International business cycle accounting: the case of Japan and the US 1980-2008*

Keisuke Otsu†
Sophia University, Faculty of Liberal Arts

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Abstract

It is well known that replicating bilateral international business cycle comovements across countries with the two-country international real business cycle model is challenging. In this paper, I apply the business cycle accounting method a la Chari, Kehoe and McGrattan (2007) to a two-country setting and quantitatively account for the impacts of the disturbances in the labor, investment, resource, efficiency, and international markets on business cycle comovements between Japan and the U.S. I show that the disturbances in the U.S. labor market, Japanese production efficiency and international relative prices are important in accounting for the recent business cycle correlation patterns between Japan and the U.S. over the 1980-2008 period. Furthermore, in the two country setting, disturbances in labor and investment markets have larger effects in accounting for business cycle fluctuations than in the closed economy setting.

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†e-mail: k-otsu@sophia.ac.jp.

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1 Introduction

International real business cycle models are intended to explain international cross-correlations of aggregate variables such as output and consumption. Baxter and Crucini (1995) showed that the correlation of output among developed countries is positive. This is not true in the case of Japan and the U.S. during the recent years. The quarterly correlation of output over the 1980-2008 period is approximately zero and is negative during the 90s. 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 wedges in relevant markets on the business cycle correlation between Japan and the US and show that disturbances in the labor market, production efficiency and international financial market are important in accounting for the business cycle correlation pattern between Japan and the US.

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. They also trade state contingent bonds 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, Kehoe and McGrattan (2007) shows that distortions created by various frictions can be mapped into a prototype model with distortionary taxes. Following their study, instead of analyzing the effects of actual distortionary taxes on the business cycles, as in Braun (1994) and McGrattan (1994), I assess in which market exists the important distortions in accounting for the business cycle correlation between Japan and the U.S. The disturbances in resource, labor, investment, production efficiency and international financial markets are computed as "wedges" from equilibrium conditions and are taken as exogenous. Resource, labor, investment and production efficiency wedges are identical to those introduced in Chari, Kehoe and McGrattan (2007). Resource wedges are disturbances in the resource constraints which correspond to government expenditure 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 captures the discrepancy between the intertemporal marginal rate of substitution of future consumption to current consumption and the return on capital. Production efficiency wedges are equivalent to total factor productivity, i.e. Solow residuals. Wedges in the international market are additions I made to the original literature. International price wedges are disturbances in the cross-country arbitrage condition which drives wedges between the marginal utility of consumption across countries. Trade wedges are disturbances in the international resource constraint that captures the discrepancy in the trade balances of the two countries evaluated at international prices.

Taking productivity shocks as given, canonical international real business cycle models, such as Baxter and Crucini (1995), Backus, Kydland and Kehoe (1994, 1995) and Stockman and Tesar (1995), can replicate the positive output correlation between developed countries. However, the cross-country output correlation generated by these models is lower than data since they cannot replicate the positive correlation of inputs across countries. That is, in a canonical model, production factors should shift towards the country that faces a relatively higher productivity shock. Therefore, although output has positive correlation due to positive productivity correlation, production factors have negative correlations across countries. These are known as the quantity anomalies. This paper shows that the sources of this anomaly can be quantified by the wedges in each markets. The business cycle accounting results show that Japanese efficiency wedges and U.S. labor wedges are important in accounting for the correlation pattern of output.

Another well known fact is that the cross-country correlation of consumption generated by a canonical two country real business cycle model is too high compared to data. This is due to the international risk sharing that takes place in the model, which does not seem to take place in reality. In order to account for the low internationla risk sharing, the model needs some distortionary shock to international consumption smoothing. I show that fluctuations in real exchange rates cannot account for these distortions. This is a straight forward application of the Backus-Smith puzzle that a the movements in real exchange rates move in the opposite direction to the pricing kernel. I show that this is also true for the U.S.-Japan case with complete markets and that this holds under a wide set of preference cases.

One notable finding is that investment wedges, even with capital adjustment cost, is necessary to prevent investment to concentrate to the relatively efficient country. It might be important to consider financial frictions as an important ingredient of a more sophisticated model after all. Therefore, researchers who intend to model the patterns of international capital flows might benefit from this extension of the business cycle accounting framework.

The paper is organized as follows. In section 2 and 3, I describe the data and the model. In section 4, I explain the quantitative method and present the simulation results. Section 5 concludes the paper.

2 Data

In this paper, I focus on the recent business cycle correlation between Japan and the US. Table 1 shows the cross-country correlations of quarterly data over the 1980-2008 after detrended with the Hoddrick-Prescott (HP) filter. 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, government consumption and net exports follow conventional definitions. As shown in Ambler, Cardia and Zimmerman (2004), recent data of Japan and the US 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. Surprisingly, cross country correlations of consumption and investment are negative on average over the whole period.

Figure 1 shows the HP filtered output series in Japan and the US. This figure shows the reason why the business cycle correlations are weak in the 1980s and negative in the 1990s. During the early 1980s, US experienced a recession while 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 is negative in the 1990s since the US experienced a steady growth while Japan went through a decade long recession known as the lost decade. In the 2000s, the business cycle correlation is stronger.

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 1980-2008 period. Consumption is less volatile than output whereas investment is much more volatile than output.

3 The Model

The model is a competitive market version of a standard two-country model a la Baxter and Crucini (1995) in which there is a single final tradable good produced in both countries. Each country $i = JP, US$ consists of a representative household, final good firm, government and trading firm. 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[1] using a Cobb-Douglas production technology which is affected by aggregate TFP, A_t:

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

where θ represents the capital share. I decompose the aggregate TFP into the trend, $\Gamma_t = (1+\gamma)\Gamma_{t-1}$, and stationary shocks z_t:

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

Using this decomposition, the production function can be rewritten as

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

Thus, the trend component Γ_t is also known as the labor augmenting technical progress. Then, dividing both sides of the equation by Γ_t, the production

[1] 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. Average hours worked per worker is defined as the average weekly hours worked per worker divided by $14 * 7$ assuming that 14 hours is the maximum each worker can work per day.

function can be rewritten as

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

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

$$\max \pi_t^i = \exp(z_t^i)(k_t^i)^{\theta^i}(l_t^i)^{1-\theta^i} - w_t^i l_t^i - r_t^i k_t^i$$

where w_t are real wages and r_t are real capital rental rates[2].

3.2 Households

The households in each countries maximizes lifetime utility:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \left[\Psi^i \ln c_t^i + (1-\Psi^i)\ln(1-l_t^i)\right] \tag{2}$$

where c_t and l_t denote detrended consumption and labor supply, respectively, subject to a budget constraint:

$$(1-\tau_{lt}^i)w_t^i l_t^i + r_t^i k_t^i + p_t^i d_t^i + \tau_t^i = c_t^i + (1+\tau_{xt}^i)x_t^i + p_t^i q_t d_{t+1}^i + \Phi_t k_t^i \tag{3}$$

where x_t is investment, d_t is the state contingent international bond, q_t is the price of the bond, τ_{lt} and τ_{xt} represent distortionary taxes on labor income and investment, respectively, and τ_t is the lump-sum transfers from the government. I assume that there is a disturbance in the international financial market p_t^i where $p_t^{JP} = 1$ and $p_t^{US} = p_t$. The capital adjustment

[2] According to the Kaldor growth facts, real wages grow as labor augmenting technical progress Γ_t grows. Thus they are detrended by Γ_t. On the other hand, real interest rates do not have a trend.

cost Φ_t is assumed to take the form of

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

where $d^i = \Gamma^i - (1-\delta^i)$[3]. Investment is assumed to follow the capital law of motion:

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

3.3 International Financial Market

The state contingent international bonds are traded at the price q_t. However, I assume that there are disturbances in the market such that the effective price of the claim is q_t for Japan and $p_t q_t$ for the U.S. I also assume that there is a disturbance to resource that flows across borders, t_t[4]. That is,

$$[q_t d_{t+1}^{JP} - d_t^{JP}] + p_t[q_t d_{t+1}^{US} - d_t^{US}] = t_t$$

or

$$tb_t^{JP} + p_t tb_t^{US} = t_t. \tag{5}$$

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. That is,

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

As mentioned above, the main focus of this paper is not to analyze the effect of distortionary taxes, but to assess which wedge is important in accounting

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

[4]This can be considered as a variable iceberg cost. This term is important accounting-wise since it captures the trade of each country with other countries, which is not modeled in this paper.

for the business cycle correlation in Japan and the U.S. Therefore, actual data on distortionary taxes are not used in the quantitative analysis.

3.5 Shocks

The 10 exogenous variables are $exo = \{g^i, \tau_l^i, \tau_x^i, z^i, p, t\}$. I assume they follow a VAR process

$$exo_t = P_0 + P * exo_{t-1} + \varepsilon_t \tag{7}$$

where $\varepsilon = \{\varepsilon_g^i, \varepsilon_l^i, \varepsilon_x^i, \varepsilon_z^i, \varepsilon_p, \varepsilon_{ts}\}$. Agents expect the future levels of the exogenous variables according to this process.

3.6 Equilibrium

The competitive equilibrium is characterized by the prices and quantities $\{y^i, c^i, l^i, x^i, tb^i, k^i, w^i, r^i, \tau^i, g^i, \tau_l^i, \tau_x^i, z^i, q, p, t\}$ such that, households optimize given prices and wedges $\{w^i, r^i, q, p, \tau^i, \tau_l^i, \tau_x^i\}$, final goods firms optimize given prices and wedges $\{w^i, r^i, z^i\}$, government budget constraint (6) holds, the resource constraints hold, and shocks follow the process (7).

The equilibrium can be summarized by the following equations. The capital Euler equation in both countries

$$\Gamma^i(1+\tau_{xt}^i+\Phi_t')\frac{\Psi^i}{c_t^i} = \beta^i E_t\left[\frac{\Psi^i}{c_{t+1}^i}\left(\theta^i\frac{y_{t+1}^i}{k_{t+1}^i} + (1-\delta^i)(1+\tau_{xt+1}^i) + \Phi_{t+1}'\frac{k_{t+2}}{k_{t+1}} + \Phi_{t+1}\right)\right], \tag{8}$$

the labor first order condition in both countries

$$\frac{1-\Psi^i}{1-l_t^i} = (1-\tau_{lt}^i)(1-\theta^i)\frac{y_t^i}{l_t^i}\frac{\Psi^i}{c_t^i}, \tag{9}$$

the production function in both countries (1), the capital law of motion in both countries (4), the resource constraint in both countries

$$y_t^i = c_t^i + x_t^i + g_t^i + tb_t^i + \Phi\left(\frac{x_t^i}{k_t^i}\right) k_t^i, \tag{10}$$

the trade balance constraint (5), and the international first order condition

$$p_t = \frac{\Psi^{JP}/c_t^{JP}}{\Psi^{US}/c_t^{US}}. \tag{11}$$

These 12 equations characterizes the equilibrium of the following 12 endogenous variables $\{y^i, c^i, l^i, x^i, tb^i, k^i\}$ given 10 exogenous variables $\{g^i, \tau_l^i, \tau_x^i, z^i, p, t\}$.

4 Quantitative Analysis

The quantitative analysis is done in the following order. First I use the equilibrium conditions and data over the 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 the linear decision rules. Finally, I simulate the model using the computed wedges and linear decision rules.

4.1 Parameter Values

The structural parameter values are calibrated using the data of Japan and the U.S. over the 1980-2008 period. I assume symmetry across Japan and the U.S. and use the average of these numbers as common parameter values in both countries. The values of structural parameters are listed in Table 2.

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[5]. The values are 0.36 for Japan and 0.29 for the US, respectively[6]. Since output is defined as GDP plus the flow income from durable and government capital stock ($FLOW$), the capital share is computed as

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

The depreciation rate is computed directly from data using the capital law of motion (4)[7]. The growth trend Γ is computed as the average growth rate of per capita output. The subjective discount rate β is calibrated to data of average capital to output ratio with the steady state version of capital Euler equation (8)

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

The utility parameter Ψ is calibrated to match data of average labor and consumption to output ratio with the steady state version of the labor first order condition (9)

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

I assume that the steady state values of wedges $\{\tau_l^i, \tau_x^i, z^i\}$ are zero for simplification. The steady state level of government wedges g are computed directly from data. The steady state levels of international prices p and trade shocks ts are computed by steady state versions of (11) and (5), respectively. The parameter of capital adjustment cost ϕ is set so that the marginal Tobin's q is equal to one.

