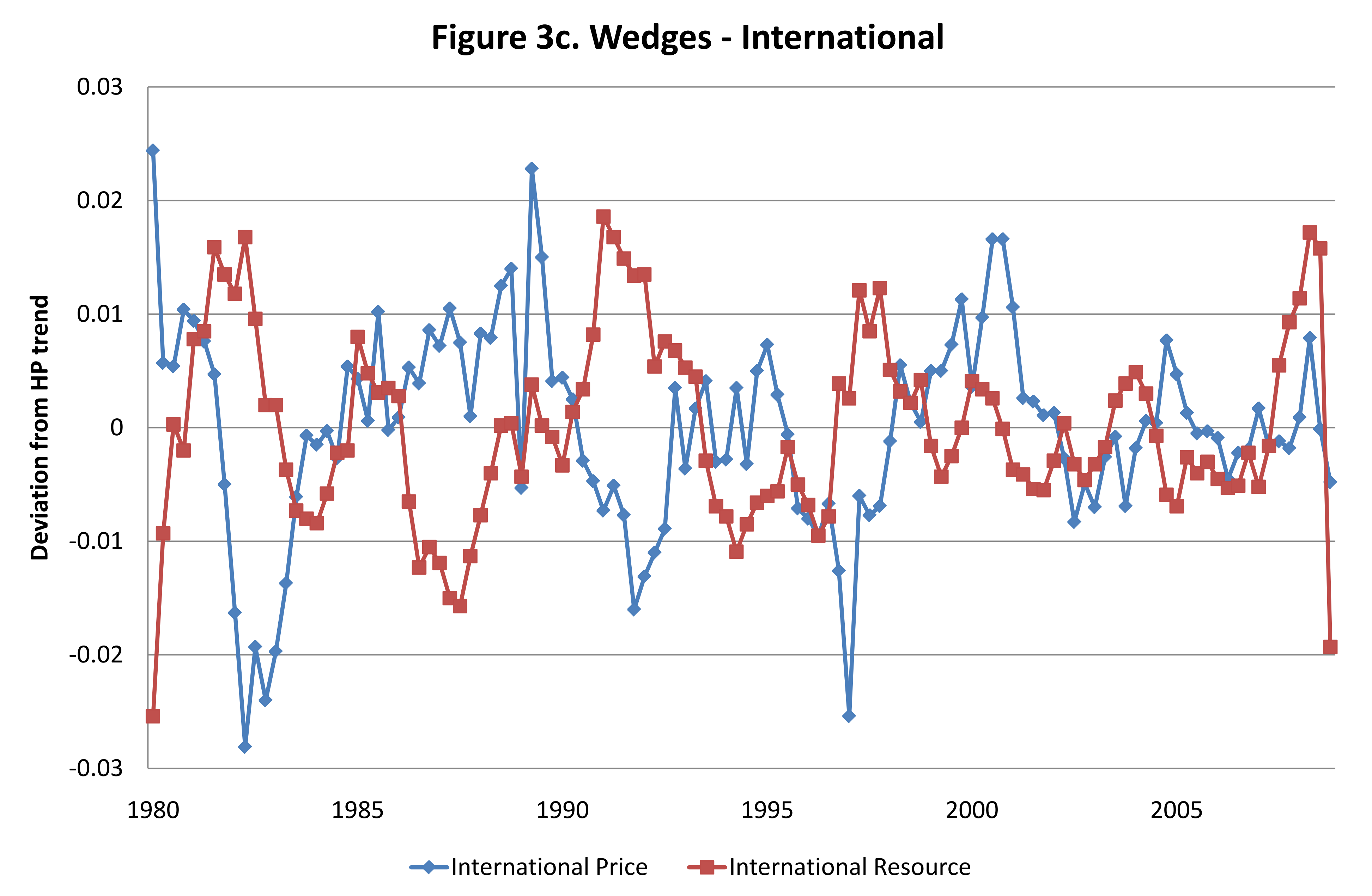
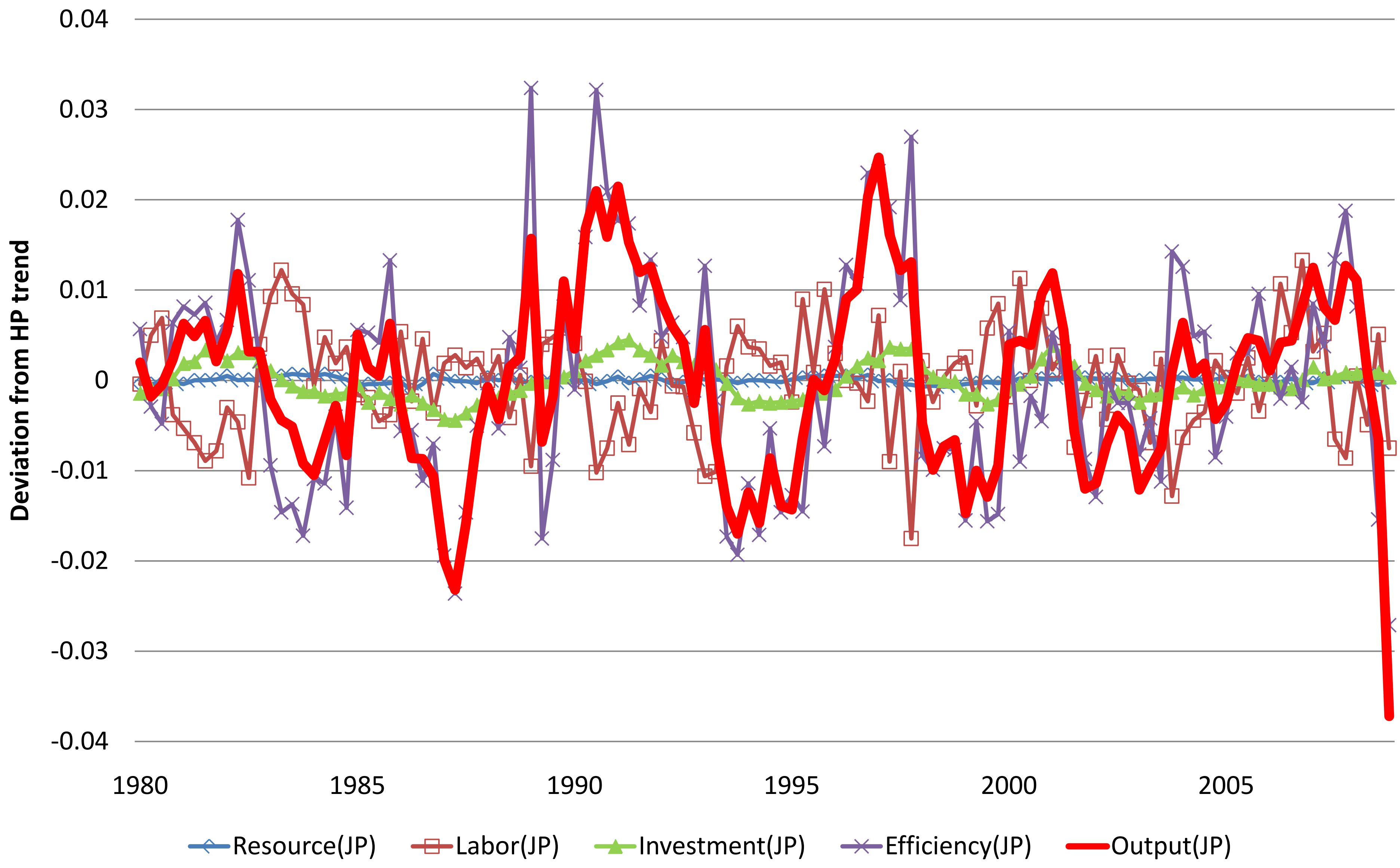


Figure 3c. Wedges - International
Deviation from HP trend
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
