The High Correlations of Prices and Interest Rates across Nations*

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Abstract

We document that at business cycle frequency, nominal variables, such as aggregate price levels and nominal interest rates, are more correlated across countries than real output. Since national central banks control the domestic money supply and their objective has been to keep the nominal environment stable this might seem puzzling. We ask whether a simple, transparent standard international business cycle model can account for these nominal as well as the real aspects of international business cycles. It can. Due to spillovers of technology shocks across countries, responses of national central banks to fluctuations in domestic output and inflation generate responses of prices and interest rates that are synchronized across countries even when output is not. Even modest spillovers produce correlations like those in the data.

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1 Introduction

It has been argued recently that closer international integration of asset, goods, and factor markets will affect the monetary transmission mechanism and might decrease the ability of national central banks to control domestic interest rates and inflation (see Woodford, 2007, for a survey of such views). Implicit in these worries is that central banks' ability to control the nominal side of national economies might about to erode.

National central banks control the domestic money supply. Though the stated objectives have been different across countries and over time a common feature has been to keep a stable nominal environment. Even if individual central banks respond to shocks that are common to all countries, we would expect the cross-country correlations of nominal variables to be at most as high as those of output. This paper documents that, for a sample of the largest industrialized economies since 1960, the opposite was the case: over the business cycle, prices and nominal interest rates have been substantially more correlated across countries than output.

Previous studies have documented that national inflation rates have a significant "common component" (see, for example, Ciccarelli and Mojon (2005) and Mumtaz and Surico (2007)). In addition, Wang and Wen (2007) find that cross-country correlations of inflation rates are substantially higher than those of output. These studies, however, look at actual inflation rates, not their cyclical fluctuations. The high cross-country correlations they document thus to a large extent reflect the fact that in many countries inflation was low in the 1960s, high and volatile in the 1970s, decreasing in the 1980s, and low and stable in the 1990s. In contrast to these studies, this paper documents that high cross-country correlations of nominal variables are also a business cycle phenomenon.

In particular, we find that in a sample of six major industrial economies (Australia, Canada, Germany, Japan, the United Kingdom, and the United States) for the period 1960.Q1-2006.Q4 the average bilateral correlation of aggregate price levels was 0.52, that of short-term nominal interest rates was 0.57, while that of real GDP was only 0.25. The bilateral correlations of real GDP are also much more dispersed in the sample than those of the two nominal variables. This finding is broadly robust to the inclusion of two other countries (Austria and France) from 1970.Q1, the exclusion of the Bretton Woods years, and splitting the sample into two subsamples in 1984, the year generally associated with the start of the so-called "Great Moderation".

In addition to these cross-country correlations, we observe that for all countries in our sample a country's price level is negatively correlated contemporaneously with its own output and has a pronounced phase shift in the direction of leading the cycle with a negative sign. A country's short-term nominal interest rate also leads output with a negative sign, but is correlated positively with output contemporaneously.[1]

A possible "textbook" explanation for the high cross-country correlations of nominal variables is that national central banks have not had full monetary autonomy due to memberships in various exchange rate mechanisms, such as the Bretton Woods agreement and

[1]This "inverted leading indicator" property of nominal interest rates has been previously noted for the United States, for example, by King and Watson (1996).

the exchange rate mechanism of the European Monetary System (EMS). This explanation, however, cannot be the whole story since we find high cross-country correlations of nominal variables also in the post-Bretton Woods period of floating exchange rates. And only two countries in our sample (France and Germany) participated in the EMS exchange rate mechanism for a significant period of time.

Another explanation could be that the high correlations are due to common price shocks, such as the oil price shocks of the 1970s. This explanation is unconvincing for two reasons. First, we observe the high correlations also in the post-1984 period, in which it is hard to find significant common price shocks at business cycle frequencies. And second, price shocks, such as the oil price shocks, are first and foremost changes in relative prices. Therefore there is no reason why, by themselves, they should lead to substantial fluctuations in the aggregate price level.

Indeed, it is possible that the high cross-country correlations of nominal variables are due to responses of national central banks to shocks that are common to all countries. For example, central banks might accommodate oil-price shocks. But, to the extent that such shocks also cause fluctuations in output, the question still remains why are nominal variables more correlated across countries over the business cycle than output?

In this paper we ask to what extent a simple international business cycle model with money can account for the documented international nominal, as well as real, correlations. Business cycle theory has been successful in accounting for many features of the real side of the international business cycle (e.g. the dynamics of terms of trade with respect to net exports, and the dynamics of net exports with respect to output). At the same time, closed-economy business cycle models, when appropriately extended to include money, are also consistent with features of the nominal side of the domestic business cycle (e.g., the countercyclical behavior of the price level and a positive comovement between broad money and output). We view the empirical regularity that prices and nominal interest rates are more correlated across nations than output as an important characteristic of the nominal side of the international business cycle, and believe that answering this question will enhance our understanding of how inflation is transmitted across borders.

To this end we extend the two-good international business cycle model developed by Backus, Kehoe and Kydland (1994) to include a role for nominal assets as means of payment, an international asset market, and a domestic monetary authority in each country that sets monetary policy according to a (domestic) Taylor-type rule (see Taylor, 1993).

We find that to a large extent the model does account for the observed international nominal business cycle statistics. Due to spillovers of technology shocks from one country to another, responses of national central banks to fluctuations in domestic output and inflation generate responses of prices and interest rates that are synchronized across countries even when output is not. We find that even modest spillovers produce correlations like those in the data. These findings are robust to a broad range of parameter values of the monetary policy rule.

These findings, however, do not mean that national central banks cannot stabilize the nominal side of their economies. Computational experiments show that nominal variables will be more strongly correlated across countries than output even when national central banks put a large weight on stabilizing domestic inflation, and no weight on output at all. This result can account for the empirical finding that high cross-country correlations of nominal variables also characterize the "Great Moderation" period.

In addition to the international correlations, the model also produces a countercyclical price level. However, it does not generate the phase-shifts of the price level and the nominal interest rate observed in the data. Since these are well-known anomalies, we are not surprised that the model can not account for them.

That this simple model successfully account for the high correlation of nominal variables at business cycle frequency does not mean that any more complicated models can't contribute to account for these facts. Potential candidates include models with where international monetary policy is described as a strategic game or where markets for good and inputs are imperfect. citeWW2007 ask whether the high correlations of inflation rate levels across countries which they document can be accounted for in a one-good two-country models, with either sticky prices or sticky information, in which the main sources of business cycles are monetary shocks. They find that such models cannot account for both the international correlations, as well as for the domestic nominal business cycle. There also exists a large and somewhat related literature on inflation and exchange-rate pass through (see Taylor, 2000, for a survey). There the main focus is on how imperfectly competitive firms "pass through" both foreign price changes and exchange rate movements to their own prices. We do not exclude the possibility that imperfect competition or nominal rigidities play some role in the international nominal business cycle. Nevertheless, we believe that before introducing such features into model economies, we need to understand to what extent a standard international business cycle model can account for the empirical regularities, and to understand the channels that generate the results. Our findings demonstrate that the standard model can go a long way.

The outline of the rest of the paper is as follows. Section 2 documents the empirical regularities, Section 3 introduces the model, Section 4 presents the findings from our benchmark experiment, Section 5 conducts sensitivity analysis, and Section 6 concludes.

2 Properties of nominal business cycles

2.1 International nominal business cycles

Figures 1, 2, and 3 plot deviation from bandpass trend for quarterly series for output, nominal interest rates, and price levels across a set of eight major industrialized countries for the period 1960-2005. As we see from the figures, all variables are highly correlated across countries. The bilateral correlations are given in Tables 1, 2 and 3. For both the price level and the nominal interest rate, the mean correlation is, approximately, 0.55, while it is approximately 0.3 for real GDP.

The co-movements among national price levels and among national short-term nominal interest rates are less dispersed than those among national real GDP – the relative standard deviation for the correlations is about 0.25 for both the price level and the nominal interest rate, while for real GDP it is about 0.85 (see Tables 1-6).

The mean correlation and the associated relative standard deviation are about the same for short-term nominal interest rate and the price level (see Tables 2, 3, 5, and 6). The mean correlation and the associated relative standard deviation for a short-term nominal interest rate and for the price level are about the same for different samples and time periods, while those for real GDP are not (see Tables 1-6).

Figure 4 plots the bilateral correlations of the price level and the nominal interest rate against the bilateral correlations of output for each of the 28 pairs in our eight-country samples. We see that for most pairs, correlations of the nominal variables are higher than the correlations of real GDP. In addition, the slope of the regression lines fitted to the data points is substantially less than one (0.1 for the correlations of the nominal interest rate, and 0.43 for the correlations of the price level). Moving from countries with high bilateral correlation of output to those with low correlation reduces their bilateral correlations in nominal variables less than proportionally.

Visual inspection of Figure 3 shows a striking comovement in the price level in all postwar business cycles, not just the two cycles associated with oil price shocks. It is therefore unlikely that the comovement in the data is due to common energy price shocks.

Theory suggests that countries operating under a fixed exchange rate regime should have higher comovement in inflation than those operating under flexible exchange rates. Our six-country sample includes 14 years of the Bretton Woods agreement. However, the mean values of the bilateral correlation coefficients for both the price level and the nominal interest rate are virtually unaffected by excluding the Bretton Woods years. Furthermore, the non-Bretton Woods years are not much affected by the European Monetary System (EMS) and the European Monetary Union since only Germany and the UK belonged to the former, and only Germany belongs to the latter. We can also see that, for instance, the price level in France comoves as strongly with the price level in the UK (a fellow EMS member) as with the price level in Japan.

2.2 Domestic nominal business cycles

A short-term nominal interest rate is positively correlated with real GDP contemporaneously and lags real GDP (see Figure 5 and Table 7).

The aggregate price level is negatively correlated with real GDP contemporaneously and leads real GDP with a negative sign (see Figure 6 and Table 7).

3 The model economy

A world economy consists of two countries, denoted 1 and 2, that are populated by equal measures of identical, infinitely lived consumers. Producers in each country use country-specific capital and labor to produce a single good. The good produced in country 1 is labelled by a, while that produced in country 2 is labelled by b. These are the only traded goods in the world economy. Within each country goods a and b are combined to form a good that can be used for local consumption and investment, and that we refer to as the "expenditure good". In order to purchase the expenditure good for consumption purposes, consumers have to incur a time cost, which depends positively on the amount of purchases made and negatively on the amount of real money balances held.

Each country is subject to technology shocks that affect the productivity of capital and labor. International risk sharing is incomplete – the international asset market is restricted to one real bond. Consumers in each country can therefore only partially insure against country-specific risk.[2] In addition to international bonds, consumers in each country can hold domestic currency and domestic nominal bonds, which are in zero net supply.