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

[6]I use the Hayashi and Prescott (2002) data set over the 1980-2002 period for Japan, and BEA data over the 1980-2006 period for the US, respectively.

[7]The capital stock series is constructed by the perpetual inventory method. For further discussion see the appendix.

The persistence parameters of the shock process (7) is obtained using the maximun likelihood estimation[8]. For the estimation, I use linearly detrended data of output, consumption, labor, investment and government purchases of both countries as observable variables. Since there are 10 shocks and 10 observable variables, the system is just identified. Notice that I do not restrict the variance-covariance matrix of the error term so that they have contemporaneous correlation. Unlike the structural parameters, I do not assume symmetry across countries in the stochastic process[9].

4.2 Wedges

Once the parameter values are obtained, the model can be solved for decision rules numerically. In this paper, I use the linear solution method a la Uhlig (1999) to solve the model. I compute the wedges using the data of the observable variables used for the estimation, their obtained linear decision rules and the obtained linear decision rules of the endogenous state variables, capital stock in each country.

The linear decision rules of endogenous variables are functions of state variables $\{k^i, g^i, \tau_l^i, \tau_x^i, z^i, p, t\}$. Initial capital stock in each country is assumed to be at the steady state level. Once the initial capital stock level is given, in the initial period there are 12 known variables including initial capital stock in both countries and 12 unknown variables including the second period capital stock in both countries. Thus, we can solve the linear system of equations and compute the unknown variables. The same procedure can

[8]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 so they cannot be directly computed. Therefore, the entire system must be estimated.

[9]Unfortunately, for the U.S. estimation, the acceptance rate of the MCMC process is very low indicating a poor estimate for the stochastic process. This is most likely because over the data period, 1980-2008, consumption, labor and output are too highly correlated. The original CKM paper uses data over the 1959-2004 period. As CKM, I check that the key results presented below hold for a wide range of parameter values for the stochastic process.

be used for the next period using the computed level of the second period capital stock from the first step. We can continue this procedure until the whole series of wedges are computed.

Figure 3a and 3b plot the HP filtered output and wedges in each country. In Japan, efficiency wedges are highly correlated with GDP. However, government, labor and investment wedges do not have clear correlations with output. In the U.S., efficiency wedges are positively correlated to output whereas, labor wedges are negatively correlated to output. Government and investment wedges do not have clear correlations with output. In addition, investment wedges are much more volatile than the other wedges in both countries. Table 3 presents the cross-country correlation of domestic wedges. Investment wedges have almost perfect negative correlation across the two countries, whereas the labor wedges are positively correlated. The correlation of efficiency wedges are negative over the whole period while it turns positive in the 2000s. Figure 2c plots the international price and trade wedges. The international price wedges fall dramatically in the early 1980s which implies that the price of Japanese goods must have fallen during this period. Also, the international price wedges and trade wedges do not have a clear correlation with each other.

The key economic effects of changes in each wedges are as follows. A rise in resource wedges or trade wedges will generate a negative income effect for the household in whichever country experiencing the rise. This tends to reduce consumption and leisure. An increase in labor wedges increases the relative price of leisure to consumption. The substitution effect leads the household to reduce consumption and increase leisure. An increase in current investment wedges increases the relative price of investment to consumption so the household should increase consumption and reduce investment, and hence reduce future consumption. An increase in production efficiency wedges causes a real business cycle effect in which output, consumption, labor and investment should all increase. Finally, a rise in the price of Japanese goods relative to U.S. goods should lead to a fall in Japanese consumption and a rise in U.S. consumption.

4.3 Simulation Results

Simulation is done using the linear decision rules and the computed wedges. Since there are 10 wedges, I can provide 10 separate simulations for each wedge as well as simulations using multiple wedges simultaneously. For simplicity, I focus on results for simulations using the following 5 sets of wedges: government wedges in both countries, labor wedges in both countries, investment wedges in both countries, efficiency wedges in both countries and international price and trade wedges. All simulation results are detrended with the HP filter.

Figure 4 and 5 plots the endogenous fluctuations of output, consumption, labor and investment in response to fluctuations of each set of wedges. In Japan, output and investment mainly responds to efficiency wedges, consumption mainly responds to international wedges, and labor mainly responds to labor wedges. In the US, output responds to labor and efficiency wedges, labor mainly reacts to labor wedges, consumption mainly reacts to international wedges, and investment mainly reacts to investment wedges.

The results are summarized in Table 4. The table reports the HP filtered cross-country correlation of each simulated variable as well as the standard deviation of them in each country. The results illustrate the common problem with single good international real business cycle model such as Baxter and Crucini (1995) that consumption correlation across countries would be too high relative to data with only productivity shocks. This can be shown by the international risk sharing condition (11) which guarantees that consumption across countries would be perfectly correlated without international price wedges. Another common problem with international real business cycle models is that production factors will have negative correlations across countries with only efficiency wedges i.e. productivity shocks. In the case of

Japan and the U.S., efficiency wedges in Japan are more volatile than in the US so the effect of fluctuations in Japanese efficiency wedges dominates the effect of fluctuations in US efficiency wedges[10]. High productivity in Japan leads to high labor supply in Japan and low labor supply in the US. Labor wedges in the US are important in accounting for the fluctuation in U.S. labor and output.

Table 5 presents the simulation results for output by decade. The results show that although simulations with labor and efficiency wedges both predict stronger business cycle correlation between Japan and the U.S. during 2000s, the output correlation is still negative. Investment wedges are important in accounting for the positive business cycle correlation during the 2000s. This is an application of the quantity anomaly that inputs react to the opposite direction in both countries in response to productivity shocks. In order to cancel out this negative correlation of input fluctuation, not only labor wedges but also investment wedges are important.

4.4 The Backus-Smith Puzzle

The international price wedges represent the relative price of Japanese goods to U.S. goods, which is by definition the real exchange rate between yen and US dollars. Figure 6 plots the HP filtered real exchange rate denominated by U.S. dollar per yen, where the deviation from its HP trend is measured by the right axis. The sharp increases in the real exchange rate during the mid 1980s and early 1990s correspond to the post Plaza Agreement and the post bubble period yen appreciation, respectively. The solid line with diamonds denoted as Benchmark is the international price wedges computed in the previous section. This shows that international price wedges cannot account for the actual yen appreciation episodes. This is an example of the well known Backus-Smith puzzle, introduced by Backus and Smith (1993), that inter-

[10] This is more apparent with linearly detrended (non HP filtered) data. Linearly detrended results are shown in the appendix.

national real business cycle models fail to replicate the relationship between real exchange rates and the international marginal rate of substitution.

Backus, Kehoe and Kydland (1994) generate endogenous fluctuation in international relative prices by introducing a structure of intermediate goods production into the two country economy setting. Stockman and Tesar (1995) generate endogenous fluctuation in international relative prices through preference shocks which directly affect the marginal utility of consumption. No matter how the international prices are endogenized, they are defined as the international marginal rate of substitution. In order to assess whether this discrepancy is created by a misspecification of the preference function, I consider alternative forms of preference functions and compute international price wedges. The HP filtered international price wedges are reported in Figure 3 measured by the left axis.

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 (2) 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 solid line with triangles plots the implied international relative prices for the cases in which $\sigma = 5$. Altering the risk aversion parameter does not reduce the gap between the implied international relative price and the real exchange rate.

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. With habit persistence, marginal utility is a function of consumption growth rather than the level of consumption. The solid line with Xs show that this alternative preference function also does not seem to be able to reduce the gap.

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 due to its ability to generate high volatility in consumption and countercyclical trade balance through the lack of income effects on labor supply. Raffo (2008) shows that the GHH preference can generate a countercyclical trade balance in a two-country Backus, Kehoe and Kydland (1994) model through countercyclical fluctuation of goods rather than counter cyclical international prices. The solid line with circles shows that the international price wedges computed with GHH preferences also are not useful in filling the discrepancy between the real exchange rate and the international relative prices implied by the model.

In Figure 6, only the real exchange rate is measured by the right axis because the volatility of it is large compared to the that international price wedges. This is also part of the price anomaly a la Backus and Smith (1993) that the model cannot account for the size of the real exchange rate fluctuation in the data. The wedge analysis in this section shows that this is also the case in Japan and the U.S[11].

[11] The standard deviation of the HP filtered international price wedges are $0.9\%, 1.4\%, 1.7\%, 0.9\%$ for the model with log preferences, non-separable preferences with $\sigma = 5$, preferences with habit formation, GHH preferences, respectively, while the standard deviation of the HP filtered real exchange rate is 9.3%.

4.5 Error Terms

The assumption in (7) is that there are no lagged spill over effects between domestic wedges and international wedges. However, there are no restrictions on the contemporaneous correlation among the error terms. Table 5 shows the correlation between the error terms. Labor wedges are positively correlated while investment and efficiency wedges are negatively correlated across countries. International price wedges are negatively correlated to Japanese investment and production efficiency wedges whereas they are positively correlated to US investment and production efficiency wedges. It is clear that the international price wedges is strongly correlated to the Japanese efficiency wedges.

Early studies on international business cycles such as Backus, Kehoe and Kydland (1994) and Stockman and Tesar (1995) can be considered as models connecting international price wedges to domestic wedges. In Backus, Kehoe and Kydland (1994), productivity shocks to intermediate goods firms in both countries endogenously shift the terms of trade which shows up as international price wedges in the business cycle accounting model. In Stockman and Tesar (1995), preference shocks affect the international relative prices directly where preference shocks show up as labor wedges in the business cycle accounting model. Business cycle accounting does not provide for an evaluation on which model is correct.

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, we can define fundamental economic shocks and understand how they form wedges. That is, the error terms can be expressed as

$$\varepsilon_t = Ce_t$$

where $ee' = I$. However, this involves an identification process which is usually problematic since there is not enough information. Sophisticated international business cycle models, such as the ones mentioned above, identify the contemporaneous relationship of error terms by assuming a certain structure of the economy. However, these assumptions may or may not be true. A further investigation of the error terms is needed to truly understand the nature of international business cycle correlations.

5 Conclusion

This study focuses on the Japan and US business cycle correlation over the 1980-2008 period. The cross-country correlation of output is weak in the 1980s and negative in the 1990s while after 2000 the correlation turns positive. I extend the business cycle accounting method a la Chari, Kehoe and McGrattan (2007) to a two-country open economy framework and show that production efficiency wedges in Japan and labor wedges in the U.S. are important in accounting for the output correlation while international price wedges are important in accounting for the consumption correlation between the two countries over this period. Furthermore, investment wedges are necessary to prevent investment to flow towards the relatively efficient economy. A successful model for business cycle correlations between Japan and the U.S. must account for this fact. This study should serve as a foundation for future research to construct a more sophisticated international business cycle model.

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A Non HP Filtered Results

In this paper, I present HP filtered results since I focus on high frequency properties of the two country business cycle correlation following the literature. However, non-filtered results are also useful. Figures A1 and A2 plot the output simulation results for each country. The results show that there is a larger medium term fluctuation in Japan than in the US. Figure A3 shows the non-filtered international relative price. The real yen appreciation in 1985 and in 1990 are shown much clearer than in the HP filtered case.

