International Business Cycles

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We estimate a dynamic two-country model in which economic fluctuations are driven by a worldwide supply shock, country-specific supply shocks, and relative fiscal, money, and preference shocks. Identification is achieved using only long-run restrictions, based on a theoretical model. The main results, are: (i) supply shocks, particularly country-specific ones, are very important in generating international business cycles, (ii) although the post-1973 flexible-exchange-rate period has been inherently more volatile, there are no differences in transmission properties of economic disturbances across exchange-rate regimes for the endogenous variables we focus on. (*JEL* E32, F41, C32)

A major focus of attention in macroeconomics in recent years has been to identify empirically the forces that induce fluctuations in economic aggregates. The motivation of this literature has been to assess the relative importance of real versus nominal shocks, and of aggregate supply versus aggregate demand disturbances in the generation and propagation of business cycles. These studies, the results of which have important positive and normative implications, have been carried out almost exclusively within the context of a closed economy.

The purpose of this paper is to extend this literature to an open-economy setting. We develop and estimate a multivariate, structural, two-country, two-good model of the world economy to measure the relative contribution of supply shocks, fiscal and monetary policy shocks, and preference shocks in explaining movements in key macroeconomic variables for the United States and a five-nation OECD aggregate.[1] Our empirical results enable us to assess whether the correlation of real GNP movements across countries is primarily due to a common world disturbance, or whether spillover effects of shocks originating in one country to the other play the major role.

A second goal of the paper is to study the role of exchange-rate regimes. Economists have theorized about the relative transmission properties of fixed and floating exchange rates, but to the best of our knowledge, there has been no empirical work dealing with this issue that goes beyond purely examining the statistical properties of the data.[2] We begin with the premise that empirical analysis of the transmission of shocks across exchange-rate regimes is intimately tied up with the problem of identifying the actual shocks that were experi-

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[1]Alan Stockman (1988) presents empirical evidence on comovements of industrial output across countires. David K. Backus et al. (1989) provide some simulation results from a two-country model in which risk-sharing is important.

[2]However, theoretical papers addressing the role of exchange-rate regimes abound. Some examples are Robert Flood and Nancy Marion (1982), Stockman (1983), and Jeffrey A. Frankel and Katharine Rockett (1988).

enced by the economies in question. Identification of these fundamental disturbances using a structural model allows us to examine not only whether there is increased volatility in flexible-exchange-rate periods, but if so, whether it is due to changes in the manner in which the economic system responds to shocks or due to a change in the volatility of the underlying fundamental disturbances themselves. This is an important question to address in evaluating whether the post-Bretton Woods flexible-exchange-rate system has failed and some type of international monetary reform is needed. As Jacob A. Frenkel (1987 p. 207) has noted, the crucial factor is whether "[the] faults reflect deficiencies of the *international monetary system* or of *macroeconomic policies*."

Our econometric methodology, similar to that of Olivier J. Blanchard and Danny Quah (1989) and Matt D. Shapiro and Mark W. Watson (1988), is to rely exclusively on *long-run* restrictions—based on a theoretical model—to identify the fundamental disturbances and short-run dynamics. Since most macroeconomic disputes are about short-run phenomena, this enables us to use less controversial assumptions than would be the case if we had to impose short-run restrictions as well. This argument applies with particular force to our goal of studying the effects of the exchange-rate regime on the transmission of shocks. In order to test the hypothesis that there was no structural change due to a shift in regime, we need to identify the model without resort to restrictions that would be appropriate to one regime alone. To obtain a model that nests both the fixed- and floating-exchange-rate periods, it is desirable to employ only long-run identification restrictions, since most economists consider differences, if any, in the transmission across exchange-rate regimes to be important predominantly in the short run.[3] Thus, our analysis makes it possible to discriminate between competing theories that share our long-run identification assumptions but differ widely in terms of short-run predictions and the role of exchange-rate regimes.

Our work is related to two very different lines of inquiry. On the one hand, it follows in the line of papers devoted to assessing the importance of different shocks in propagating economic fluctuations. Examples of this are the Blanchard-Quah, Shapiro-Watson papers mentioned above and Robert G. King et al. (1991). These papers, however, focus on a closed economy. Besides focusing on the world economy, our paper departs from these other papers by introducing fiscal and preference shocks into the model.