Preferences of the representative consumer in country i are characterized by the utility function

$$\mathrm{E}_0 \sum_{t=0}^{\infty} \beta^t U\left(c_{it}, 1 - n_{it} - s_{it}\right), \tag{1}$$

where $U\left(c, 1-n-s\right) = \left[c^{\mu}\left(1-n-s\right)^{1-\mu} - 1\right]^{1-\gamma} / \left(1-\gamma\right)$, with $0 < \mu < 1$ and $\gamma \geq 0$, and where c_{it} is consumption, n_{it} is time spent working, and s_{it} is time spent shopping. Shopping time is given by the following parametric representation

$$s_{it} = \kappa_1 \left(\frac{p_{it} c_{it}}{m_{it}}\right)^{\kappa_2}, \tag{2}$$

where $\kappa_1 > 0$, $\kappa_2 \geq 1$, p_{it} is the domestic price level (the price of consumption in terms of country i's currency) and m_{it} is holdings of domestic currency.

3.1 Real side of the economy

We find it useful to describe the real side of the economy by following the three different approaches to measuring aggregate output: the product approach, the income approach, and the expenditures approach.

3.1.1 Product approach

Consumers supply labor and capital to domestically-located perfectly-competitive producers that have access to an aggregate Cobb-Douglas production function

$$z_{it} H\left(k_{it}, n_{it}\right) = z_{it} k_{it}^{\alpha} n_{it}^{1-\alpha} = y_{it},$$

[2]We make this assumption in order to ensure that our results are not driven by market completeness and excessive risk sharing.

where z_{it} is country-specific technology level, k_{it} is capital, y_{it} is output of the local good (either a or b), and $0 < \alpha < 1$ is the capital share in production. Technology in the two countries is assumed to follow a joint first-order autoregressive process

$$\lambda_{t+1} = A_0 + A\lambda_t + \varepsilon_{t+1}, \qquad \varepsilon_{t+1} \sim N(0, \Sigma),$$

where $\lambda_t = [\ln z_{1t}, \ln z_{2t}]'$. Market clearing for goods a and b requires

$$\begin{aligned} a_{1t} + a_{2t} &= y_{1t}, & (3) \\ b_{1t} + b_{2t} &= y_{2t}, & (4) \end{aligned}$$

where a_{1t} is the amount of good a used by country 1, while a_{2t} is the amount used by country 2. Similarly, b_{1t} is the amount of good b used by country 1, while b_{2t} is the amount used by country 2.

Consumption and investment are composites of foreign and domestic goods. In the absence of available measurement of the composition of these different types of expenditures in terms of domestic and foreign components, we assume that consumption and investment have the same domestic and foreign content. The device for aggregating domestic and foreign goods used here is the Armington (1969) aggregator G

$$\begin{aligned} c_{1t} + x_{1t} &= G(a_{1t}, b_{1t}), & (5) \\ c_{2t} + x_{2t} &= G(b_{2t}, a_{2t}), & (6) \end{aligned}$$

where x_{it} is investment and $G(a, b) = (\omega_1 a^{-\rho} + \omega_2 b^{-\rho})^{-(1/\rho)}$ is homogenous of degree one, with $0 < \omega_1 < 1$, ,$\omega_2 = 1 - \omega_1$, and $\rho \geq -1$. Here, ω_1 determines the extent to which there is a home bias in domestic expenditures. This aggregator is a standard feature of general equilibrium models of trade.

The Armington aggregator in each country is operated by perfectly competitive producers that purchase goods a and b from their respective producers and sell the expenditure good to the consumer at a price that we normalize to equal to one. The prices of goods a and b in terms of the expenditure good of country 1 are therefore given by the marginal products of these two goods

$$q^a_{1t} = \frac{\partial G(a_{1t}, b_{1t})}{\partial a_{1t}}, \qquad q^b_{1t} = \frac{\partial G(a_{1t}, b_{1t})}{\partial b_{1t}}. \tag{7}$$

Similarly, the prices in terms of country 2's expenditure good are given by

$$q^a_{2t} = \frac{\partial G(b_{2t}, a_{2t})}{\partial a_{2t}}, \qquad q^b_{2t} = \frac{\partial G(b_{2t}, a_{2t})}{\partial b_{2t}}. \tag{8}$$

Using these prices, we can measure output of the two countries in terms of their respective expenditure good as

$$\begin{aligned} q^a_{1t} z_{1t} H(k_{1t}, n_{1t}) &= q^a_{1t} y_{1t}, \\ q^b_{2t} z_{2t} H(k_{2t}, n_{2t}) &= q^b_{2t} y_{2t}. \end{aligned}$$

This is the definition of GDP employed in our model. We thus use the following notation

$$GDP_{1t} = q^a_{1t} y_{1t}, \quad GDP_{2t} = q^b_{2t} y_{2t}.$$

None of our results, however, significantly changes if we define GDP as measured in terms of the price of the local good.

3.1.2 Income approach

Households derive income from selling capital and labor services to the domestically-located producers at competitively determined rental and wage rates. Aggregate income measured in terms of the local good is thus

$$r_{it}^{k}k_{it} + w_{it}n_{it} = \frac{\partial H}{\partial k_{it}}k_{it} + \frac{\partial H}{\partial n_{it}}n_{it} = y_{it}, \tag{9}$$

where r_{it}^{k} is the rental rate for capital and w_{it} is the wage rate. Here, the first equality follows by assuming perfect competition, while the second equality follows from the constant-returns-to-scale property of the production function. Measured in terms of the expenditure good, aggregate income of country 1 is

$$q_{1t}^{a}\frac{\partial H}{\partial k_{1t}}k_{1t} + q_{1t}^{a}\frac{\partial H}{\partial n_{1t}}n_{1t} = GDP_{1t}. \tag{10}$$

Aggregate income of country 2 is measured similarly, evaluating its output of good b at the price q_{2t}^{b}.

3.1.3 Expenditure approach

Total expenditures, measured in terms of the local good, are

$$\begin{aligned} \frac{c_{1t}+x_{1t}}{q_{1t}^{a}} + \left(a_{2t} - \frac{q_{1t}^{b}}{q_{1t}^{a}}b_{1t}\right) &= y_{1t}, \\ \frac{c_{2t}+x_{2t}}{q_{2t}^{b}} + \left(b_{1t} - \frac{q_{2t}^{a}}{q_{2t}^{b}}a_{2t}\right) &= y_{2t}. \end{aligned}$$

Here the equalities follow from combining the resource constraints (5) and (6) with the goods market clearing conditions (3) and (4), and exploiting the constant-returns-to-scale property of the Armington operator and the pricing functions (7) and (8). Measured in terms of the expenditure good, total expenditures are

$$c_{1t} + x_{1t} + \left(q_{1t}^{a}a_{2t} - q_{1t}^{b}b_{1t}\right) = GDP_{1t}, \tag{11}$$

$$c_{2t} + x_{2t} + \left(q_{2t}^{b}b_{1t} - q_{2t}^{a}a_{2t}\right) = GDP_{2t}, \tag{12}$$

where the expressions in the brackets are net exports, denoted by nx_{1t} and nx_{2t}, respectively. We define the terms of trade e as the price of country 2's local good in terms of country 1's local good

$$e_t = q_{1t}^{b}/q_{1t}^{a} = q_{2t}^{b}/q_{2t}^{a}, \tag{13}$$

where the second equality holds in equilibrium. The real exchange rate, in contrast, is defined as the price of consumption in country 2 relative to the price of consumption in country 1, i.e. q_{2t}^{a}/q_{1t}^{a}, which, by applying the relationship (13), is equal to q_{2t}^{b}/q_{1t}^{b}.

Finally, investment and capital are measured in the same units and the capital stock in each country evolves as

$$k_{i,t+1} = (1-\delta)\,k_{it} + x_{it}. \tag{14}$$

3.2 Nominal side

Each country has a central bank that issues local currency. Following Taylor (1993), it has become common in the literature to describe a central bank's policy as following a rule according to which the bank sets the nominal interest rate in response to deviations of inflation from some implicit target and deviations of output from some trend or "potential" level of output. A number of studies document that such rules capture well the interest rate setting behavior of the Fed, as well as of other major central banks (see, for example, Woodford (2003), chapter 1, Clarida, Gali and Gertler (1998), Clarida, Gali and Gertler (2000), and Nelson (2000)). We therefore assume that the central bank in the model follows such a rule

$$R_{it} = (1-\phi)\left[r^k + \pi + \nu_y\left(\ln GDP_{it} - \ln GDP\right) + \nu_\pi\left(\pi_{it} - \pi\right)\right] + \phi R_{i,t-1}, \tag{15}$$

where R_{it} is the domestic nominal interest rate, $\pi_{it} \equiv \ln p_{it} - \ln p_{i,t-1}$ is the inflation rate, and a variable's symbol without a time subscript represents the variable's steady-state value. In line with the literature we also assume that the central bank wants to smooth the nominal interest rate by putting a weight $\phi \in (0,1)$ on the past interest rate. The bank implements its policy by monetary transfers to the consumer

$$v_{it} = \frac{m_{it} - m_{i,t-1}}{p_{it}}. \tag{16}$$

Consumers hold currency in order to save on shopping time. In addition, they invest in capital, an international real bond f_{it}, and the domestic nominal bond d_{it}. The international bond pays one unit of good a in all states of the world in period $t+1$, while the domestic bond pays one unit of domestic currency in all states of the world in period $t+1$. Measured in terms of the domestic expenditure good, the consumer's budget constraint is

$$\frac{q^a_{it} f_{it}}{1+r^f_t} + \frac{d_{it}}{p_{it}\left(1+R_{it}\right)} + \frac{m_{it}}{p_{it}} + c_{it} + x_{it} = r^k_{it} k_{it} + w_{it} n_{it} + q^a_{it} f_{i,t-1} + \frac{d_{i,t-1}}{p_{it}} + \frac{m_{i,t-1}}{p_{it}} + v_{it}, \tag{17}$$

where r^f_t is the real return on the international bond, in terms of good a.

The domestic nominal bond is in zero net supply. In equilibrium therefore $d_{it} = 0$. Substituting in for v_{it} from equation (16) and using equations (9) and (10), the resource constraints of country i, measured in terms of its expenditure good, is

$$\frac{q^a_{it} f_{it}}{1+r^f_t} + c_{it} + x_{it} \quad = \quad q^\varsigma_{it} z_{it} H\left(k_{it}, n_{it}\right) + q^a_{it} f_{i,t-1}, \tag{18}$$

where q^ς_{it} is equal to q^a_{1t} in the case of country 1, and to q^b_{2t}, in the case of country 2.

3.3 International flows

As mentioned above, the two countries can share their country-specific risk by trading in each period the international bond. The net foreign asset position in the model is simply the real international bond holdings. By definition, current account is equal to the change in net foreign asset position

$$ca_{it} = q^a_{it} f_{it} - q^a_{it} f_{i,t-1}.$$

Combining the expenditure approach measures of aggregate output (11) and (12) with the resource constraint (18) for each country provides a link between international trade in financial assets and international trade in goods, measured by net exports

$$nx_{it} = \frac{q^a_{it} f_{it}}{1 + r^f_t} - q^a_{it} f_{i,t-1}.$$

Current account and net exports are then related as

$$ca_{it} = nx_{it} + \frac{r^f_t}{1 + r^f_t} q^a_{it} f_{it}.$$

3.4 Equilibrium

In each country, the representative consumer chooses plans for c_{it}, x_{it}, $k_{i,t+1}$, m_{it}, d_{it}, f_{it}, n_{it}, and s_{it} in order to maximize (1) subject to (2), (14), and (17). Producers of the local good choose k_{it} and n_{it} until their marginal products equal r^k_{it} and w_{it}, respectively, while producers of the expenditure good choose a_{it} and b_{it} until their marginal products equal q^a_{it} and q^b_{it}, respectively.