B Tables and Figures

Table 1. Japan-US Business Cycle Correlation

	output	*consumption*	*investment*	*government*	*labor*
1980 – 2008	0.06	−0.08	−0.06	−0.21	0.24
1980 – 1989	0.09	−0.14	−0.01	−0.42	−0.04
1990 – 1999	−0.33	−0.11	−0.47	−0.06	−0.08
2000 – 2008	0.70	0.23	0.63	0.07	0.73

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. International Correlation of Wedges

	g	τ_l	τ_x	z
$1980-2008$	-0.21	0.14	-0.99	-0.12
$1980-1989$	-0.42	-0.30	-0.99	-0.05
$1990-1999$	-0.06	0.23	-0.99	-0.34
$2000-2008$	0.09	0.46	-0.99	0.05

Table 4. Results of Simulations

		output	*consumption*	*labor*	*investment*
	$g^{JP}\&g^{US}$	0.61	1.00	0.91	-0.99
	$\tau_l^{JP}\&\tau_l^{US}$	-0.43	1.00	-0.44	-0.22
cor	$\tau_x^{JP}\&\tau_x^{US}$	0.45	1.00	0.87	-0.63
	$z^{JP}\&z^{US}$	-0.62	1.00	-0.99	-0.99
	$p\&ts$	-0.66	-0.66	-0.66	0.42
	$DATA$	0.06	-0.08	0.24	-0.06
	$g^{JP}\&g^{US}$	0.04	0.05	0.07	0.37
	$\tau_l^{JP}\&\tau_l^{US}$	0.88	0.40	1.45	0.42
$std(JP)$	$\tau_x^{JP}\&\tau_x^{US}$	0.32	0.33	0.44	5.98
	$z^{JP}\&z^{US}$	0.99	0.46	0.76	5.98
	$p\&ts$	0.49	0.58	0.79	0.19
	$DATA$	1.14	0.67	1.33	4.39
	$g^{JP}\&g^{US}$	0.04	0.05	0.07	0.37
	$\tau_l^{JP}\&\tau_l^{US}$	0.88	0.40	1.45	0.42
$std(US)$	$\tau_x^{JP}\&\tau_x^{US}$	0.32	0.33	0.44	5.98
	$z^{JP}\&z^{US}$	0.99	0.46	0.76	4.84
	$p\&ts$	0.49	0.58	0.79	0.19
	$DATA$	1.14	0.67	1.33	4.39

Table 5. Results of Simulations by Decade (Output)

	g	τ_l	τ_x	z	$p\&ts$	$DATA$
$1980-2008$	0.61	-0.43	0.45	-0.62	-0.66	0.06
$1980-1989$	0.65	-0.70	0.48	-0.59	-0.77	0.09
$1990-1999$	0.70	-0.34	0.33	-0.77	-0.60	-0.33
$2000-2008$	0.49	-0.10	0.73	-0.46	-0.40	0.70

Table 6. Correlation of Shocks

	ε_g^{JP}	ε_l^{JP}	ε_x^{JP}	ε_z^{JP}	ε_g^{US}	ε_l^{US}	ε_x^{US}	ε_z^{US}	ε_p	ε_{ts}
ε_g^{JP}	1.00	-0.69	0.11	0.50	0.18	-0.29	0.15	-0.56	-0.02	-0.11
ε_l^{JP}		1.00	-0.20	-0.57	-0.23	0.51	-0.13	0.66	0.05	0.19
ε_x^{JP}			1.00	-0.55	0.07	0.08	-0.94	0.01	0.61	-0.14
ε_z^{JP}				1.00	0.19	-0.41	0.76	-0.52	-0.38	0.01
ε_g^{US}					1.00	0.03	0.01	0.04	0.06	0.06
ε_l^{US}						1.00	-0.22	0.55	-0.11	0.27
ε_x^{US}							1.00	-0.27	-0.63	0.07
ε_z^{US}								1.00	0.28	0.26
ε_p									1.00	0.03
ε_{ts}										1.00

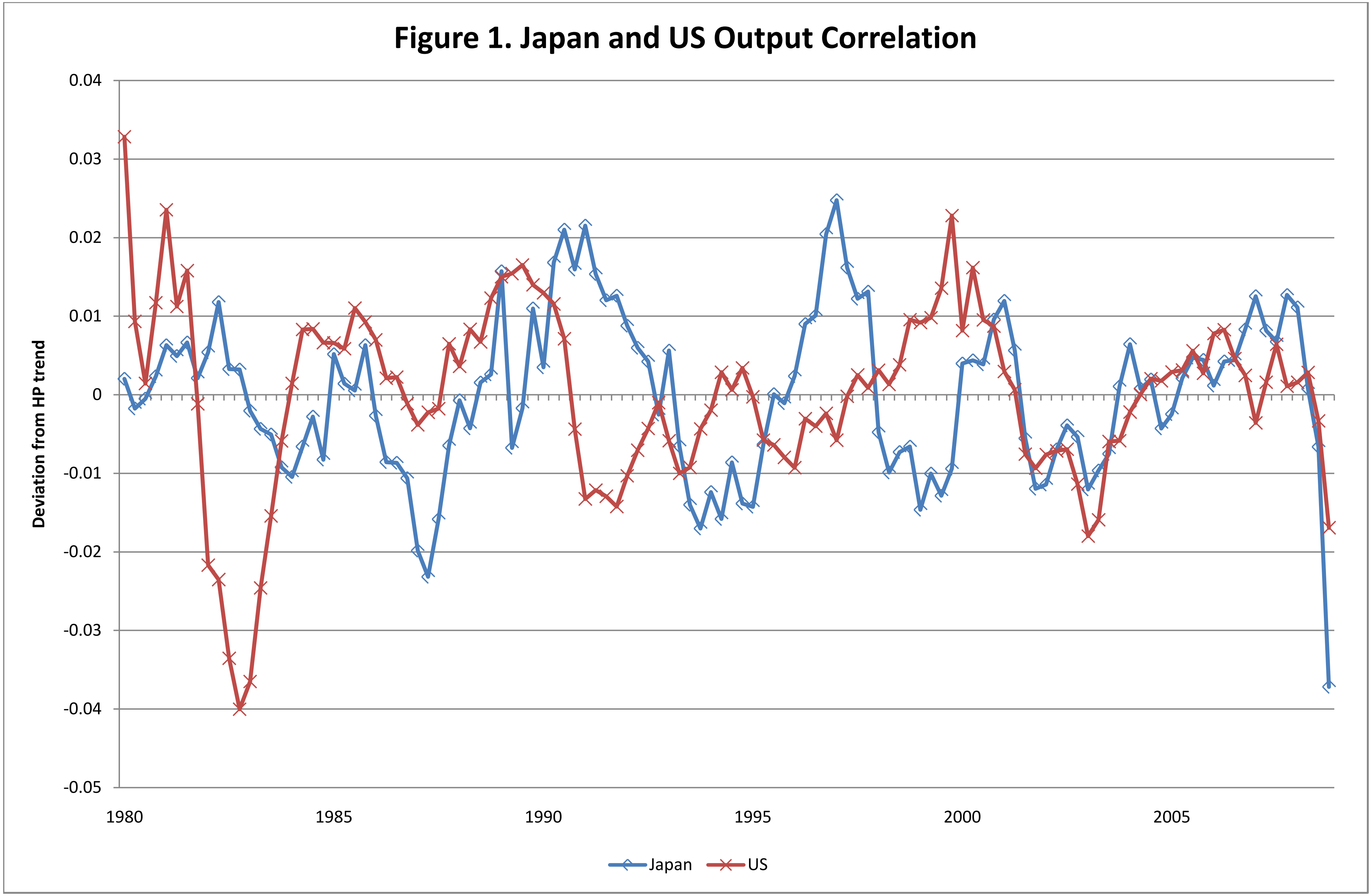


Figure 1. Japan and US Output Correlation
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
Deviation from HP trend
1980
1985
1990
1995
2000
2005
Japan
US

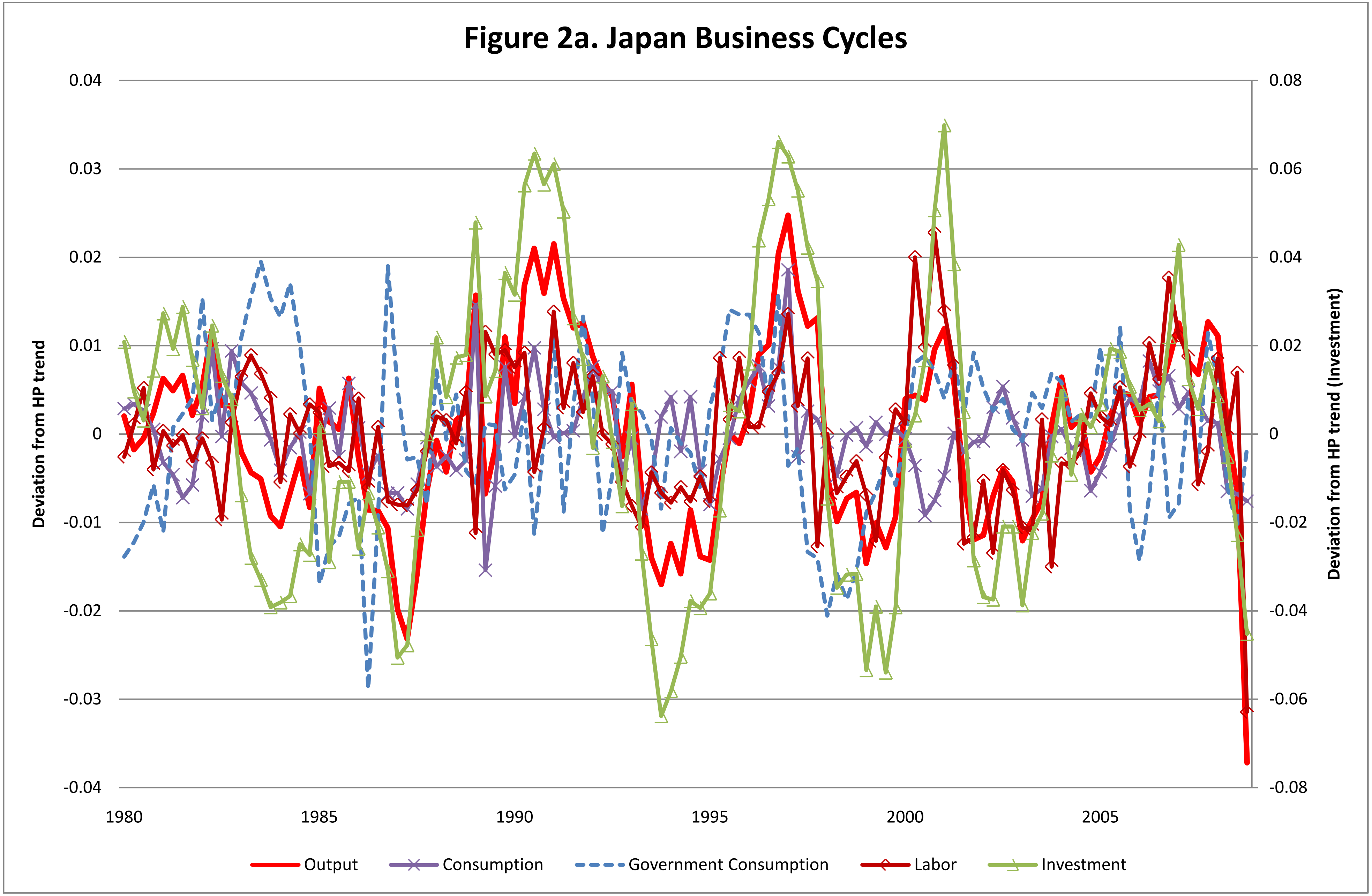


Figure 2a. Japan Business Cycles
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
Deviation from HP trend
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
Deviation from HP trend (Investment)
1980
1985
1990
1995
2000
2005
Output
Consumption
Government Consumption
Labor
Investment