The second line of inquiry to which our work is related is the investigation of the correlation of business cycles across countries, which has a long history. Wesley C. Mitchell (1927) found a positive correlation of business cycles across countries and concluded that this correlation was growing over time. He attributed this to the growth in international financial linkages. Oskar Morgenstern (1959) compared the correlation of the business cycles in the United States, United Kingdom, France, and Germany under the gold standard (1879–1914) and during the interwar period (1919–1932). He found that the business cycles were in phase more often in the gold-standard period than in the later periods. Rudiger Dornbusch and Stanley Fischer (1986), following Morgenstern, studied the period 1953–1980, in order to gauge the effects of the floating-exchange-rate period. They found less cross-country correlation than did Morgenstern.

An important recent contribution to this literature is that of Marianne Baxter and Alan Stockman (1989). They study univariate statistical properties and simple cross-correlations across countries of macroeconomic variables in 49 countries for both fixed- and flexible-exchange-rate periods. Their principal finding is that, aside from the greater volatility of real exchange rates under the flexible-exchange-rate system, there is little evidence of systematic differences in the univariate properties of

[3]This statement applies to real variables. It is possible that the behavior of nominal variables, such as the price level or the nominal exchange rate, differs across exchange-rate regimes, even in the long run. Nothing in our approach is inconsistent with this possibility.

macroeconomic aggregates across regimes. Stefan Gerlach (1988) also examines the cross-correlations across countries of industrial production using spectral methods. He finds that, at the business-cycle frequency at least, the correlation across countries is higher for the flexible-exchange-rate post-1973 period.

Our work on exchange-rate regimes differs from this previous work. We consider a multivariate, structural, two-country model of the world economy. The model is estimated using postwar quarterly data, with the United States as the home country and an aggregate of Canada, France, Japan, the United Kingdom, and West Germany as the foreign country. We consistently interpret our reduced-form results in the light of this full-fledged structural model. This framework enables us to examine the relative importance of various structural shocks and to distinguish between differences across regimes in transmission properties and differences due to changes in the volatility of the fundamental disturbances.

The organization of the remainder of the paper is as follows. In Section I we develop the long-run theoretical model, discuss the restrictions that are imposed to identify the model, and derive a system of linear equations that describe the paths of the endogenous variables. In Section II we discuss the econometric methodology that is used to estimate the model. In Section III we present and interpret our empirical results. Section IV concludes the paper.

I. Theoretical Framework

In this section we develop a simple two-country theoretical model of the world economy in which the long-run neutrality of money holds. Since the model does not restrict the *short-run* dynamic interactions between the variables in any way, it is consistent with a wide range of commonly used macroeconomic models. These include Mundell-Fleming open-economy models with long-run flexibility of prices, Fischer-Gray labor-contracting rational-expectations models, Lucas-Barro misperceptions models, and real-business-cycle models.

Our long-run theoretical model helps to serve two main purposes. First, it explicitly specifies the different shocks that could be potential sources of stochastic trends in the time series of the variables in the model. These shocks are: (i) a worldwide labor-augmenting productivity shock, (ii) country-specific supply shocks, modeled here as labor-supply disturbances, (iii) country-specific fiscal policy shocks, (iv) country-specific monetary policy shocks, and (v) relative demand disturbances, modeled here as preference shocks. Second, the theory highlights the long-run restrictions on the model that will be used to identify some interesting linear combinations of the abovementioned disturbances.

Consider a system of dynamic equations:

$$\mathbf{X}_t = \mathbf{C}(L)\boldsymbol{\xi}_t \tag{1}$$

where $\mathbf{X}_t$ is a vector of stationary, observable endogenous variables, $\mathbf{C}(L)$ is a matrix polynomial in the lag operator L $[\mathbf{C}(L) = \sum_{j=0}^{\infty} C_j L^j]$, and $\boldsymbol{\xi}_t$ is a vector of unobservable exogenous shocks that are serially and mutually uncorrelated at all leads and lags. Intercept terms have been left out for convenience. In order to study the sources of the movements in the endogenous variables, we develop a model that provides an economic interpretation of the elements of $\boldsymbol{\xi}_t$.[4] We can rewrite the dynamic system to separate out the long-run coefficients as follows:

$$\mathbf{X}_t = \mathbf{C}(1)\boldsymbol{\xi}_t + (1-L)\mathbf{C}^*(L)\boldsymbol{\xi}_t \tag{2}$$

where $\mathbf{C}^*(L)$ satisfies

$$(1-L)\mathbf{C}^*(L) = \mathbf{C}(L) - \mathbf{C}(1)$$

and $\mathbf{C}(1)$ contains the desired long-run multipliers obtained by setting $L = 1$. We demonstrate in Section II below (see also

[4]We assume that the moving-average representation, (1), that goes along with the structural model is invertible. This is standard practice. For a discussion of the consequences of the noninvertibility of (1), see Marco Lippi and Lucrezia Reichlin (1990).