In period t the state of the world economy is defined by the vector of exogenous state variables $\lambda = (z_{1t}, z_{2t})$, a vector of domestic endogenous state variables $\Upsilon_i = (p_{i,t-1}, R_{i,t-1}, k_{it}, m_{i,t-1}, d_{i,t-1}, f_{i,t-1})$, and a vector of foreign state variables $\Upsilon_j = (p_{j,t-1}, R_{j,t-1}, k_{jt}, m_{j,t-1}, d_{j,t-1}, f_{j,t-1})$. The equilibrium of the world economy is then characterized by a set of pricing functions for each country $\{r^k_i(\lambda, \Upsilon_i, \Upsilon_j)$, $w_i(\lambda, \Upsilon_i, \Upsilon_j)$, $q^a_i(\lambda, \Upsilon_i, \Upsilon_j)$, $q^b_i(\lambda, \Upsilon_i, \Upsilon_j)$, $p_i(\lambda, \Upsilon_i, \Upsilon_j)$, $R_i(\lambda, \Upsilon_i, \Upsilon_j)\}$, a set of aggregate decision rules for each country $\{n_i(\lambda, \Upsilon_i, \Upsilon_j)$, $k_i(\lambda, \Upsilon_i, \Upsilon_j)$, $m_i(\lambda, \Upsilon_i, \Upsilon_j)$, $d_i(\lambda, \Upsilon_i, \Upsilon_j)$, $f_i(\lambda, \Upsilon_i, \Upsilon_j)\}$, and a pricing function for the rate of return on the internationally traded bond $r^f(\lambda, \Upsilon_i, \Upsilon_j)$, such that the allocations and prices generated by these functions satisfy the consumer's and the producers' optimization problems, the resource constraints (5) and (6), the goods market clearing conditions (3) and (4), a market clearing condition for domestic bonds $d_{it} = 0$, a market clearing condition for the internationally traded bond $f_1 + f_2 = 0$, and the monetary policy rule (15). Each country's resource constraint (18) is then satisfied by Walras' Law.

Because the state space is large, we compute log-linear approximations to the equilibrium decision rules and pricing functions in the neighborhood of the model's non-stochastic steady-state using the linear-quadratic method described by Hansen and Prescott (1995). Before computing the equilibrium, all nominal variables are normalized so that they are stationary. We also impose a small quadratic cost of adjustment on international bond holdings in the consumer's problem in order to avoid non-stationarity in international bond holdings that occurs in models with incomplete markets.

4 Findings

4.1 The benchmark experiment

Table 8 summarizes the parameter values for our benchmark experiment. In subsection 4.3 we study the sensitivity of our results to parameter values that are calibrated with a large degree of uncertainty. Much of the calibration is based on empirical estimates of steady-state relations among the model's variables. To start, a period in the model is set equal to one quarter. Since preferences and technology in our model are the same as those used by Backus et al. (1994), the parameters of the utility function, the production function, and of the stochastic process for technology are either the same as in their paper, or are calibrated to the same calibration targets.[3]

In particular, we set the risk aversion parameter γ equal to 2, capital's share in production α equal to 0.36, and the elasticity of substitution between domestic and foreign goods $\sigma \equiv 1/(1+\rho)$ equal to 1.5. The share of locally produced goods in the Armington aggregator ω_1 is set equal to 0.761, which implies that in a symmetric steady state (one characterized by $y_1 = y_2$, $b_1 = a_2$, and $e = 1$) the ratio of imports to output b_1/y_1 is equal to 0.15. The depreciation rate δ is set equal to 0.025. Given a share of investment in GDP equal to 0.25, this depreciation rate implies a steady-state capital-output ratio equal to 10. The capital-output ratio and the depreciation rate than imply a discount factor equal to 0.989. The weight on consumption in utility μ is determined by the first-order condition for labor supply

$$\frac{U_c}{U_l} = \left(\frac{\mu}{1-\mu}\right)\frac{1-n-s}{c},$$

where c is equal to 0.75, n is equal to 0.3, and s is determined by the calibration of the shopping time parameters described below. The weight on consumption implied by this condition is 0.34. Finally, the diagonal elements of the transition matrix for technology shocks A are set equal to 0.906, the off-diagonal elements, which measure the degree of spillovers of technology shocks across countries, are set equal to 0.088, the standard deviations of the ε's are set equal to 0.00852, and their correlation is set equal to 0.258. The values of A_0 are chosen so that output of the locally produced good y is equal to 1 in a steady state, which is a convenient normalization.

The parameters of the shopping time function (2) are chosen so that the money demand function in the model has the same interest rate elasticity and implies the same average velocity of money as its empirical counterpart estimated for the United States. Money demand function in the model is given implicitly by an optimality condition for money holdings. In a steady state this optimality condition has the form

$$\kappa_1\kappa_2\left(\frac{pc}{m}\right)^{\kappa_2}\frac{p}{m} = \frac{1}{w}\left(\frac{R}{1+R}\right). \tag{19}$$

[3] We refer the reader to Backus et al. (1994) for a more detailed discussion of the calibration.

Setting the curvature parameter κ_2 equal to 1, the money demand function implied by the optimality condition (19) has the form

$$\frac{m}{p} = \left[\kappa_1 cw \left(1 + \frac{1}{R}\right)\right]^{0.5}, \tag{20}$$

which has interest elasticity equal to -0.5, consistent with a number of empirical studies (see Lucas (2000) for a review of some of these studies). We set the level parameter κ_1 equal to 0.0054, which implies a steady-state annual velocity of money $(4p_1 GDP_1/m_1)$ equal to 6.08 – the average annual velocity of M1 between 1959 and 2006.

The estimates of the parameters of the monetary policy rule (15) vary greatly in the literature, depending on the countries considered, periods covered, and the exact specification of the policy rule (e.g., whether the central bank responds to actual inflation and output or to their forecasts).[4] For our benchmark experiment we use the weight on inflation ν_π equal to 1.5 and the weight on output ν_y equal to 0.125 – the values used by Taylor (1993).[5] In addition, we set the steady-state inflation rate π equal to 0.0091 – the average quarterly inflation rate in the United States between 1959 and 2006 – and the smoothing coefficient ϕ equal to 0.75, which is within the range of estimates obtained by Clarida et al. (2000) and Sack and Wieland (2000).

Table 9 reports the findings from our benchmark experiment. The statistics in the Table are for simulated data filtered with the Christiano and Fitzgerald (2003) filter. Panel A shows the standard deviations of key domestic variables, relative to that of GDP, and their correlations with GDP at various leads and lags. Panel B then reports correlations of selected variables across the two countries. In order to compare the statistics reported in panel A to the data, Table 10 contains the same statistics for the US economy. Although the characteristics of business cycles differ across countries, the statistics reported in Table 10 can to a large extent be regarded as representative of the salient features of the business cycle in many industrial countries (see, for example, Zimmermann (1997), Agresti and Mojon (2001), and Sustek (2005)). In particular, in the data consumption is less volatile than GDP, investment is about three times as volatile as GDP, and hours worked are about as volatile as GDP. In addition, consumption, investment, and hours worked are procyclical, while net exports are countercyclical. We also see that the US business cycle is characterized by the typical dynamics of the price level and the nominal interest rate reported in Section 2 – the price level is countercyclical and leads GDP with a negative sign, and the nominal interest rate is procyclical and also leads GDP with a negative sign. We also report the J-curve for the United States – the dynamic relationship between net exports and terms of trade, which as pointed out by Backus et al. (1994), characterizes the dynamics of the terms of trade of a number of industrialized economies. In particular, net exports are negatively correlated with future terms of trade, and positively correlated with past terms of trade.

[4] Woodford (2003), chapter 1, provides an overview of some of the empirical studies for the United States, while Clarida et al. (1998) provide estimates for France, Germany, Italy, Japan, the United Kingdom, and the United States. Nelson (2000) estimates Taylor-type rules for the United Kingdom, one for each monetary policy regime in the United Kingdom in the past thirty years.

[5] In his paper Taylor uses the weight on output equal to 0.5. This value is scaled down by four in our calibration in order to make it consistent with our model in which GDP is measured at a quarterly rate.

As mentioned in the Introduction, the two-good international business cycle model accounts for many of the features of the fluctuations of real variables in the data. Comparing panel A of Table 9 with Table 10 we see that the model is broadly in line with the data. In particular, the model accounts for about 80 percent of the movements of GDP, predicts consumption about half as volatile as GDP, investment about three times as volatile as GDP, and net exports about 25 percent as volatile as GDP. Hours in the model are not as volatile as in the data, but this is a well known anomaly. It can be resolved either by better measurement of the labor input (measurement in efficiency units) or by the introduction of the extensive margin of labor supply (employment) into the model (see Kydland (1995) for a discussion). The model also predicts procyclical consumption, investment, and hours, and countercyclical net exports. Furthermore, it generates the J-curve.

Moving on to nominal variables, we see that in line with the empirical evidence presented in Section 2, the model generates countercyclical price level. In addition, it produces standard deviations of the price level and the nominal interest rate, relative to that of GDP, similar to those for the US economy. There are, however, important deviations of the model from the data. In particular, the model fails to produce the correct phase shift of the price level: in the model the price level lags GDP with a negative sign, whereas in the data it leads GDP with a negative sign. The model also does not produce the correct comovement between GDP and the nominal interest rate. While in the data the interest rate is somewhat positively correlated with GDP contemporaneously and strongly negatively correlated with GDP four quarters ahead, the model predicts a strong negative contemporaneous correlation and no phase shift.

Panel B of Table 9 reports the international correlations. We see that the model generates the main feature of the international nominal business cycle: prices and nominal interest rates are more strongly correlated across countries than output, and their cross-country correlations are similar. In particular, the model generates a cross-country correlation of prices of 0.69 and the same cross-country correlation of nominal interest rates. Depending on whether we use the six or the eight-country sample (and whether we exclude the Bretton Woods period), in the data these correlations are between 0.50 and 0.59 for prices, and between 0.55 and 0.59 for the nominal interest rate. At the same time the model generates cross-country correlation of GDP of only 0.23. In our samples this correlation is between 0.25 and 0.43.

We also report in panel B of Table 9 the cross-country correlations for consumption produced by the model. These are much higher than those for GDP. In the data, however, the reverse is true. This is a well known anomaly of international business cycle models and, as Heathcote and Perri (2002) show, is robust to alternative assumptions about the structure of international asset markets and alternative assumptions about the stochastic process for technology.[6] In contrast, as we show below, in the case of nominal variables, the properties of the stochastic process for technology, in particular the degree of spill-overs, are crucial for the high correlations of nominal variables reported here.