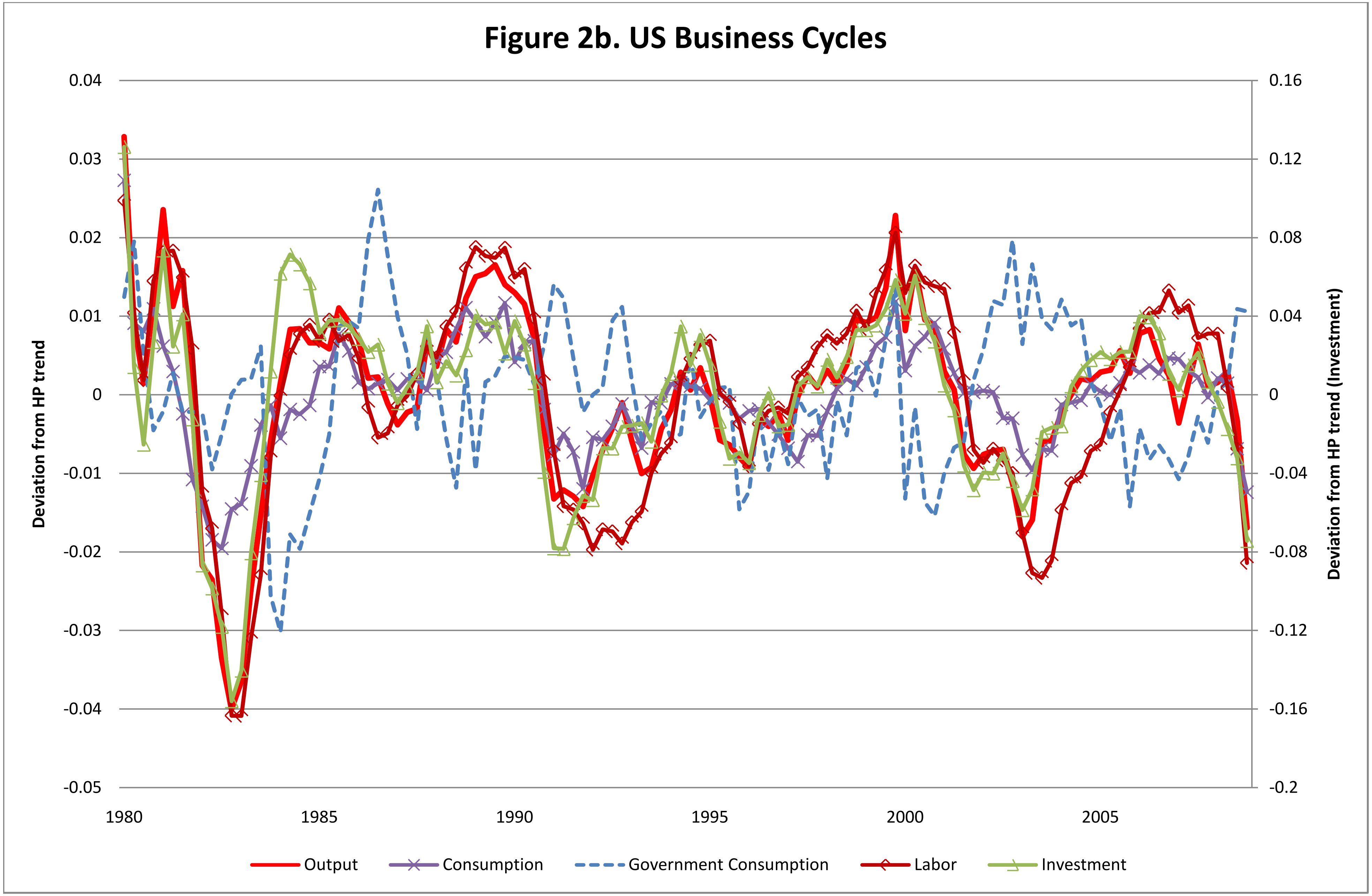


Figure 2b. US Business Cycles
Deviation from HP trend
Deviation from HP trend (Investment)
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
0.16
0.12
0.08
0.04
0
-0.04
-0.08
-0.12
-0.16
-0.2
1980
1985
1990
1995
2000
2005
Output
Consumption
Government Consumption
Labor
Investment

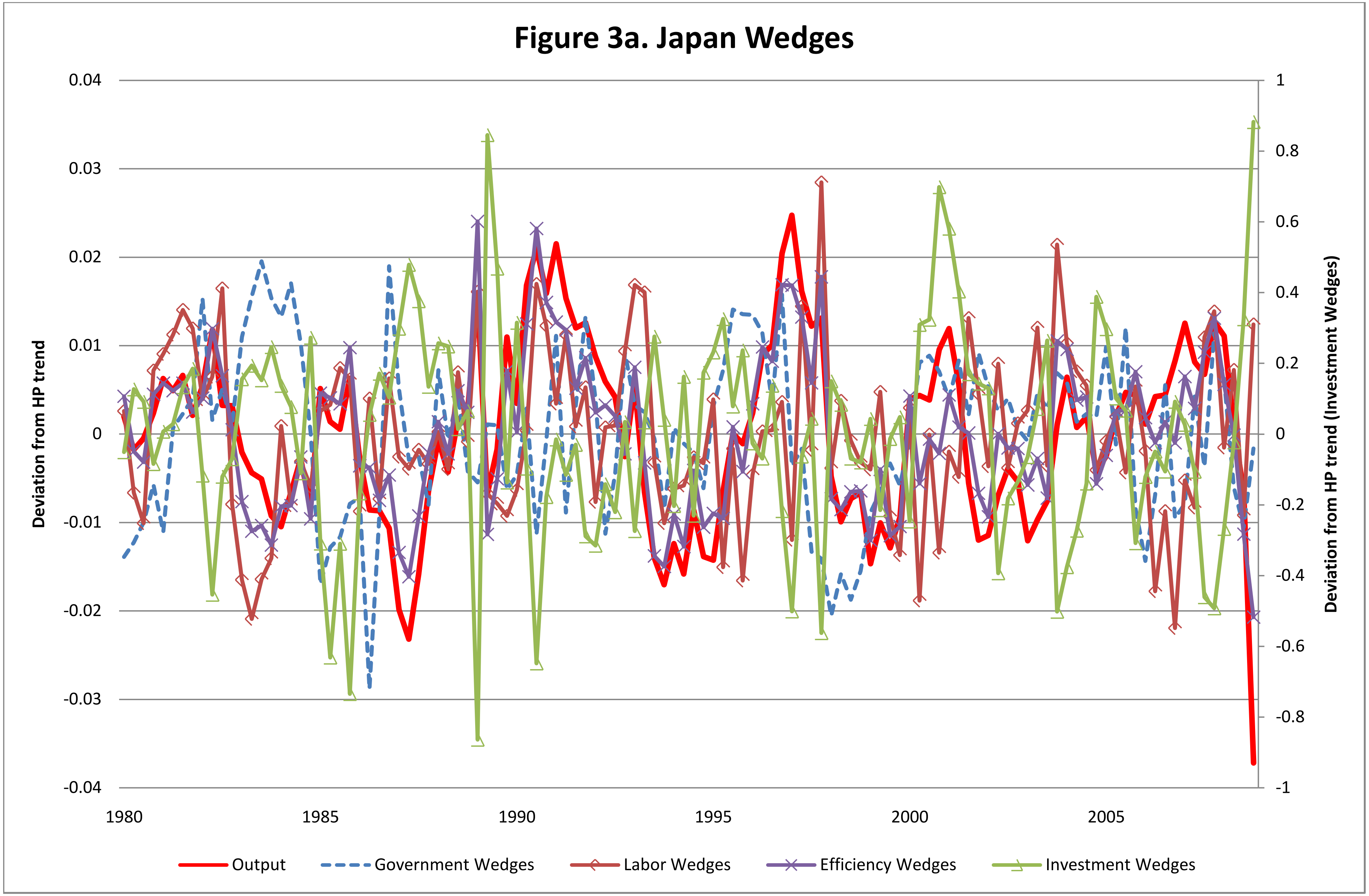


Figure 3a. Japan Wedges
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
Deviation from HP trend
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
Deviation from HP trend (Investment Wedges)
1980
1985
1990
1995
2000
2005
Output
Government Wedges
Labor Wedges
Efficiency Wedges
Investment Wedges

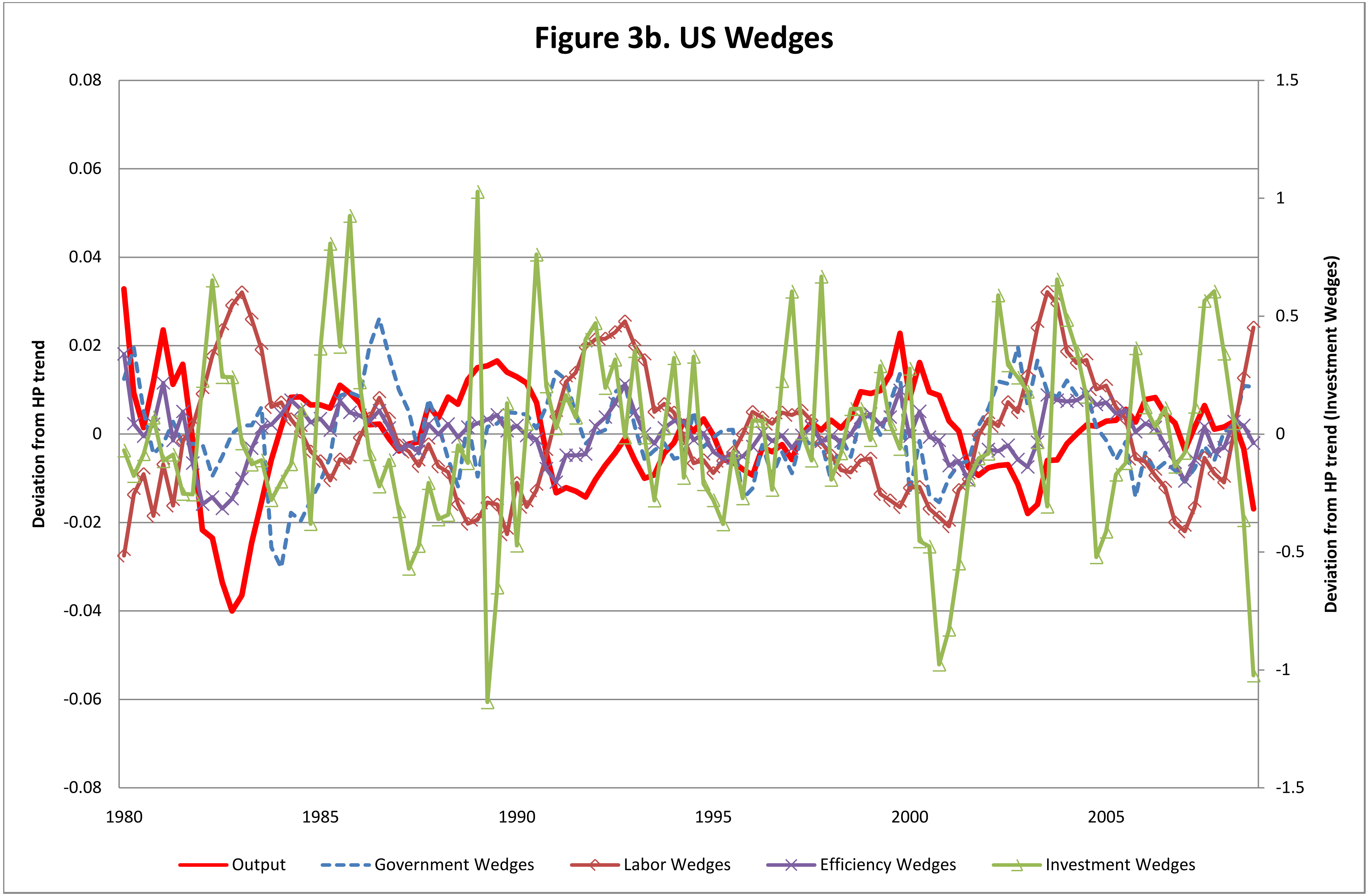
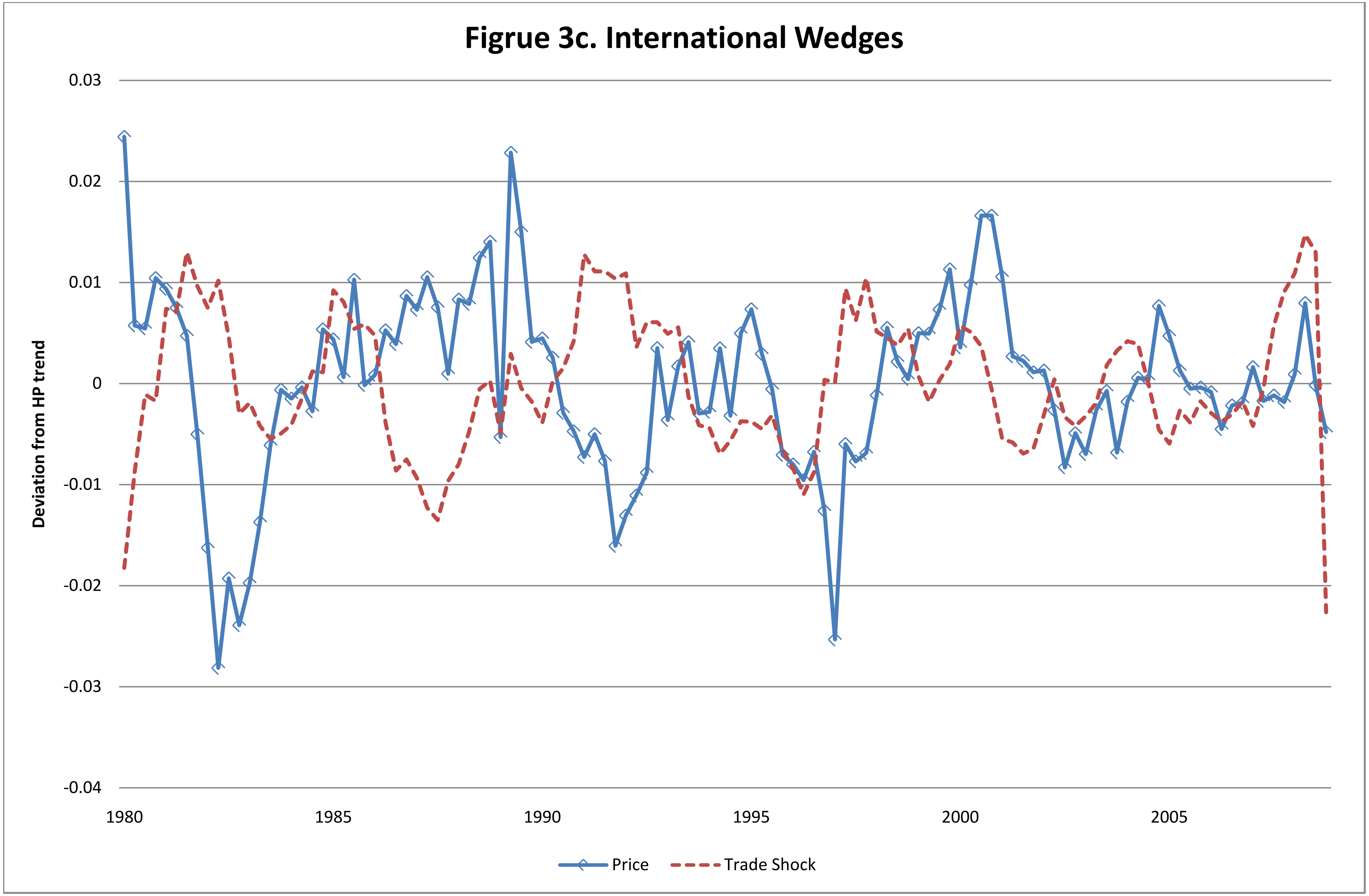