Blanchard and Quah [1989]) that, given appropriate restrictions on $\mathbf{C}(1)$, we can recover the full dynamic system.

Several features of the system of equations in (2) are worth emphasizing. First, the long-run paths of the variables and their short-run dynamics are both determined by the same vector of exogenous shocks, $\boldsymbol{\xi}$. Second, the levels of the variables in our model are I(1), requiring differencing to render them stationary. Thus, $\mathbf{X}_t$ will represent the first differences of them. Third, our identification restrictions imply a lower triangular $\mathbf{C}(1)$, so that there is no cointegration among the variables and there are six stochastic trends driving their short-run and long-run paths. We provide some evidence for this later.[5]

The point of the theoretical model that we presently develop is to highlight restrictions on $\mathbf{C}(1)$ which will allow us to estimate the full dynamics, $\mathbf{C}(L)$, when we come to the empirical part of the paper. Therefore, for now we will ignore the short-run portion of the system and focus on long-run behavior, described by

$$\mathbf{X}_t = \mathbf{C}(1)\boldsymbol{\xi}_t. \tag{3}$$

A. *Long-Run Model*

We obtain our restrictions on the $\mathbf{C}(1)$ matrix in two stages. First, we specify a real-business-cycle (RBC) model, based on optimizing behavior, with an exogenously given fiscal sector that is assumed to drive the long-run paths of the real variables in our system. Second, in order to allow us later to examine the importance of money in the short run, we augment our long-run real model to incorporate money in a fairly general way.

The world economy consists of two representative countries each of which consumes two goods. There is complete specialization in production, with the domestic country producing good h (the home good) and the foreign country producing good f (the foreign good). The main features of the augmented model can be summarized as: (i) changes in the labor input (total hours) are exogenous in the long run, (ii) the long-term behavior of output is supply-determined (i.e., its long-run path is driven by exogenous shocks to technology and the labor input), (iii) the ratio of government purchases to output is exogenously chosen by the fiscal authorities in the long run, and (iv) long-run neutrality of money holds. These four features constitute the identification restrictions of our empirical model. Below we provide more detail on the behavior of individual variables.

Output and Labor. —Total outputs in the domestic and foreign country (Y_{h} and Y_{f}, respectively) are given by

$$Y_{\mathrm{h}t} = A_{\mathrm{h}} K_{\mathrm{h}t}^{1-\alpha_{\mathrm{h}}} (N_{\mathrm{h}t} Z_t)^{\alpha_{\mathrm{h}}} \tag{4a}$$

$$Y_{\mathrm{f}t} = A_{\mathrm{f}} K_{\mathrm{f}t}^{1-\alpha_{\mathrm{f}}} (N_{\mathrm{f}t} Z_t^{\delta_{\mathrm{f}}})^{\alpha_{\mathrm{f}}} \tag{4b}$$

where N_{h} (N_{f}) is the domestic (foreign) country's labor input, K_{h} (K_{f}) is the domestic (foreign) country's capital input, Z is a world supply shock (representing a Harrod-neutral technological innovation, for example) measured in units of the home good and A_{h}, A_{f}, α_{h}, α_{f}, and δ_{f} are fixed parameters. These output specifications imply that technical progress (Z) is shared by the two countries. However, we allow the countries' outputs to respond asymmetrically to Z ($\delta_{\mathrm{f}} \neq 1$), since the ability to use technology may differ across countries.