[6] Baxter and Crucini (1995) show that in a one-good international business cycle model with incomplete markets the anomaly can be resolved when the stochastic process for technology shocks is close to a random walk.

4.2 Interpretation

We can gain intuition for our main result by plotting the responses of the model's variables to a 1% positive technology shock. These responses are reported in Figure 7. Since the focus of the paper is on nominal variables, we describe the responses of real variables only briefly and refer the reader to Heathcote and Perri (2002) for a detailed discussion. In the following discussion it is also useful to abstract from the effects of nominal variables on real variables that occur due to an inflation tax, since these effects are small for our benchmark calibration.

Because the shocks in the two countries are correlated, a 1% increase in technology in country 1 leads on impact to an increase in technology in country 2 by 0.258%, where the number 0.258 is the correlation coefficient of the ε's. In addition, due to spillovers, technology in country 2 gradually catches up with technology in country 1. As a result of a higher current and expected future technology level, consumption in both countries increases, but it increases by less in country 2 than in country 1. There are two reasons for that. First, the net present value of country 2's future income is smaller than that of country 1 because technology in country 2 does not reach the level of technology in country 1 for a while.[7] Second, there is intertemporal trade between the two countries: in order to take advantage of higher total factor productivity, country 1 increases investment by borrowing from country 2; country 2 is thus giving up some of its current consumption in return for higher future consumption. The mechanism that induces consumers in country 2 to lend to country 1 is the increase in the real return on the internationally traded bond. This intertemporal trade is reflected in the decline of net exports of country 1, and a flow of good b into country 1 (not shown).

Because of initially higher technology level in country 1, GDP (as well as hours worked) are initially higher in country 1 than in country 2. However, as technology in country 2 catches up with technology in country 1, GDP and hours worked in country 2 catch up with GDP and hours worked in country 1. As a result of initially higher output in country 1, the price of good a falls, reflecting its abundance in the world market relative to good b.[8] The terms of trade of country 1 therefore worsen, following the shock.

The dynamics of the price level and the nominal interest rate in country i can be understood by deriving their pricing equations. The first-order conditions for accumulation of capital, domestic, and foreign bonds in country i give, respectively, equilibrium conditions for the return to capital, the return to domestic bonds, and the return to the internationally

[7] The difference in the net present value that occurs due to the difference in the dynamics of technology in the two countries is somewhat reduced by the response of the terms of trade of country 1, which worsen following the shock.

[8] The price of good a falls more in country 2 than in country 1 since there is an inflow of good b into country 1, which somewhat reduces the fall in the marginal product of good a that occurs due the increase in its quantity.

traded bond

$$\begin{aligned}
E_t\left[Q_{it}\left(1+r^k_{i,t+1}-\delta\right)\right] &= 1,\\
(1+R_{it})E_t\left[Q_{it}\left(\frac{1}{1+\pi_{i,t+1}}\right)\right] &= 1,\\
(1+r_t)E_t\left[Q_{it}\left(\frac{q^a_{i,t+1}}{q^a_{i,t}}\right)\right] &= 1,
\end{aligned}$$

where $Q_{it} \equiv \beta(U_{c,t+1} - U_{l,t+1}s_{c,t+1})/(U_{ct} - U_{lt}s_{ct})$ is country i's stochastic discount factor. For the following discussion it is convenient to log-linearize these pricing equations around the model's non-stochastic steady state

$$E_t\widehat{Q}_{it} + E_t\widehat{r}^k_{i,t+1} = 0, \tag{21}$$

$$\widehat{R}_{it} + E_t\widehat{Q}_{it} - E_t\widehat{\pi}_{i,t+1} = 0, \tag{22}$$

$$\widehat{r}_t + E_t\widehat{Q}_{it} + E_t\widehat{q}^a_{i,t+1} - \widehat{q}^a_{it} = 0, \tag{23}$$

where $\widehat{r}^k_{i,t+1} \equiv (r^k_{i,t+1} - r^k)/(1+r^k-\delta)$, $\widehat{R}_{it} \equiv (R_{it} - R)/(1+R)$, $\widehat{\pi}_{it} \equiv (\pi_{it} - \pi)/(1+\pi)$, $\widehat{r}_t \equiv (r_t - r)/(1+r)$ are the percentage deviations of the gross rates from steady state, and $\widehat{Q}_{it} \equiv \log Q_{it} - \log Q_i$ is the percentage deviation of the stochastic discount factor from steady state. Combining equations (21) and (22), and (21) and (23) then gives, respectively, a no-arbitrage condition between domestic real and nominal assets, and between real domestic and international assets

$$E_t\widehat{r}^k_{i,t+1} = \widehat{R}_{it} - E_t\widehat{\pi}_{i,t+1}, \tag{24}$$

$$E_t\widehat{r}^k_{i,t+1} = \widehat{r}_t + E_t\widehat{q}^a_{i,t+1} - \widehat{q}^a_{it}. \tag{25}$$

In addition, combining condition (25) for country 1 with that for country 2 gives us a relationship between the return to capital in the two countries

$$E_t\widehat{r}^k_{1,t+1} + E_t\left(\widehat{q}^a_{2,t+1} - \widehat{q}^a_{1,t+1}\right) - \left(\widehat{q}^a_{2t} - \widehat{q}^a_{1t}\right) = E_t\widehat{r}^k_{2,t+1}, \tag{26}$$

where $E_t\left(\widehat{q}^a_{2,t+1} - \widehat{q}^a_{1,t+1}\right) - \left(\widehat{q}^a_{2t} - \widehat{q}^a_{1t}\right)$ is the expected change in the real exchange rate. Due to changes in the real exchange rate, the expected rates of return to capital in the two countries do not need to be equalized. This is in a sharp contrast to a one-good economy, in which the two rates of return would be the same.

The nominal interest rate and the price level in each country is determined by the no-arbitrage condition between real and nominal assets (24) and the (log-linearized) Taylor rule

$$\widehat{R}_{it} = \widetilde{\nu}_\pi\widehat{\pi}_{it} + \widetilde{\nu}_y\widehat{Y}_{it}, \tag{27}$$

where $\widetilde{\nu}_\pi \equiv \nu_\pi(1+\pi)/(1+R)$, $\widetilde{\nu}_y \equiv \nu_y/(1+R)$, and $\widehat{Y}_{it} \equiv \log GDP_{it} - \log GDP$, and where for simplicity of the exposition we set ϕ equal to 0. Combining the no-arbitrage condition (24) and the Taylor rule (27) gives us a first-order difference equation in inflation

$$E_t\widehat{r}^k_{i,t+1} + E_t\widehat{\pi}_{i,t+1} = \widetilde{\nu}_\pi\widehat{\pi}_{it} + \widetilde{\nu}_y\widehat{Y}_{it}.$$

Solving this equation forward, we obtain the price level in period t as a sum of two terms: the price level in period $t-1$ and a difference between the sum of discounted future real returns to capital and the sum of discounted current and future GDP

$$\widehat{p}_{it} = \widehat{p}_{i,t-1} + E_t \left[\sum_{j=1}^{\infty} \left(\frac{1}{\widetilde{\nu}_\pi} \right)^j \widehat{r}^k_{i,t+j} \right] - \widetilde{\nu}_y E_t \left[\sum_{j=1}^{\infty} \left(\frac{1}{\widetilde{\nu}_\pi} \right)^j \widehat{Y}_{i,t+j-1} \right]. \tag{28}$$

Substituting the price level from equation (28) into the Taylor rule (27) then gives the nominal interest rate in period t as a difference between the discounted sum of future real returns to capital and the discounted sum of future GDP

$$\widehat{R}_{it} = E_t \left[\sum_{j=1}^{\infty} \left(\frac{1}{\widetilde{\nu}_\pi} \right)^{j-1} \widehat{r}^k_{i,t+j} \right] - \widetilde{\nu}_y E_t \left[\sum_{j=1}^{\infty} \left(\frac{1}{\widetilde{\nu}_\pi} \right)^j \widehat{Y}_{i,t+j} \right].$$

The degree of comovement of nominal variables across the two countries is thus determined by the extent to which the discounted sums of the returns to capital and the discounted sums of GDP in the two countries move together. As follows from equation (26), in a two-good economy international borrowing and lending does not necessarily equate the returns to capital in the two countries. As we see in Figure 7, this is indeed the case in our benchmark experiment: the return to capital in country 1 increases on impact, whereas the return to capital in country 2 increases only gradually due to spillovers. The discounted sum of the returns nevertheless increases on impact in both countries since in both countries the return to capital is expected to stay above its steady state level for much of the duration of the technology shock. A similar argument also applies to the discounted sums of GDP. Thus, although GDP differs across the two countries between the impact period and the time country 2 catches up with country 1, the discounted sums increase immediately on impact in both countries.

Notice that in a one-good economy, the comovement between nominal variables across countries would be even stronger since the expected rates of return to capital would be equalized across the two countries in each period. Indeed, when $\nu_y = 0$, the nominal variables would be perfectly correlated.

Since the price level and the nominal interest rate in each country depend on the *difference* between the discounted sums of returns to capital and GDP, the direction of the responses of the price level and the nominal interest rate depends on the relative weight on GDP in the monetary policy rule. It turns out that for our benchmark experiment the weight on GDP is sufficiently large leading to a fall in prices and interest rates in the two countries, following the technology shock in country 1.

4.3 Sensitivity analysis

In order to check the robustness of our findings, we conduct sensitivity analysis for those parameters that are not estimated precisely in the literature or that differ across countries.

In particular, we study the properties of the model economy for alternative parameters of the monetary policy rule (ν_π, ν_y, ϕ), degrees of spillovers (A_{12}), the elasticity of substitution between home and foreign goods (σ), and the steady-state import share of GDP (b_1/y_1).

Starting with the parameters of the monetary policy rule, Figure 8 plots the properties of the model for alternative weights on GDP, which we vary between -0.05 and 0.25. This range covers most of the values reported in the literature. For example, some of the smallest values for the weight on output are reported by Kozicki (1999) and Ireland (2003), who find the weight to be close to -0.025. On the upper end, Clarida et al. (2000) estimate the weight on output (for the period 1979-96) to be close to 0.23.[9]

The upper panels of Figure 8 summarize the dynamics of the nominal variables with respect to domestic GDP. Recall that in the data the price level is negatively correlated with output contemporaneously and has a pronounced phase shift in the direction of leading the cycle with a negative sign. We see that in the model the price level is negatively correlated with GDP for ν_y greater than 0.04. However, in this interval the model does not generate the phase shift observed in the data: $corr(p_t, GDP_t)$ is smaller than $corr(p_{t-2}, GDP_t)$. We also see from the Figure that for the values of ν_y that generate negative correlation between the price level and GDP, the nominal interest rate is correlated negatively with GDP contemporaneously as well. In the data, this correlation is positive but the nominal interest rate is correlated negatively with future output. The model does not generate this phase shift for any of the values of ν_y considered: when $corr(R_t, GDP_t)$ is negative, $corr(R_{t-2}, GDP_t)$ is even smaller. The phase shifts of the price level and the nominal interest rate are anomalies, that we find are also robust to alternative values of ν_π, ϕ, A_{12}, σ, and b_1/y_1 (not reported).