Figure 3b. US Wedges
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
1.5
1
0.5
0
-0.5
-1
-1.5
Deviation from HP trend
Deviation from HP trend (Investment Wedges)
1980
1985
1990
1995
2000
2005
Output
Government Wedges
Labor Wedges
Efficiency Wedges
Investment Wedges


Figrue 3c. International Wedges
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
Deviation from HP trend
1980
1985
1990
1995
2000
2005
Price
Trade Shock

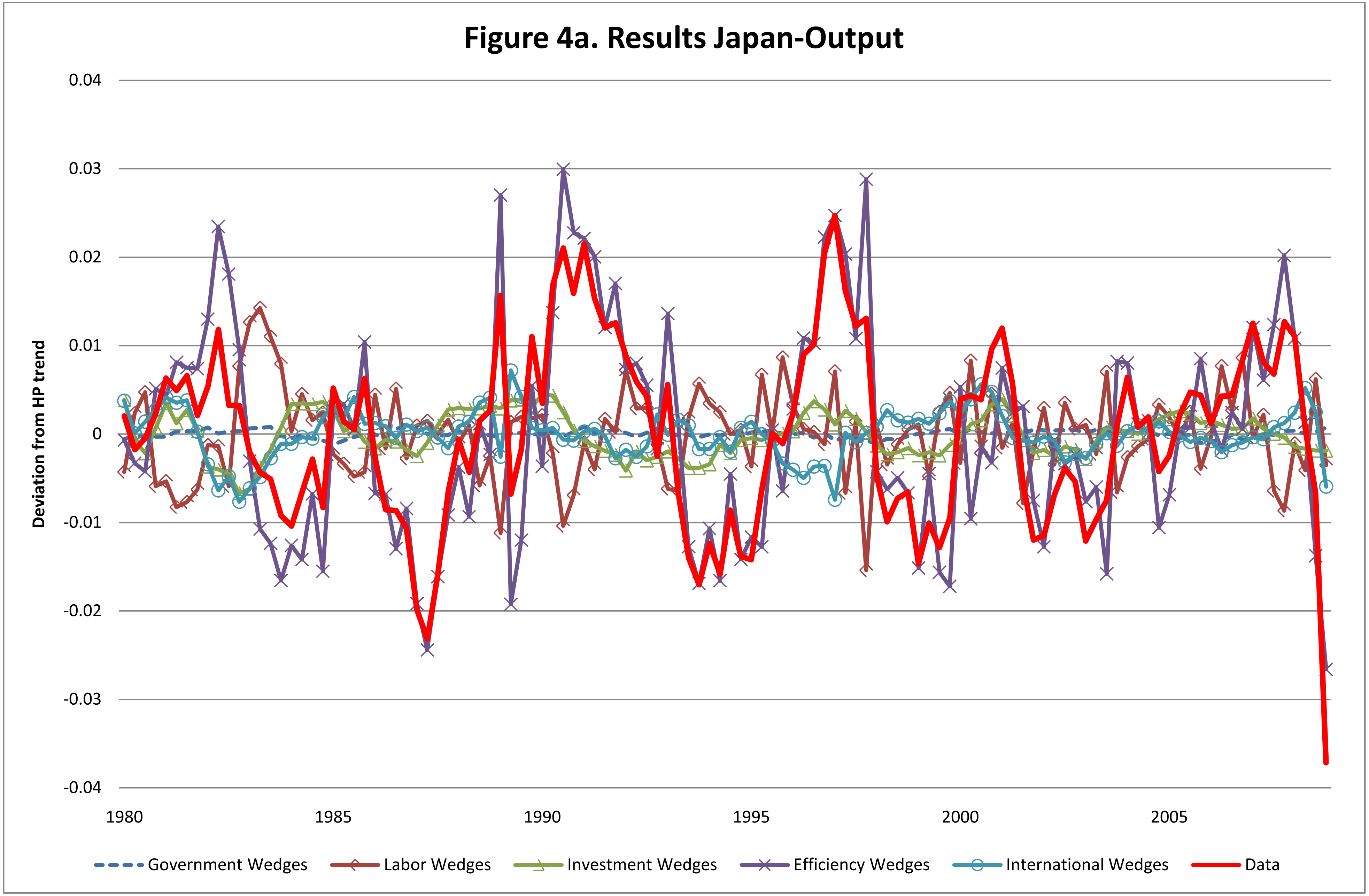


Figure 4a. Results Japan-Output
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
Deviation from HP trend
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

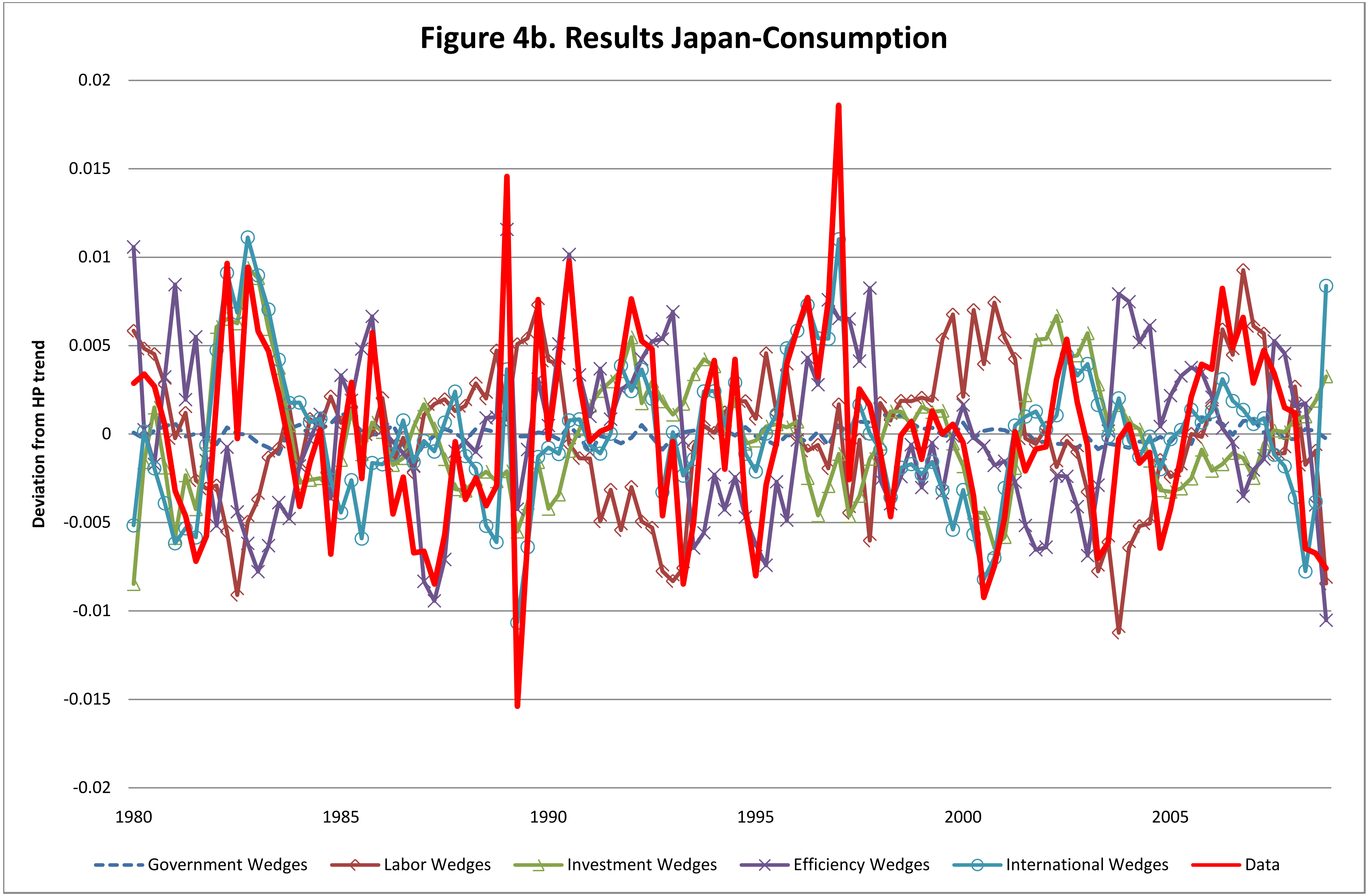


Figure 4b. Results Japan-Consumption
0.02
0.015
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
Deviation from HP trend
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

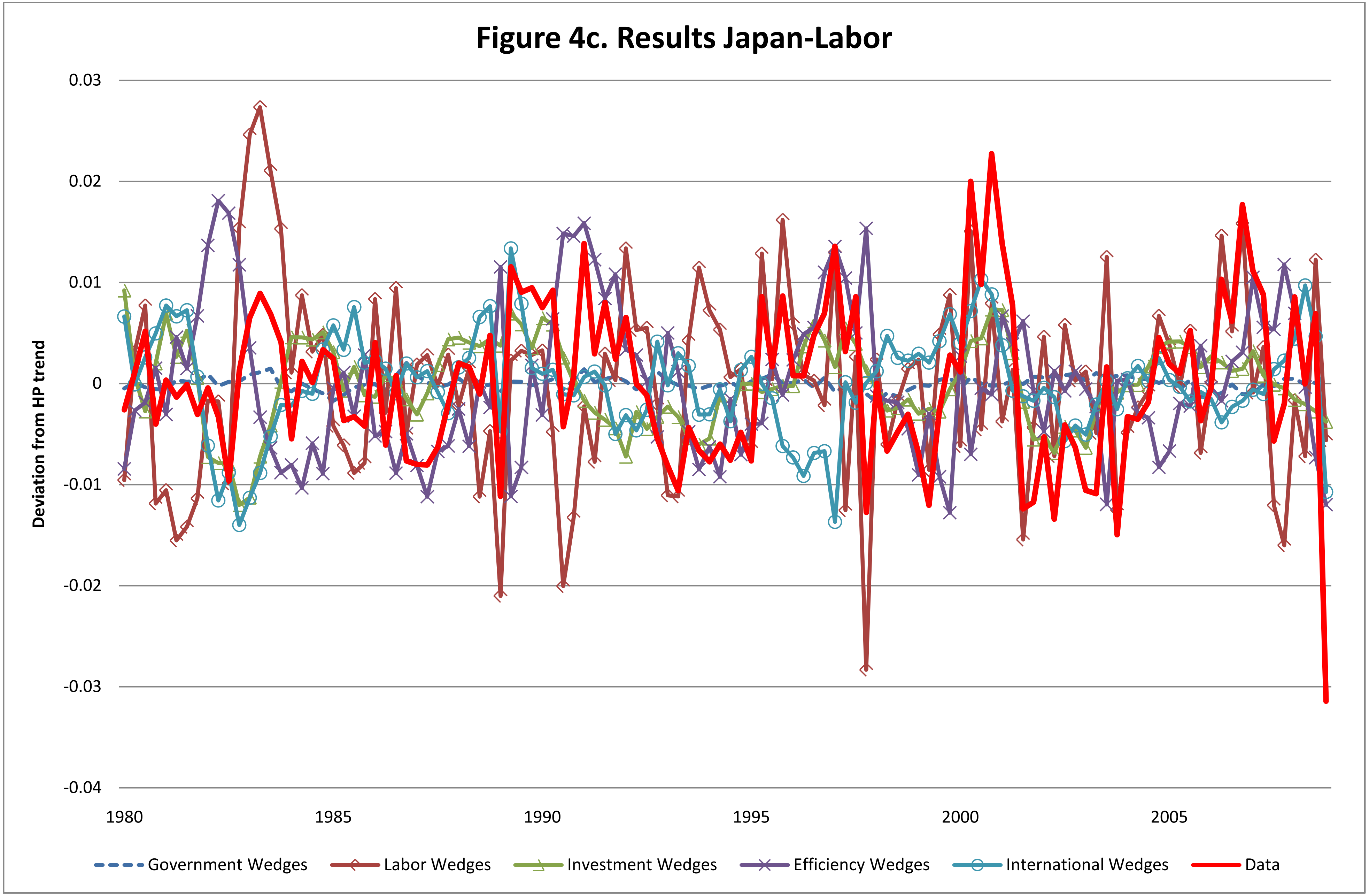


Figure 4c. Results Japan-Labor
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
Deviation from HP trend
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