1980
1985
1990
1995
2000
2005
International Price
International Resource

Figure 4a. Simulation Results-Japan (Output)



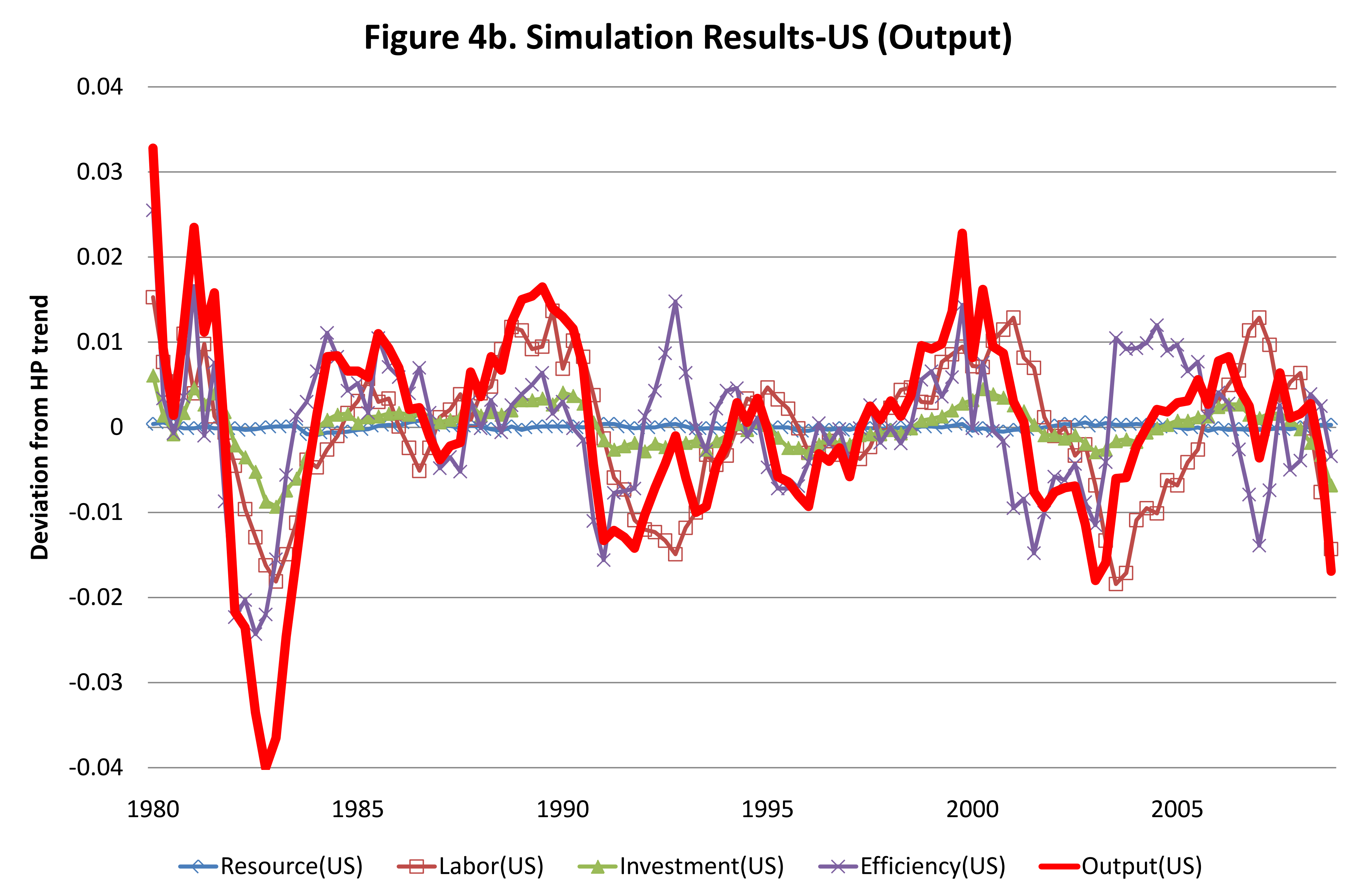


Figure 4b. Simulation Results-US (Output)
Deviation from HP trend
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
1980
1985
1990
1995
2000
2005
Resource(US)
Labor(US)
Investment(US)
Efficiency(US)
Output(US)