The presence of these two anomalies in the model should not be perhaps too surprising. Previous studies, focusing on the US business cycle, have shown that capturing the correct comovement between real and nominal variables is a challenging task (see Ireland (2003) for an overview of the literature). Our empirical finding that the comovement between nominal variables and output typical for the United States also characterizes the nominal business cycle of other industrial countries, however, makes the resolution of these anomalies all the more important.

The lower panels of Figure 8 focus on international correlations. We see that except for a small interval between 0.025 and 0.06 the cross-country correlations of nominal variables are stronger that those of GDP.

Figure 9 provides intuition for the sharp fall in the cross-country correlations of nominal variables in the interval between 0.025 and 0.06 observed in Figure 8. The upper panels of Figure 9 plot the responses of the price levels and nominal interest rates from our benchmark experiment. As mentioned in the previous subsection, when ν_y is equal to 0.125, the negative effect of the discounted sum of future GDP on prices and interest rates is stronger than the positive effect of the discounted sum of future returns to capital. Prices and interest rates in both countries therefore fall, following a positive technology shock in country 1. The

[9] The values mentioned here are the values reported in the literature divided by four in order to make them consistent with GDP in the model, which is expressed at a quarterly rate.

middle panels plot the responses for the case of a zero weight on output. In this case prices and interest rates are determined only by the discounted sum of future returns to capital. Prices and interest rates in both countries therefore increase after the shock. The bottom panels contain the responses for the case when ν_y is equal to 0.03. This weight falls into the range of values for which the comovement of nominal variables across the two countries is weak. In this case, during the first 10 to 15 quarters after the shock, the responses for country 1 behave more like those for our benchmark weight on GDP, whereas those for country 2 behave more like those for a zero weight on GDP. This is because the discounted sum of future GDP of country 2 is smaller than that of country 1. For a weight of 0.03, its negative effect on prices and interest rates is thus weaker in country 2 than in country 1, making the positive effect of the discounted sum of future returns to capital relatively more important in country 2.

In Figure 10 we plot the international correlations for alternative weights on inflation, the smoothing coefficient, and the degree of spillovers. We plot these correlations for two alternative weights on output: our benchmark weight of 0.125, and a zero weight. First we focus on varying the weight on inflation. In empirical Taylor rules, ν_π is usually in the range from 0.8 to 2.5. In our model, when ν_π is too close to one, the equilibrium is indeterminate.[10] We therefore restrict ν_π to be in the interval from 1.05 to 2.5. We see that except for the case of a zero weight on output and the weight on inflation close to our lower bound, the cross-country correlations of nominal variables are higher than the cross-country correlations of GDP.[11]

Notice that the model predicts higher cross-country correlations of nominal variables than that of output even when central banks put a large weight on stabilizing inflation. In Figure 11 we plot the standard deviations of the two nominal variables, relative to that of GDP, for alternative weights on inflation and a zero weight on output. We see that increasing ν_π reduces the relative volatility of the nominal variables well below what we observe in the data (see Table 10). However, as we see in Figure 10, the cross-country correlations of nominal variables stay well above that of output. This experiment therefore suggests that we should expect to see high cross-country correlations of nominal variables even in periods characterized by nominal stability.

Some specifications of empirical Taylor rules include no smoothing coefficient (e.g Taylor [1999]). Often, however, a smoothing coefficient is included and is usually found to be in the range between 0.5 and 0.9. In the middle panels of Figure 10 we therefore vary ϕ between 0 and 0.99. We see that the order of the cross-country correlations is robust to alternative values of the smoothing coefficient.

The spillover term in the transition matrix A is not estimated precisely in the literature. Backus, Kehoe and Kydland (1992) find that the spillover term is close to 0.088 – our benchmark value – while Heathcote and Perri (2002) report an estimate of 0.025. Yet,

[10]This is a common feature of general equilibrium models with interest rate monetary policy rules and no frictions in the money market.

[11]The large increase in the cross-country correlation of GDP in the right-hand panel is due to substantial inflation tax effects that occur with a relatively large weight on output and a small weight on inflation in the monetary policy rule.

Baxter and Crucini (1995) find little evidence for spillovers. We therefore vary A_{12} between 0 and 0.1. In all these experiments we adjust the diagonal elements of A so that its highest eigenvalue is the same as in our benchmark experiment. We see in the bottom panels of Figure 10 that except for the case of no spillovers, nominal variables are correlated more strongly across the two countries than GDP. In addition, the gap between the cross-country correlations of nominal variables and the cross-country correlations of GDP increases rapidly as we move away from the case of no spillovers. For example, even for a modest degree of spillovers, like that found by Heathcote and Perri (2002), the model generates a gap between the cross-country correlations of nominal variables and GDP like that observed in the data (for example, in the case of prices, a gap of about 0.35, when $\nu_y = 0$, and a gap of about 0.2, when $\nu_y = 0.125$).

Finally, Table 11 reports the model's properties for alternative values of the elasticity of substitution between domestic and foreign goods, and for alternative steady-state import shares of GDP. Heathcote and Perri (2002) argue that the elasticity of substitution is lower than the one used by Backus et al. (1994). In particular, they estimate it to be 0.9. We see that the elasticity of substitution, as well as the import share of GDP, have some effect on the cross-country correlations of consumption and GDP, and on the correlations of net exports with domestic GDP, but have virtually no effect on the cross-country correlations of nominal variables, or the correlations of nominal variables with domestic GDP.

5 Conclusion

[to be added]

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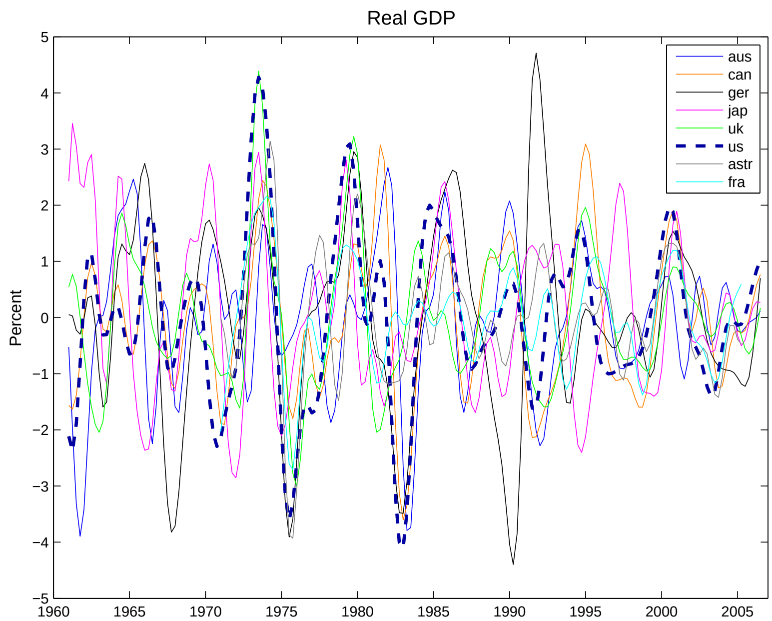

Figure 1: International business cycle.

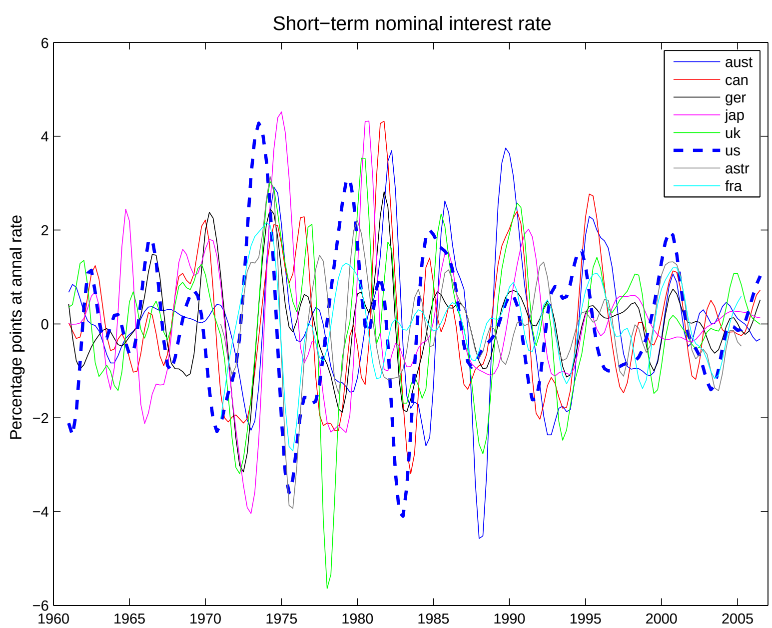

Figure 2: International short-term nominal interest rate cycle.

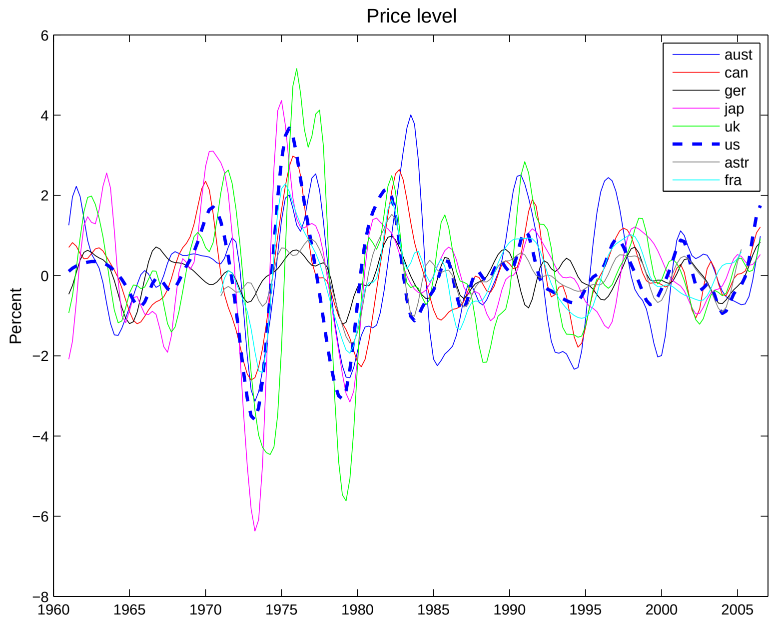

Figure 3: International price level (CPI) cycle.