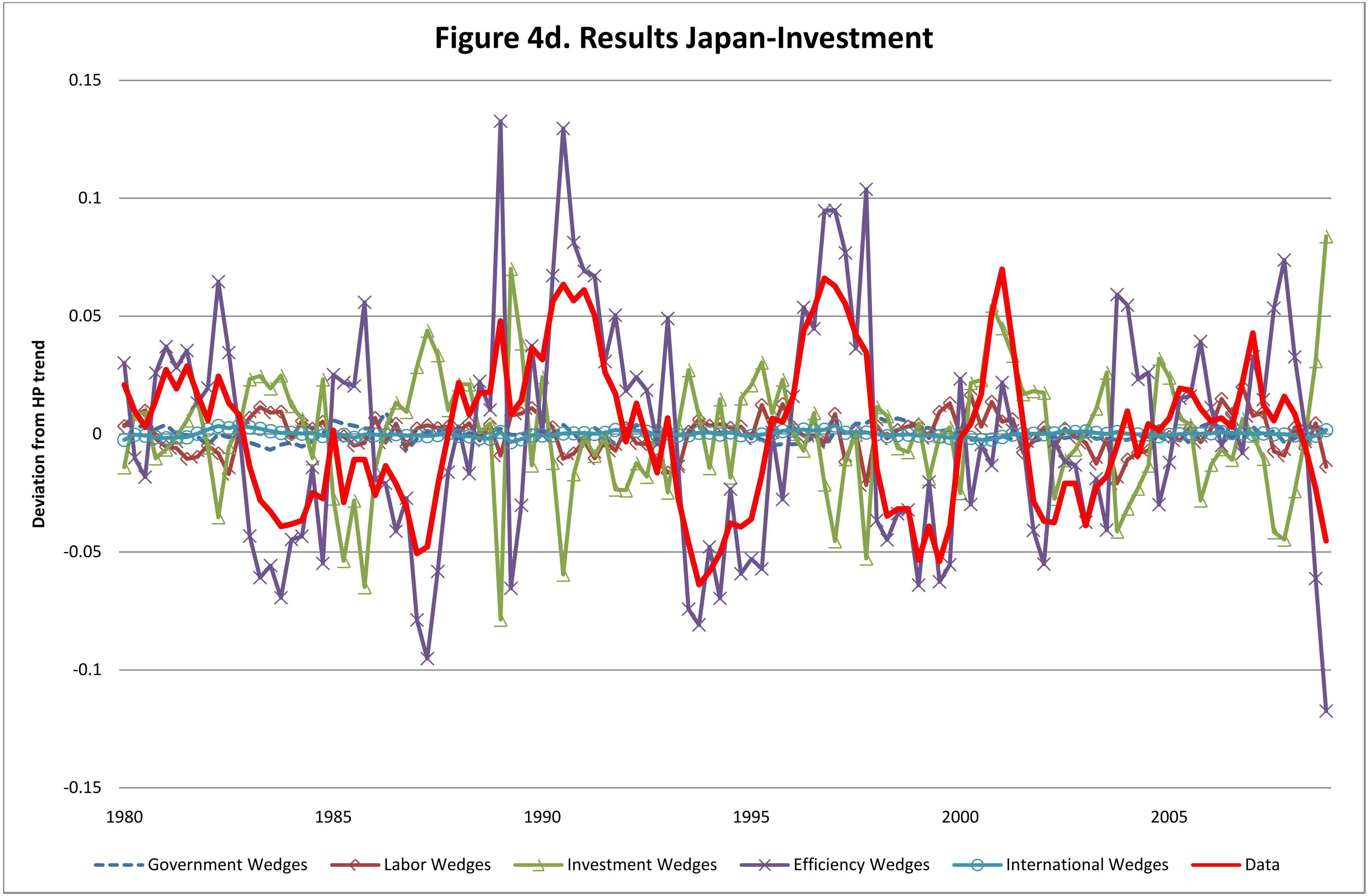


Figure 4d. Results Japan-Investment
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
Deviation from HP trend
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

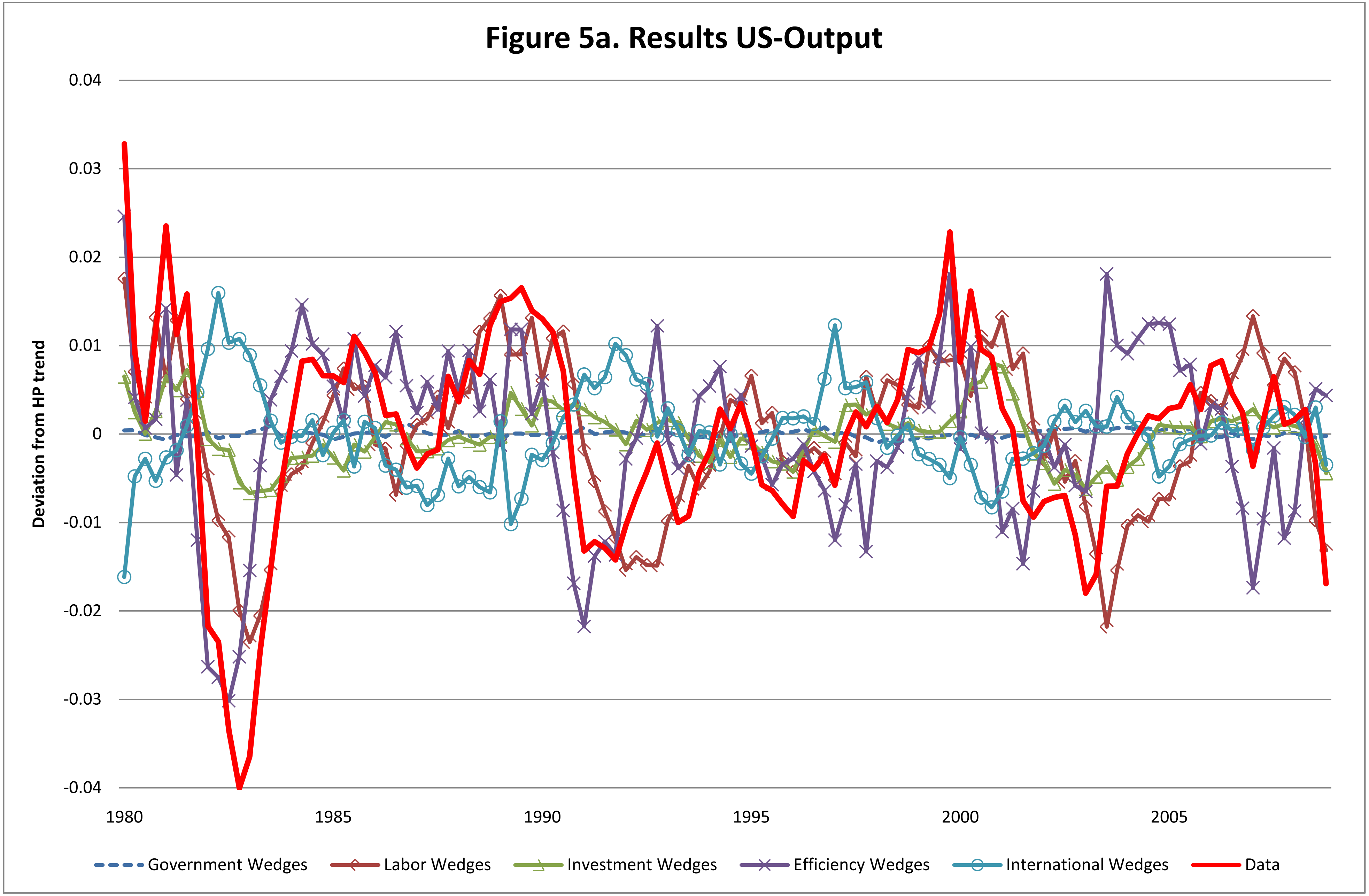


Figure 5a. Results US-Output
Deviation from HP trend
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

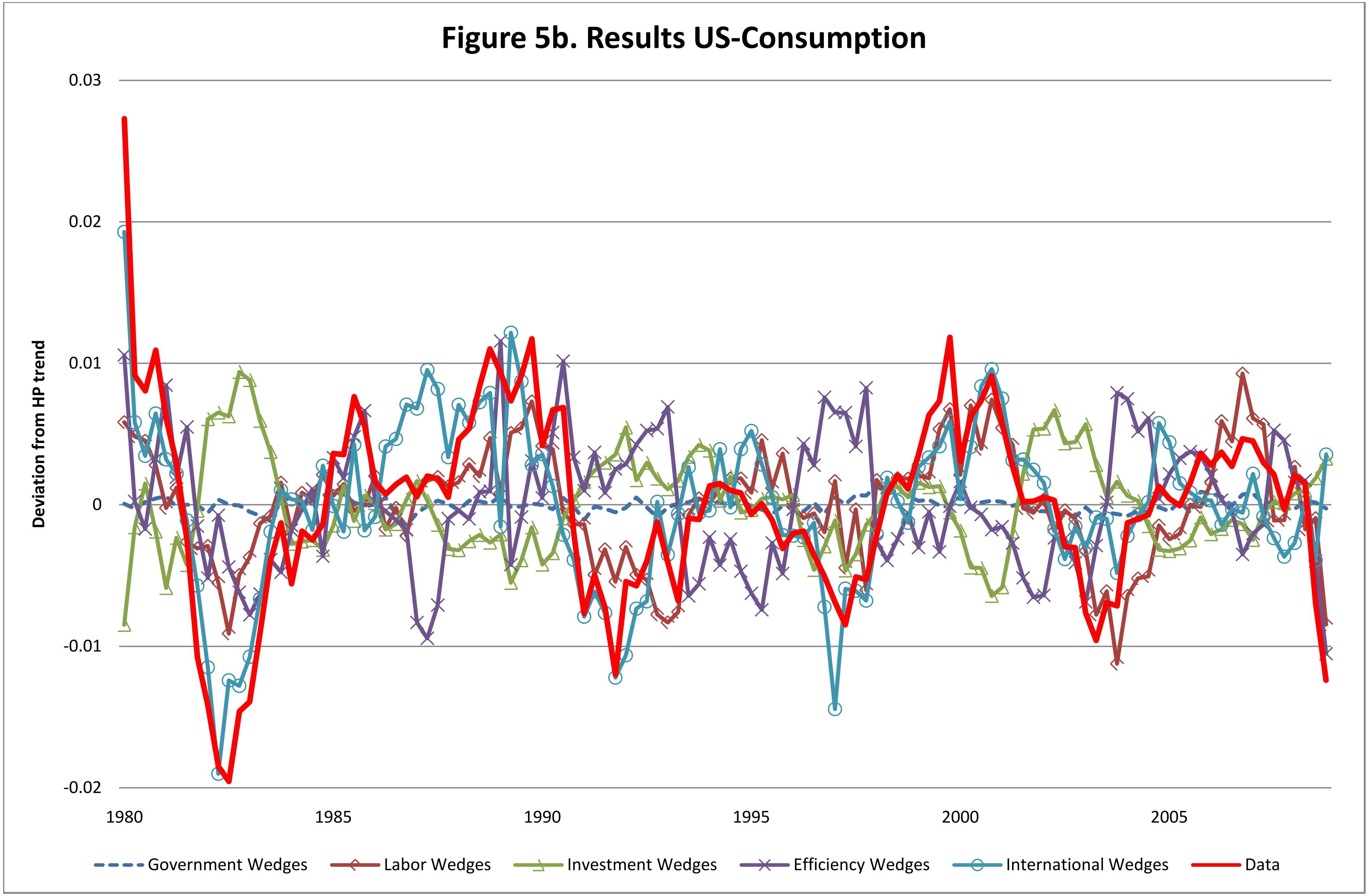


Figure 5b. Results US-Consumption
0.03
0.02
0.01
0
-0.01
-0.02
Deviation from HP trend
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