Table 1: Contemporaneous correlations for real GDP, 1960.Q1-2006.Q4[a]

	aust	can	ger	jap	uk	us
aust	1.00					
can	0.53	1.00				
ger	-0.02	0.16	1.00			
jap	-0.12	-0.06	0.39	1.00		
uk	0.19	0.45	0.21	0.18	1.00	
us	0.23	0.72	0.42	0.21	0.56	1.00
mean = 0.27						
rel. std. = 0.89						
Excluding Bretton Woods period						
mean = 0.25						
rel. std. = 1.21						
pre-1984			post-1984			
mean = 0.34			mean = 0.16			
rel. std. = 0.71			rel. std. = 3.00			

[a]The correlations are for data that are logged and filtered with Christiano-Fitzgerald (2003) band-pass filter.

Table 2: Contemporaneous correlations for short-term nominal interest rates, 1960.Q1-2006.Q4[a]

	aust	can	ger	jap	uk	us
aust	1.00					
can	0.61	1.00				
ger	0.52	0.62	1.00			
jap	0.39	0.39	0.47	1.00		
uk	0.58	0.56	0.63	0.63	1.00	
us	0.55	0.84	0.72	0.43	0.57	1.00
mean = 0.57 rel. std. = 0.22						
Excluding Bretton Woods period mean = 0.57 rel. std. = 0.26						
pre-1984 mean = 0.61 rel. std. = 0.20			post-1984 mean = 0.53 rel. std. = 0.37			

[a]The correlations are for data that are filtered with Christiano-Fitzgerald (2003) band-pass filter.

Table 3: Contemporaneous correlations for price levels (CPI), 1960.Q1-2006.Q4[a]

	aust	can	ger	jap	uk	us
aust	1.00					
can	0.68	1.00				
ger	0.25	0.43	1.00			
jap	0.33	0.63	0.41	1.00		
uk	0.50	0.52	0.42	0.58	1.00	
us	0.47	0.71	0.51	0.76	0.61	1.00
mean = 0.52 rel. std. = 0.28						
Excluding Bretton Woods period mean = 0.50 rel. std. = 0.29						
pre-1984 mean = 0.60 rel. std. = 0.17			post-1984 mean = 0.30 rel. std. = 1.03			
			post-1984 exl. ger mean = 0.40 rel. std. = 0.77			

[a]The correlations are for data that are logged and filtered with Christiano-Fitzgerald (2003) band-pass filter.

Table 4: Eight-country sample, contemporaneous correlations for real GDP, 1970.Q1-2006.Q4[a]

	aust	astr	can	fra	ger	jap	uk	us
aust	1.00							
astr	0.05	1.00						
can	0.74	0.35	1.00					
fra	0.21	0.70	0.53	1.00				
ger	-0.10	0.68	0.18	0.47	1.00			
jap	0.03	0.39	0.12	0.50	0.55	1.00		
uk	0.26	0.48	0.56	0.74	0.24	0.40	1.00	
us	0.39	0.56	0.69	0.67	0.53	0.52	0.65	1.00
mean = 0.43								
rel. std. = 0.54								
Excluding Bretton Woods period								
mean = 0.34								
rel. std. = 0.76								
post-1984								
mean = 0.19								
rel. std. = 2.07								

[a]The correlations are for data that are logged and filtered with Christiano-Fitzgerald (2003) band-pass filter.

Table 5: Eight-country sample, contemporaneous correlations for short-term nominal interest rates, 1970.Q1-2006.Q4[a]

	aust	astr	can	fra	ger	jap	uk	us
aust	1.00							
astr	0.63	1.00						
can	0.65	0.64	1.00					
fra	0.48	0.57	0.49	1.00				
ger	0.58	0.73	0.70	0.77	1.00			
jap	0.44	0.55	0.37	0.47	0.61	1.00		
uk	0.59	0.45	0.57	0.47	0.74	0.68	1.00	
us	0.58	0.61	0.85	0.57	0.77	0.46	0.58	1.00
mean = 0.59								
rel. std. = 0.20								
Excluding Bretton Woods period								
mean = 0.55								
rel. std. = 0.25								
post-1984								
mean = 0.46								
rel. std. = 0.48								

[a]The correlations are for data that are filtered with Christiano-Fitzgerald (2003) band-pass filter.

Table 6: Eight-country sample, contemporaneous correlations for price levels (CPI), 1970.Q1-2006.Q4[a]

	aust	astr	can	fra	ger	jap	uk	us
aust	1.00							
astr	0.43	1.00						
can	0.71	0.59	1.00					
fra	0.66	0.72	0.82	1.00				
ger	0.23	0.69	0.54	0.57	1.00			
jap	0.36	0.57	0.62	0.78	0.52	1.00		
uk	0.50	0.65	0.53	0.71	0.43	0.54	1.00	
us	0.44	0.69	0.67	0.76	0.59	0.77	0.57	1.00
mean = 0.59								
rel. std. = 0.23								
Excluding Bretton Woods period								
mean = 0.59								
rel. std. = 0.24								
post-1984								
mean = 0.45								
rel. std. = 0.56								

[a]The correlations are for data that are logged and filtered with Christiano-Fitzgerald (2003) band-pass filter.

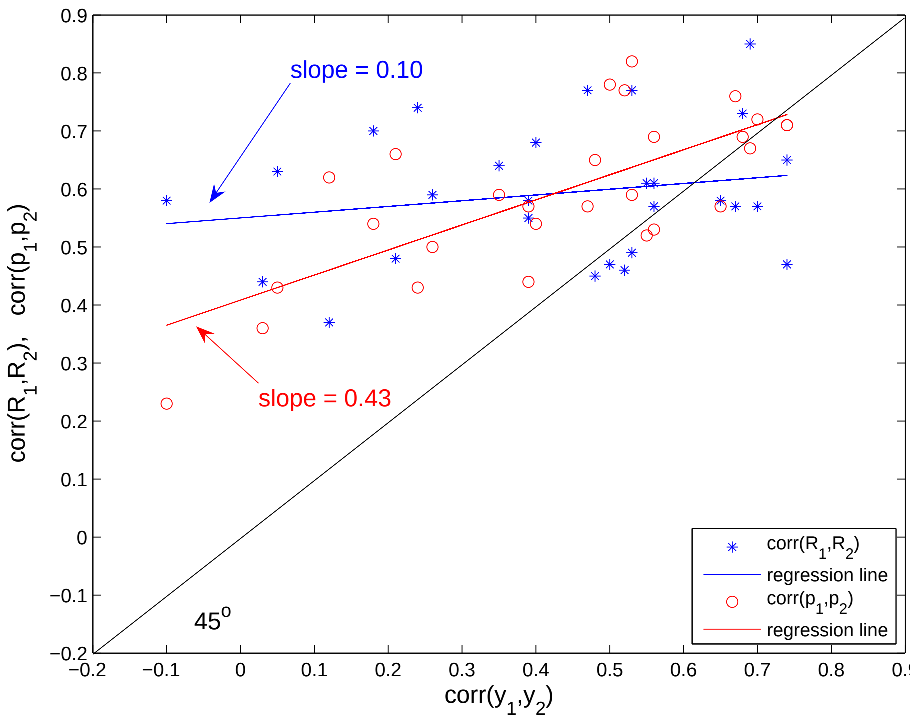

Figure 4: Comovement of nominal variables vs comovement of real GDP – the eight-country sample, 1970.Q1-2006.Q4.

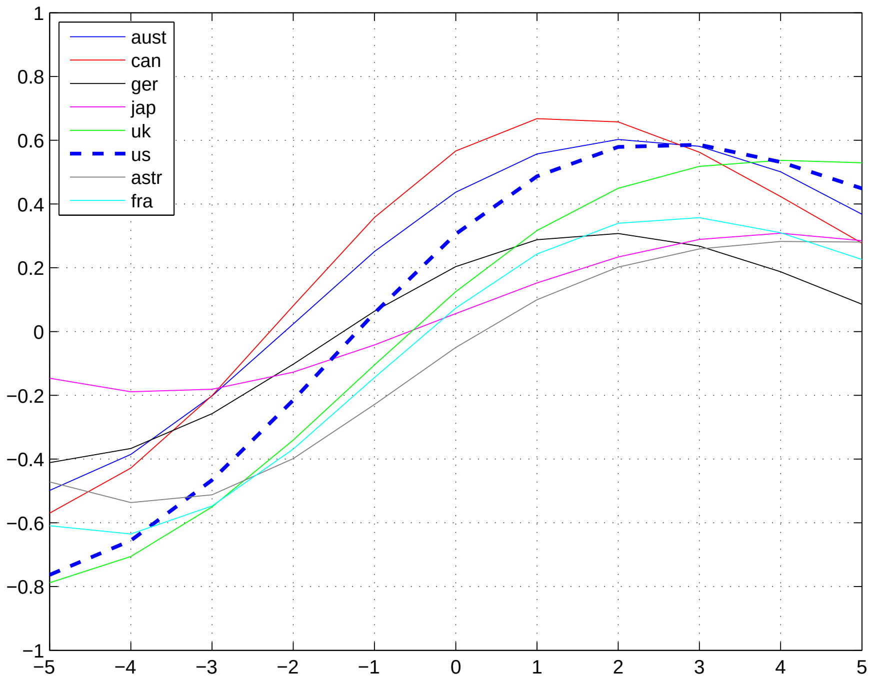

Figure 5: Domestic monetary business cycle. Correlations of a short-term nominal interest rate in period $t + j$ with real GDP in period t.

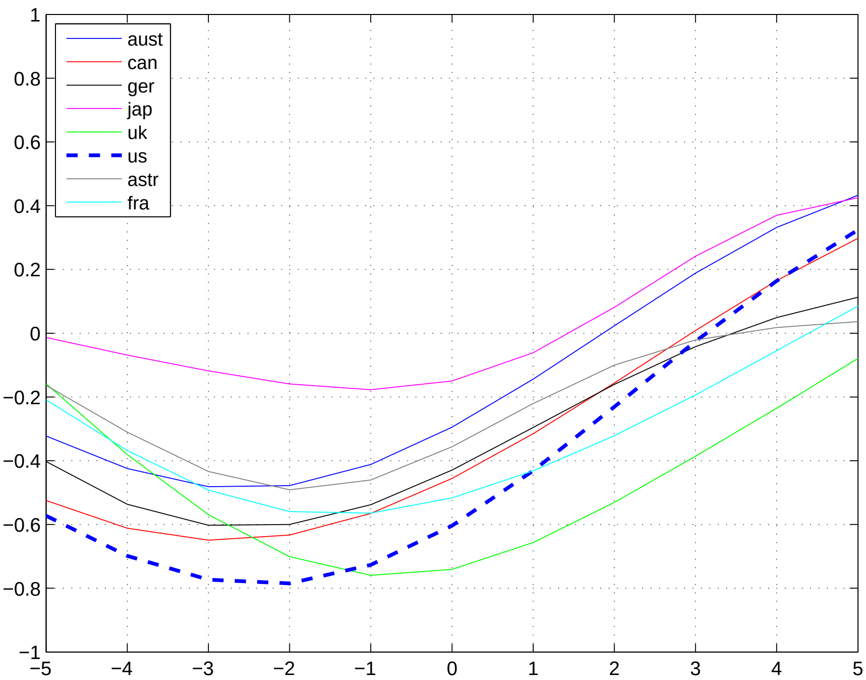

Figure 6: Domestic monetary business cycle. Correlations of the price level (CPI) in period $t + j$ with real GDP in period t.

Table 7: Mean cross-correlations with real GDP[a]

j =	-5	-4	-3	-2	-1	0	1	2	3	4	5
						Short-term nominal interest rate					
	-0.48	-0.46	-0.36	-0.20	-0.03	0.14	0.27	0.34	0.36	0.34	0.30
						Price level					
	-0.29	-0.43	-0.51	-0.55	-0.53	-0.44	-0.32	-0.18	-0.03	0.10	0.20

[a]The correlations are for data that filtered with Christiano-Fitzgerald (2003) band-pass filter; price levels are transformed by taking logs.

Table 8: Model calibration for the benchmark experiment

Symbol	Value	Definition
Period	1 quarter	
Preferences		
γ	2.0	Relative risk aversion
μ	0.34	Consumption share in utility
β	0.989	Discount factor
Production		
δ	0.025	Depreciation rate
α	0.36	Capital share in production
ω_1	0.761	Weight on domestic good
ω_2	0.239	Weight on foreign good
$\sigma = 1/(1+\rho)$	1.5	Elasticity of substitution
Shopping time		
κ_1	0.0054	Level parameter
κ_2	1.0	Curvature parameter
Monetary policy rule		
π	0.0091	Steady-state inflation rate
ν_y	0.125	Weight on GDP
ν_π	1.5	Weight on inflation
ϕ	0.75	Smoothing coefficient
Process for technology shocks		
$A_0 =$	$\begin{bmatrix} 0.00072 & 0.00072 \end{bmatrix}$	
$A =$	$\begin{bmatrix} 0.906 & 0.088 \\ 0.088 & 0.906 \end{bmatrix}$	
$\text{Var } \varepsilon_1 = \text{Var } \varepsilon_2 =$	0.00852^2	
$\text{Corr}(\varepsilon_1, \varepsilon_2) =$	0.258	

Table 9: Business cycle properties of the model economy in the benchmark experiment[a]

A. Domestic business cycle

υ_{t+j}	Relative std. dev.[b]	Correlations of GDP in period t with variable υ in period $t+j$: j = -4	-3	-2	-1	0	1	2	3	4
GDP (qy)	1.21	0.02	0.29	0.62	0.89	1.00	0.89	0.62	0.29	0.02
Consumption (c)	0.53	-0.06	0.20	0.51	0.80	0.95	0.90	0.69	0.42	0.17
Investment (x)	3.35	0.04	0.29	0.60	0.85	0.93	0.79	0.51	0.18	-0.08
Hours (n)	0.43	0.08	0.34	0.66	0.90	0.97	0.82	0.52	0.17	-0.10
Net exports (nx)	0.25	0.05	-0.13	-0.35	-0.54	-0.61	-0.53	-0.33	-0.11	0.06
Price level (p)	1.00	0.47	0.34	0.12	-0.13	-0.37	-0.52	-0.57	-0.54	-0.46
Nominal interest rate (R)	0.67	0.02	-0.24	-0.55	-0.82	-0.95	-0.88	-0.66	-0.37	-0.12

	Correlations of terms of trade (e_t) with net exports (nx_{t+j})								
J-curve	-0.50	-0.64	-0.75	-0.73	-0.57	-0.27	0.08	0.37	0.54

B. International business cycle

Correlation (GDP_1, GDP_2)	(c_1, c_2)	(p_1, p_2)	(R_1, R_2)
0.23	0.63	0.69	0.69

[a] The statistics are based on data filtered with the Christiano-Fitzgerald (2003) filter. Entries are averages over 100 simulations of 187 periods each. Except for net exports and the nominal interest rate, all variables are expressed as percentage deviations from steady state; net exports are expressed as absolute deviations; the nominal interest rate as percentage point deviations at annual rates.

[b] Standard deviations are measured relative to that of GDP; the standard deviation of GDP is in absolute terms.

Table 10: US business cycle[a]

v_{t+j}	Relative std. dev.[b]	Correlations of GDP in period t with variable v in period $t+j$: j = -4	-3	-2	-1	0	1	2	3	4
GDP	1.48	0.22	0.50	0.75	0.93	1.00	0.93	0.75	0.50	0.22
Consumption	0.52	0.15	0.37	0.58	0.73	0.80	0.78	0.68	0.53	0.34
Investment	2.99	0.35	0.58	0.78	0.91	0.94	0.86	0.68	0.43	0.17
Hours	0.90	-0.07	0.19	0.46	0.71	0.88	0.95	0.91	0.76	0.55
Net exports	0.25	-0.48	-0.52	-0.56	-0.58	-0.58	-0.52	-0.39	-0.21	-0.01
Price level	0.82	-0.70	-0.77	-0.78	-0.73	-0.60	-0.43	-0.23	-0.03	0.16
Nominal interest rate	0.73	-0.66	-0.47	-0.22	0.06	0.31	0.49	0.58	0.59	0.53
		Correlations of terms of trade (e_t) with net exports (nx_{t+j})								
J-curve		-0.09	-0.12	-0.16	-0.14	-0.03	0.17	0.39	0.55	0.60

[a] The statistics are based on data filtered with the Christiano-Fitzgerald (2003) filter. Except for net exports and the nominal interest rate, all variables are expressed as percentage deviations from trend. Net exports are first normalized by dividing the actual series by the trend of GDP obtained with the Christiano-Fitzgerald (2003) filter; the normalized series is then expressed as absolute deviations from trend. The nominal interest rate is expressed as percentage point deviations from trend at annual rates. Consumption = nondurables + services + government expenditures; investment = fixed private investment + consumer durables; hours = total hours in nonagricultural establishments; price level = CPI; nominal interest rate = yield on 3-month Treasury bills; terms of trade = ratio of import and export price deflators.

[b] Standard deviations are measured relative to that of GDP; the standard deviation of GDP is in absolute terms.

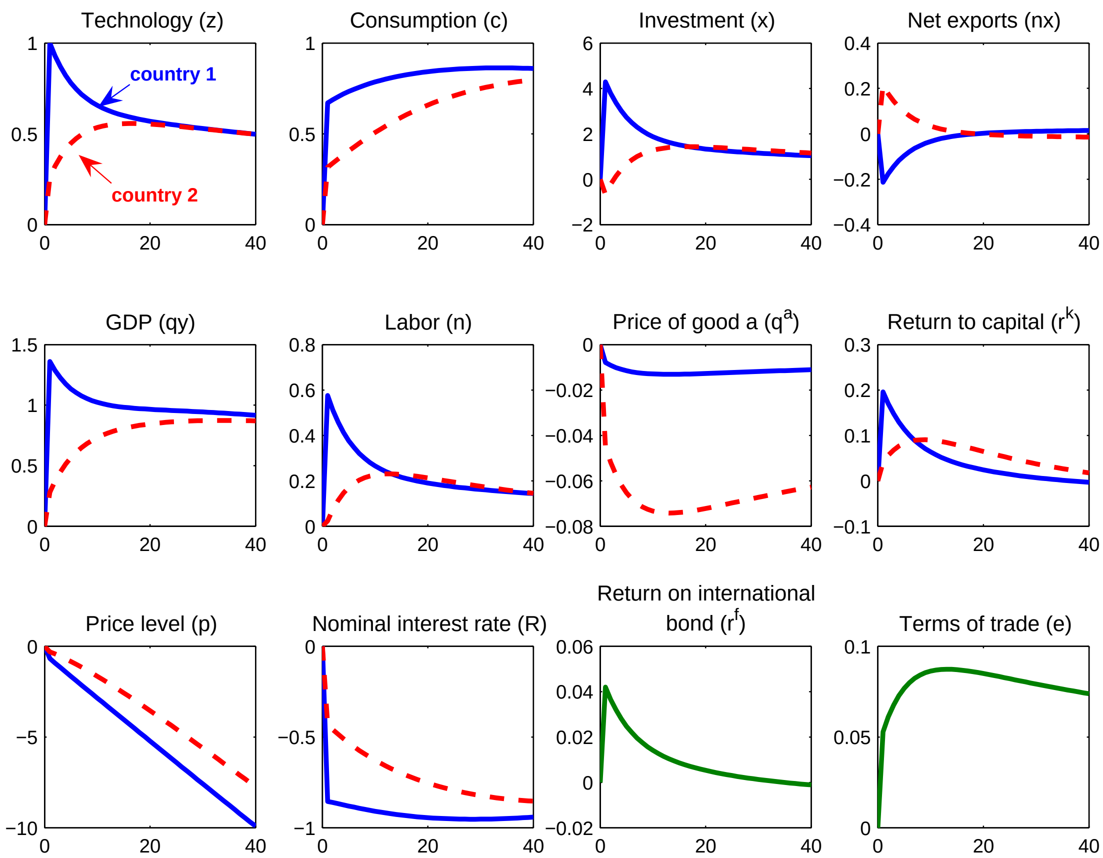

Figure 7: Responses to a 1% technology shock in country 1 in the benchmark experiment; rates of return are measured as percentage point deviations from steady state at annual rates, all other variables as percentage deviations.

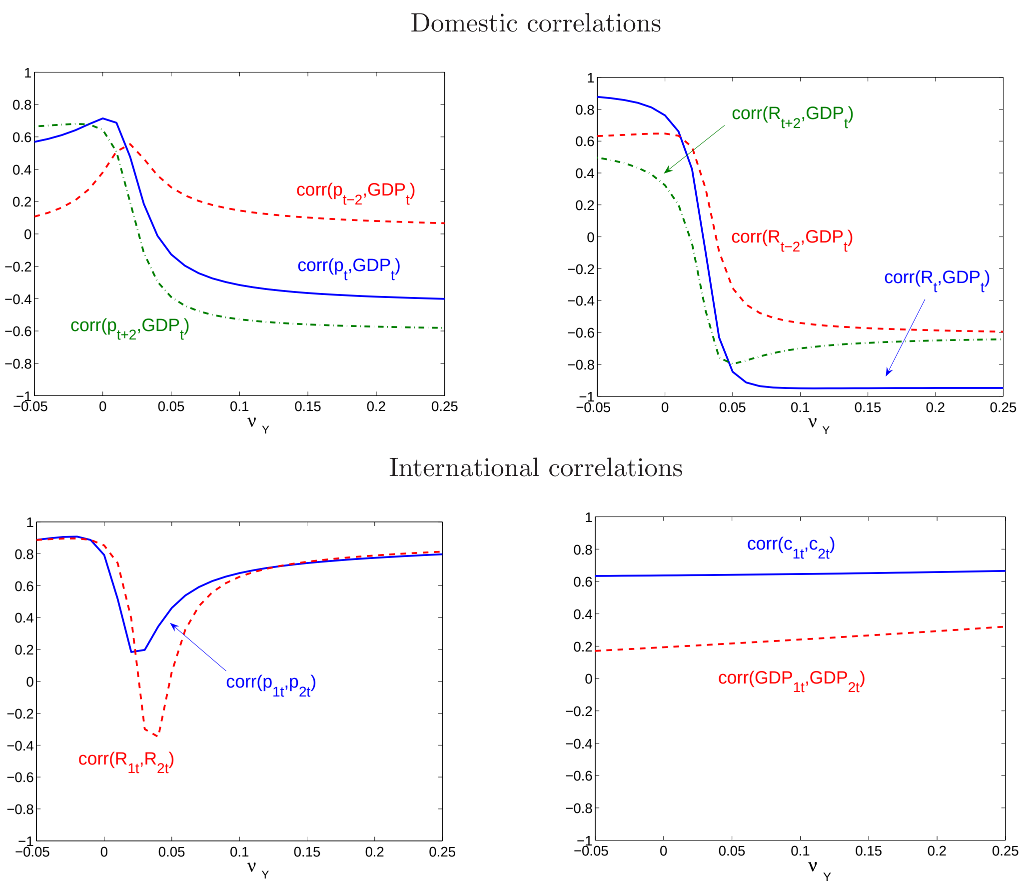

Figure 8: Varying the weight on GDP in the monetary policy rule.