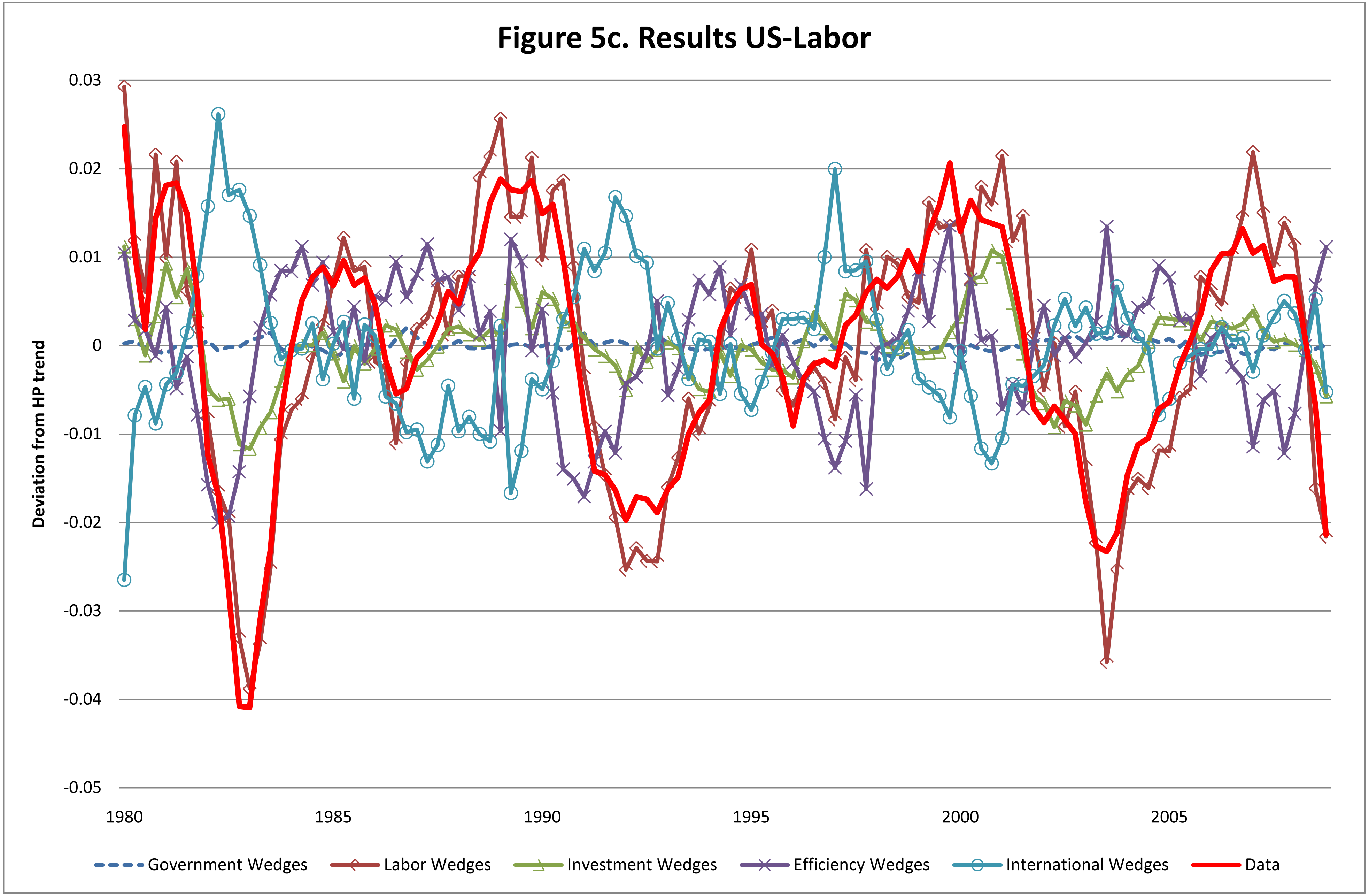


Figure 5c. Results US-Labor
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
Deviation from HP trend
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

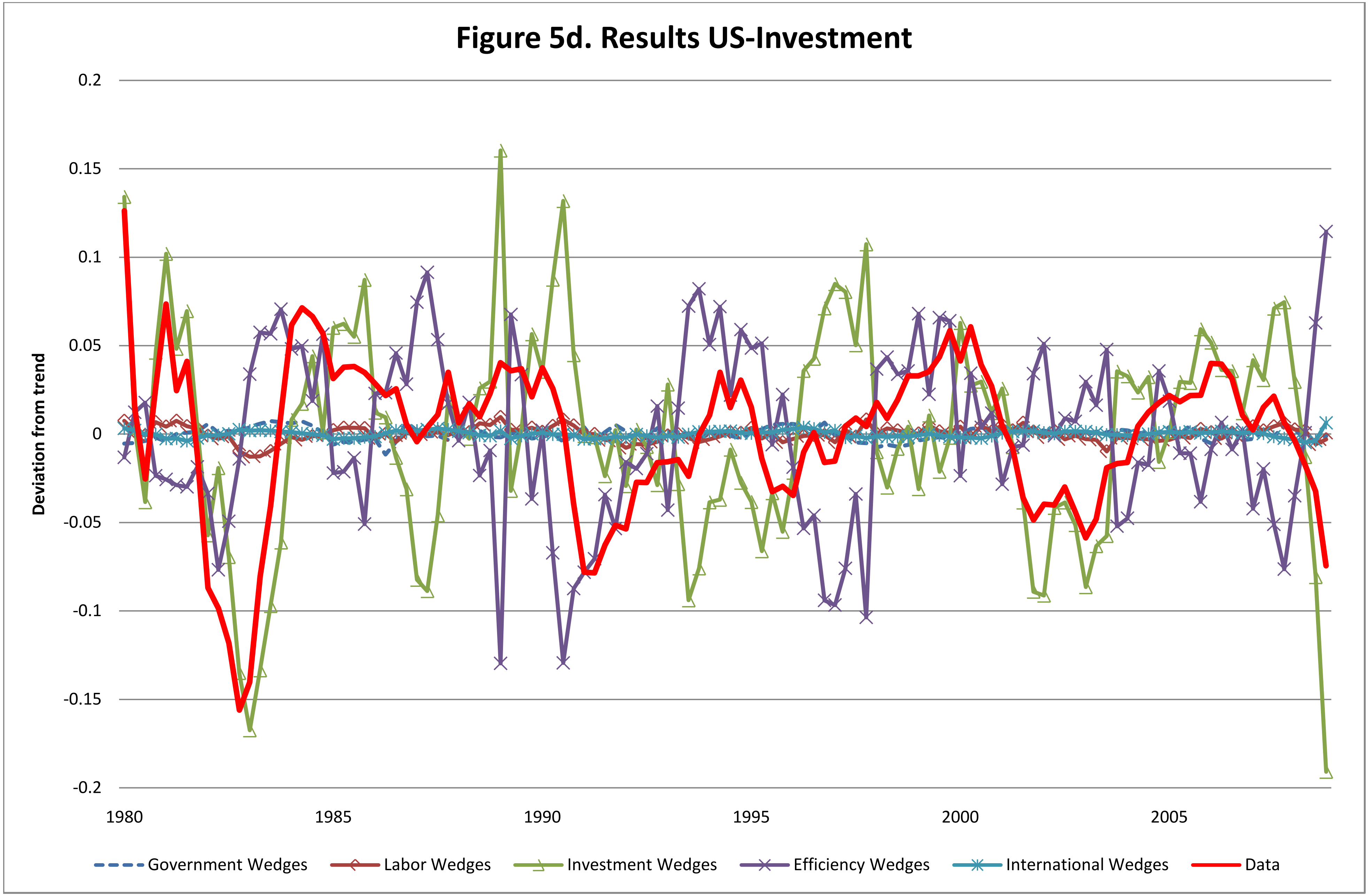
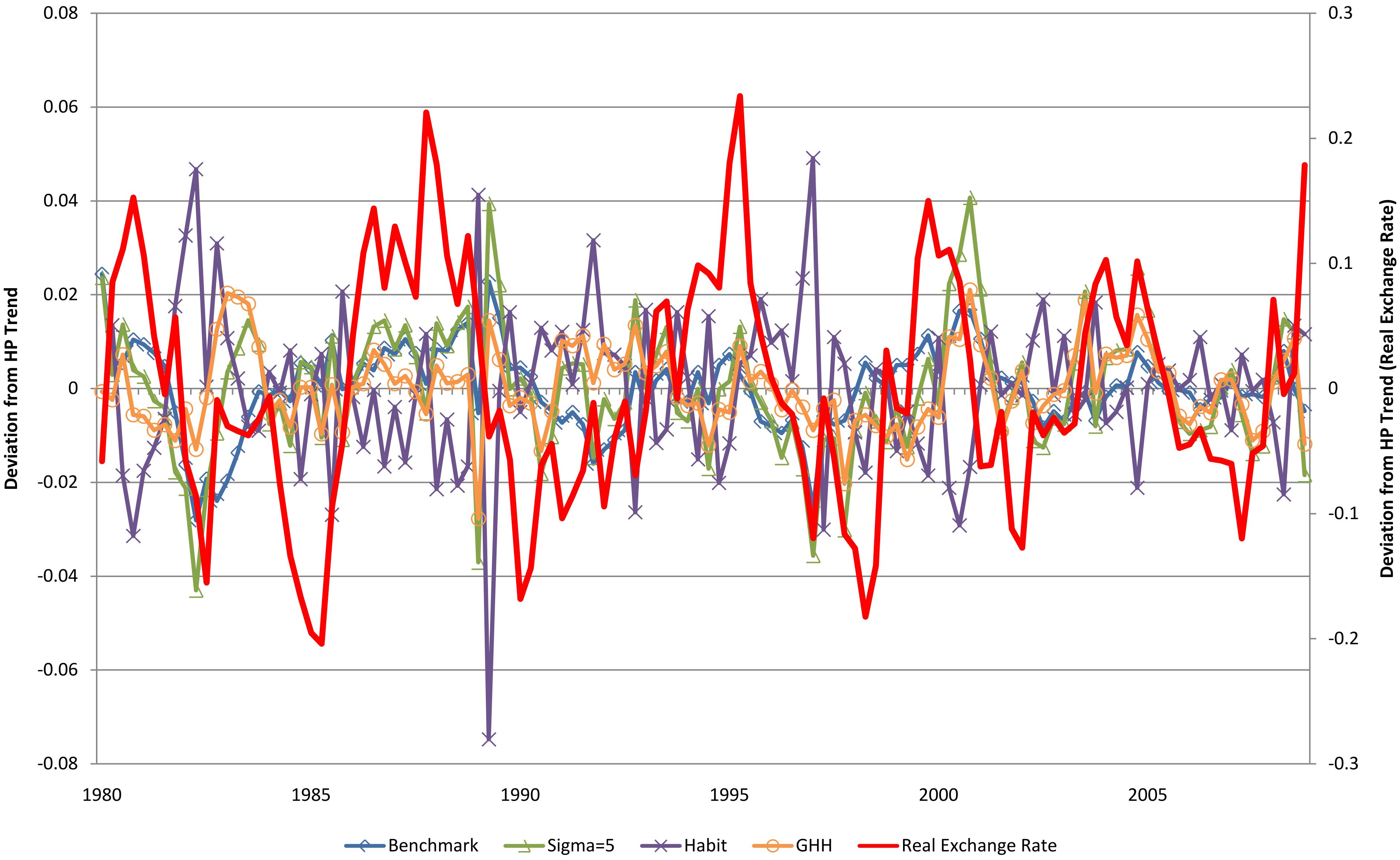


Figure 5d. Results US-Investment
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
Deviation from trend
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

Figure 6. International Relative Prices



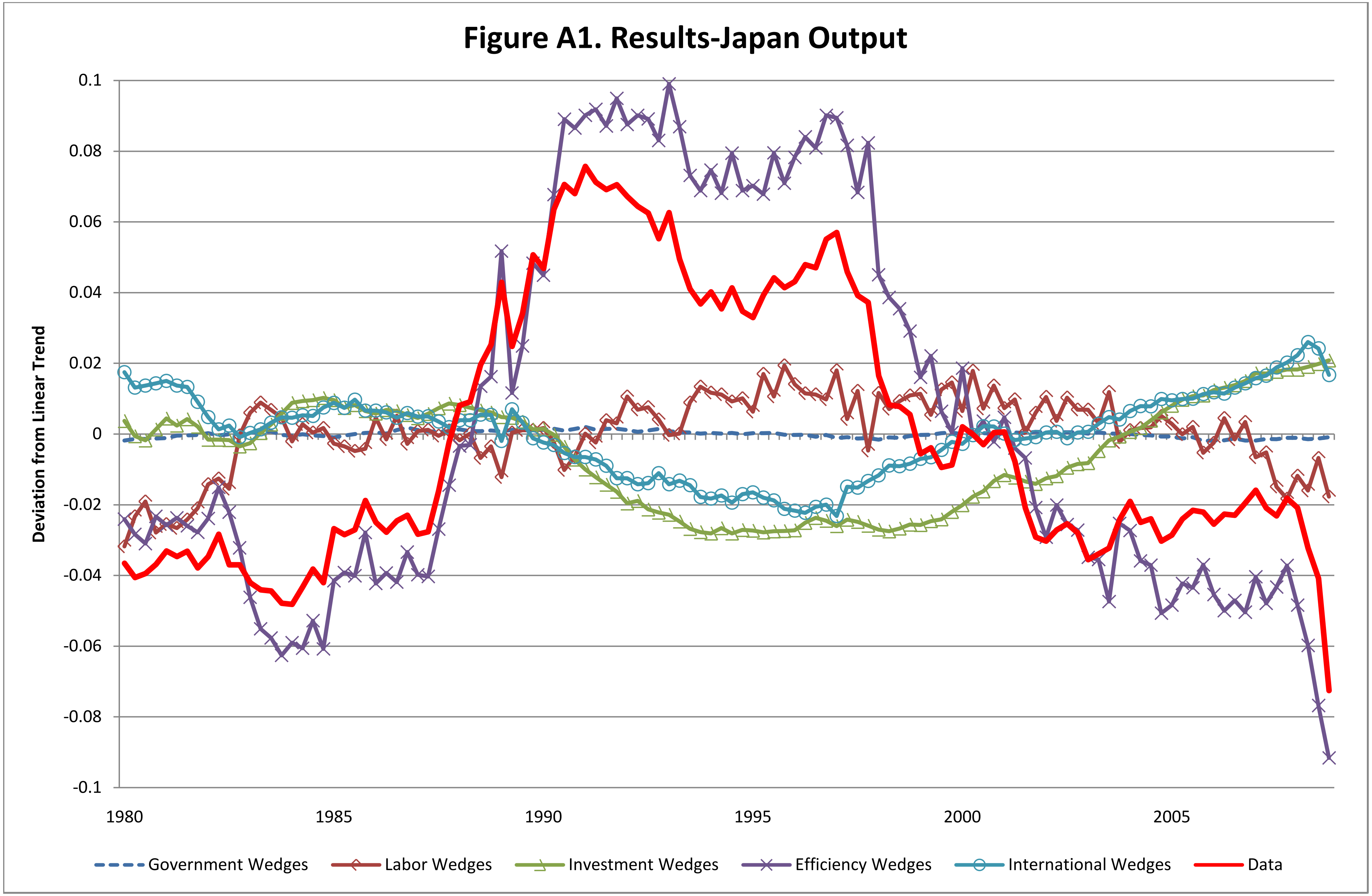


Figure A1. Results-Japan Output
Deviation from Linear Trend
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

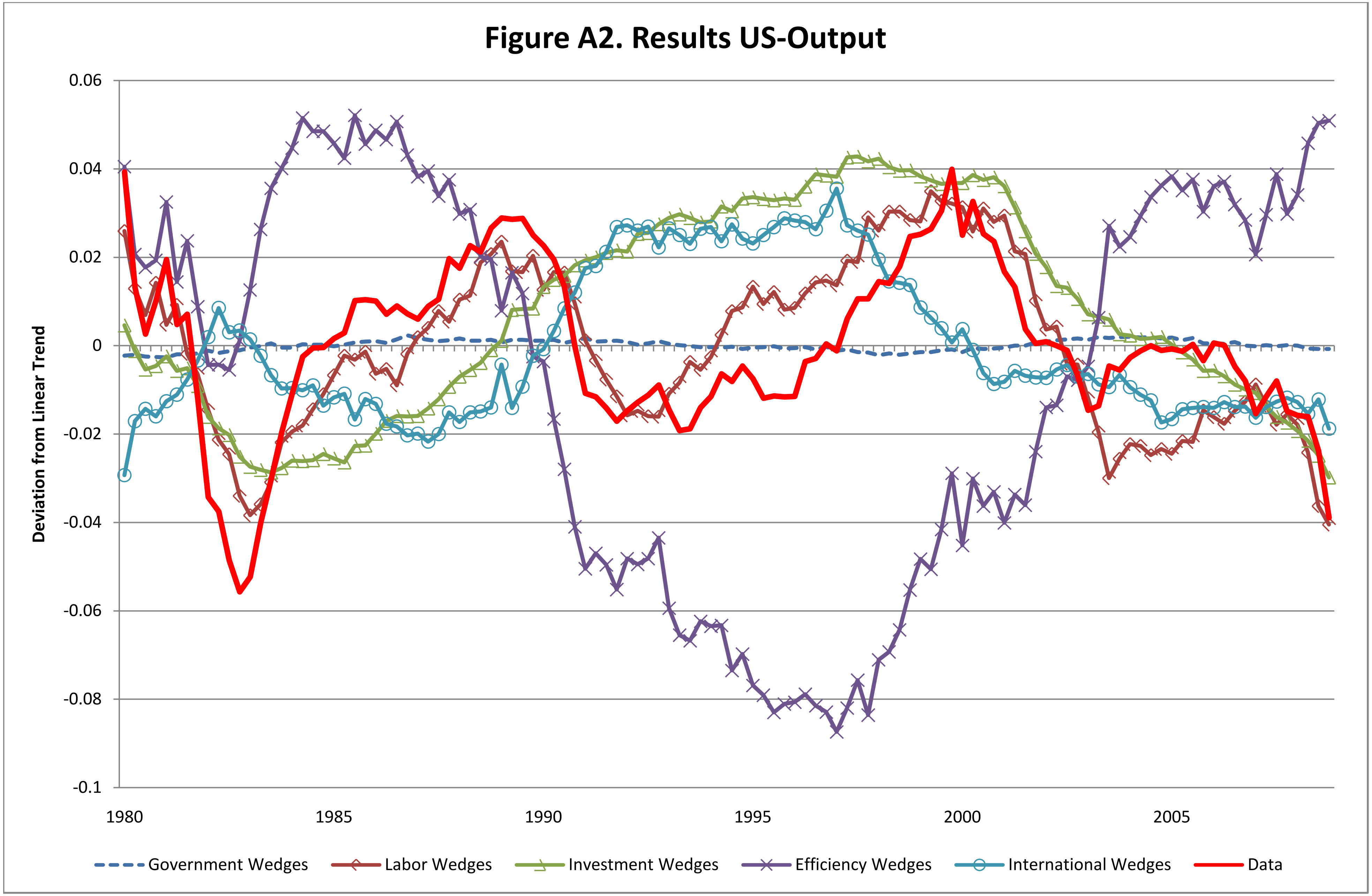


Figure A2. Results US-Output
Deviation from Linear Trend
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
1980
1985
1990
1995
2000
2005
Government Wedges
Labor Wedges
Investment Wedges
Efficiency Wedges
International Wedges
Data

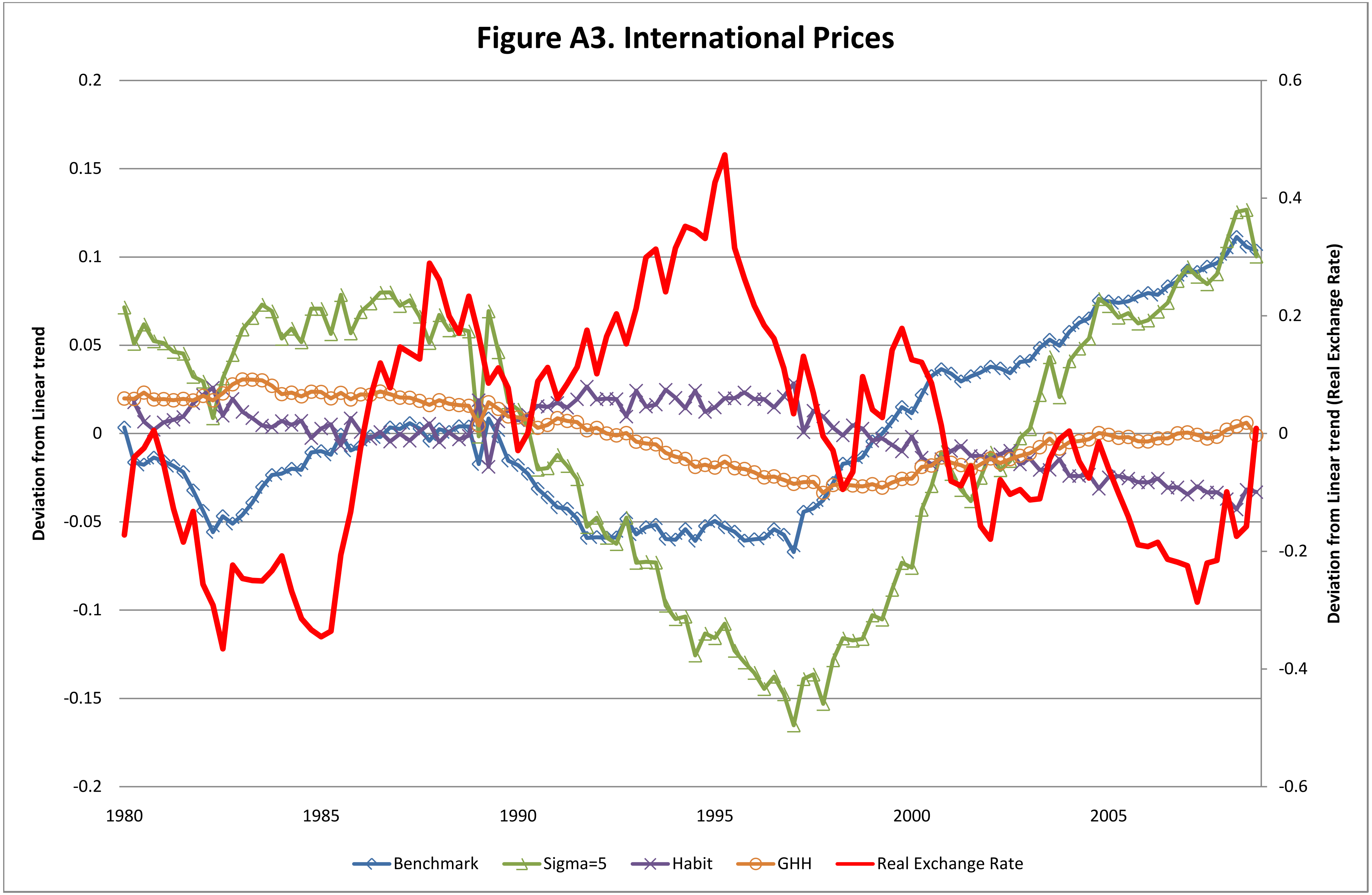


Figure A3. International Prices
Deviation from Linear trend
Deviation from Linear trend (Real Exchange Rate)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1980
1985
1990
1995
2000
2005
Benchmark
Sigma=5
Habit
GHH
Real Exchange Rate