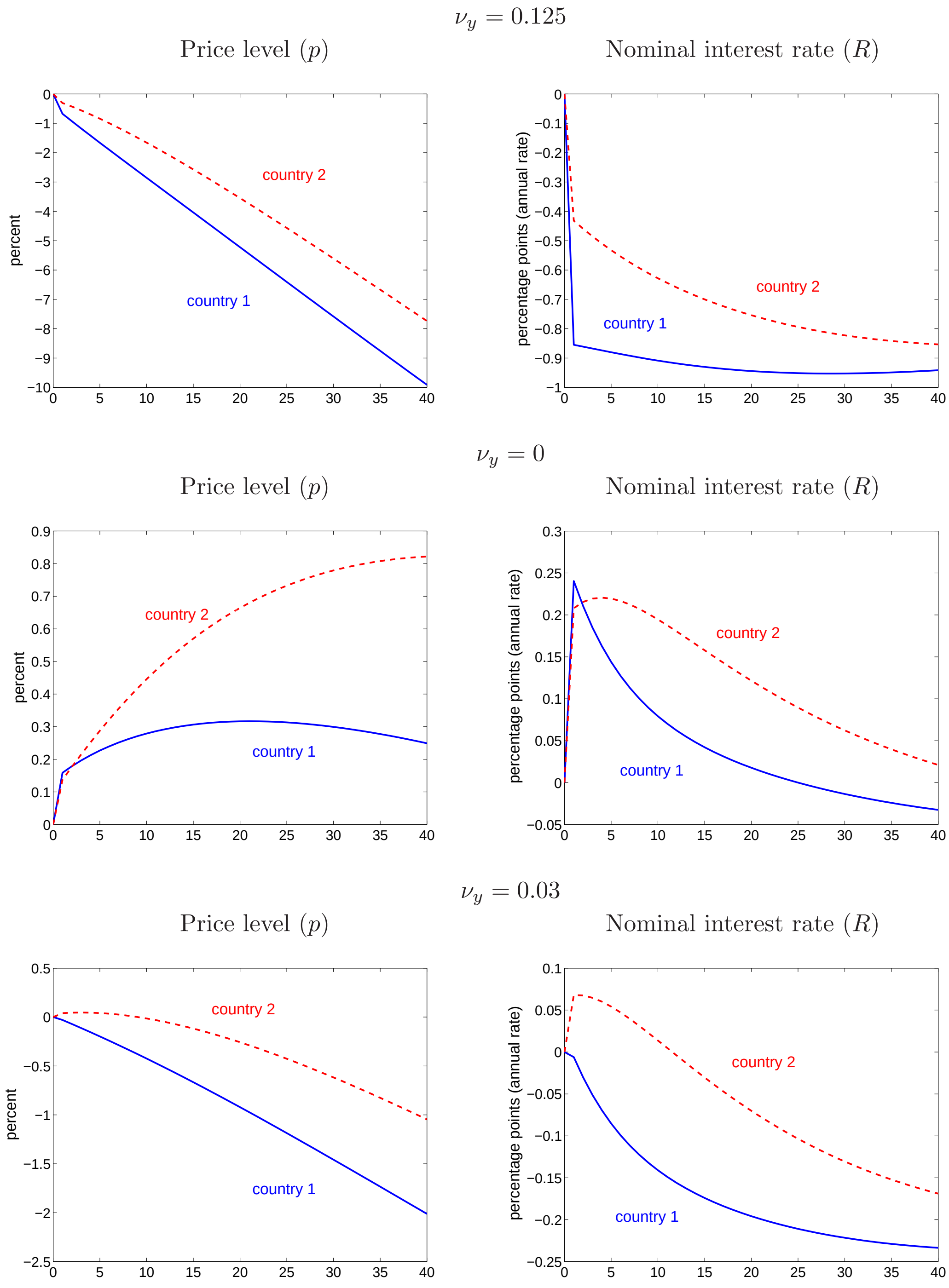

Figure 9: Responses to a 1% productivity shock in country 1; alternative weights on GDP in the monetary policy rule.

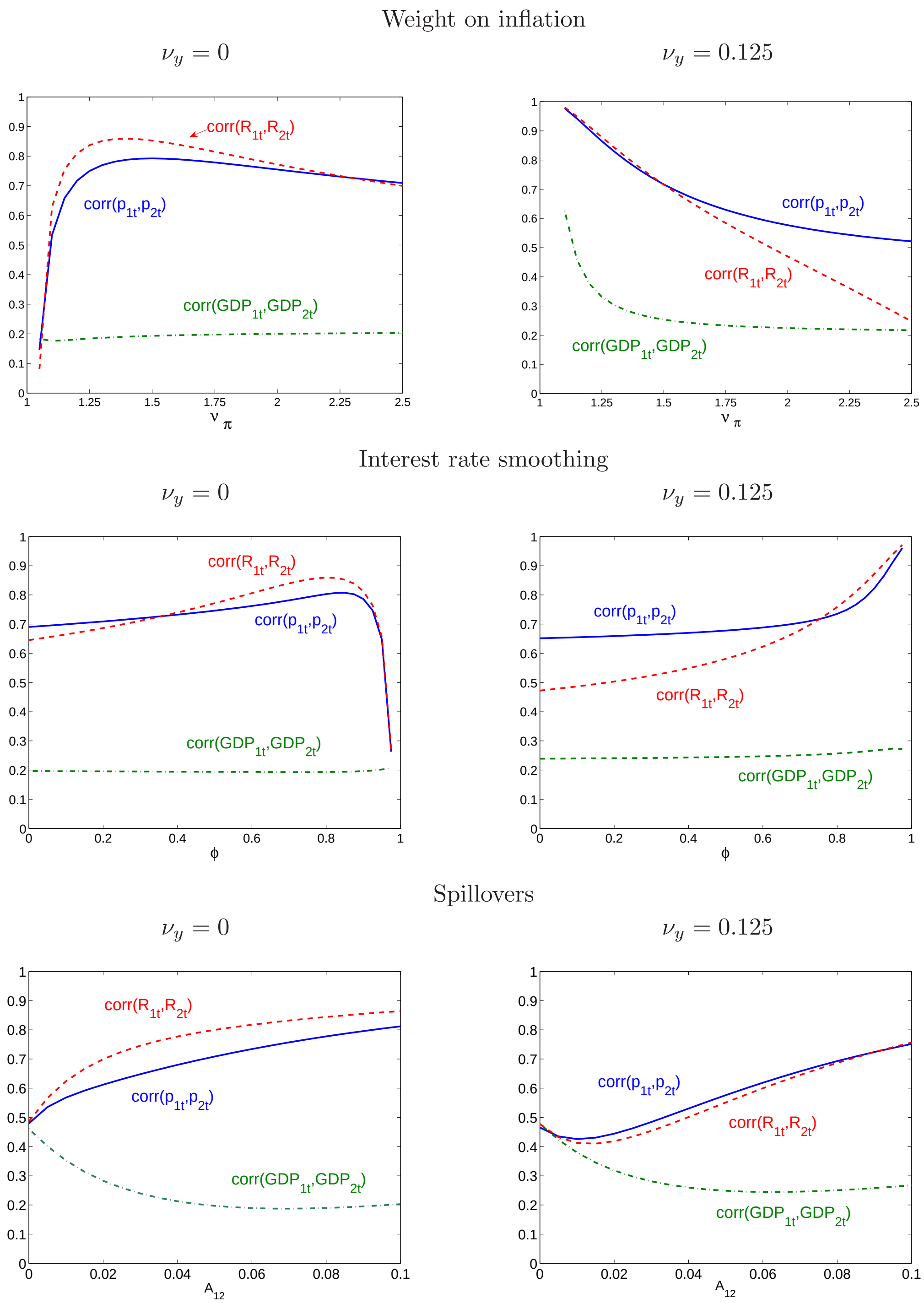

Figure 10: Comovements across countries for alternative parameterizations.

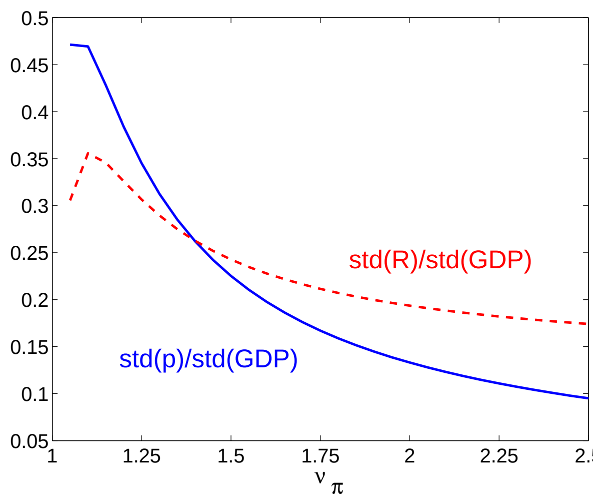

Figure 11: Stabilizing nominal variables; in this case $\nu_y = 0$.

Table 11: Alternative values of the elasticity of substitution (σ) and the steady-state import share of GDP (b_1/y_1)

	Correlation between						
	p_t, GDP_t	R_t, GDP_t	nx_t, e_t	GDP_{1t}, GDP_{2t}	c_{1t}, c_{2t}	p_{1t}, p_{2t}	R_{1t}, R_{2t}
$\sigma = 0.9$	-0.37	-0.95	-0.73	0.25	0.65	0.70	0.74
$\sigma = 1.5$	-0.37	-0.95	-0.57	0.23	0.63	0.69	0.69
$\sigma = 2.1$	-0.36	-0.95	-0.36	0.22	0.63	0.69	0.69
$b_1/y_1 = 0.10$	-0.36	-0.94	-0.51	0.20	0.67	0.70	0.71
$b_1/y_1 = 0.15$	-0.37	-0.95	-0.57	0.23	0.63	0.69	0.69
$b_1/y_1 = 0.20$	-0.37	-0.95	-0.57	0.26	0.58	0.67	0.69