Following the modern literature on RBC theory, we allow technical progress to follow a random-walk process in the long run. Thus

[5] If there was cointegration among the variables, another interesting question would arise. In that case, the number of stochastic trends would be less than the number of variables, and there would be some transitory shocks. One could then ask how much of the deviations around long-run paths is caused by innovations to transitory components and how much by innovations to permanent components as the variables move from one long-run path to another. Further identification restrictions would be needed to achieve this (see e.g., King et al., 1991). This consideration does not seem too relevant in our case, since we do not find any evidence of cointegration.

we can write Z_t in its natural-log form as

$$\log Z_t = \mu + \log Z_{t-1} + \tau_t \tag{5}$$

where μ is a drift parameter and τ_t is a zero-mean, serially uncorrelated technological innovation. This type of model leads to output, consumption, investment, and the capital stock per worker all growing at the rate of growth, Z_t, in the long run.

Since hours per worker cannot grow without bound, RBC models typically restrict themselves to the class of utility functions that will yield constant per-worker hours in the long run. Therefore, total hours in these models grow at the growth rate of the population. It would certainly be possible in our model to follow this approach. However, such a specification assumes identical agents; in particular, it does not allow for permanent changes in employment that might arise from exogenous shocks originating in the labor market. Moreover, Shapiro and Watson (1988) empirically discriminate between labor-supply and technology shocks for the United States and find that permanent labor-supply disturbances are quite important. In light of this, we allow country-specific exogenous shocks originating in the labor market to affect the long-run path of total hours. These shocks might represent permanent changes in the degree of unionization in a country. Alternatively, they could result from permanent changes in government policies aimed specifically at the labor market (such as unemployment insurance) or changes in the labor-force participation rates of women. We label these shocks country-specific labor "supply" disturbances, since they can be thought of as exogenous shifts in the long-run vertical employment supply curve.

The above discussion implies that the long-term behavior of total hours in each country can be described by

$$\Delta n_{it} = \overline{N}_i + \tau_{it} \qquad i = \mathrm{h,f} \tag{6}$$

where $\overline{N}_\mathrm{h}$ and $\overline{N}_\mathrm{f}$ are constants, $\tau_{\mathrm{h}t}$ and $\tau_{\mathrm{f}t}$ are independently and identically distributed zero-mean, country-specific home and foreign labor-supply disturbances, respectively, $n_{\mathrm{h}t} \equiv \log N_{\mathrm{h}t}$, $n_{\mathrm{f}t} \equiv \log N_{\mathrm{f}t}$, and Δ is the first difference operator.

Equations (4)–(6) and the long-run constancy of capital–output ratios allow us to express long-run output growth in the two countries as a function of the common world technology shock and country-specific shocks originating in the labor market:

$$\Delta y_{\mathrm{h}t} = \mu + \overline{N}_\mathrm{h} + \tau_t + \tau_{\mathrm{h}t} \tag{7a}$$

$$\Delta y_{\mathrm{f}t} = \delta_\mathrm{f}\mu + \overline{N}_\mathrm{f} + \delta_\mathrm{f}\tau_t + \tau_{\mathrm{f}t}. \tag{7b}$$

Private Outputs and the Government Sector.—While some simulation studies on the effects of fiscal policy have been carried out, the majority of RBC models ignore the fiscal sector. Rather than doing so, we make simple assumptions about fiscal policy that allow us to study the effects of changes in the size of the government. We assume that the government in each country purchases only goods and services produced in the own country and that the government's budget balances in the long run. We further assume that the government exogenously chooses the long-run value of the ratio of government purchases of goods and services to output. Specifically, let G_h denote purchases of domestic goods and services by the domestic government. Then, in the long run, the size of the domestic government, $g_\mathrm{h} \equiv G_\mathrm{h} / Y_\mathrm{h}$, behaves according to

$$g_\mathrm{h} = g_{\mathrm{h},t-1} + \eta_{\mathrm{h}t} + \phi_\mathrm{h}\eta_{\mathrm{f}t}$$

subject to the constraint $0 < g_{\mathrm{h}t} < 1$. The disturbance term η_h is the permanent exogenous shock to the size of the domestic government and $\phi_\mathrm{h}\eta_\mathrm{f}$ is the feedback reaction by the domestic fiscal authority in response to an exogenous change in the foreign country's government size. The feedback could be interpreted either as policy coordination or policy retaliation. The disturbances η_h and η_f are assumed to be zero-mean and to be independently and identically distributed.[6]

Next we define private output in the domestic country as

$$Y_{\mathrm{h}t}^{\mathrm{P}} \equiv Y_{\mathrm{h}t} - G_{\mathrm{h}t} = (1 - g_{\mathrm{h}t})Y_{\mathrm{h}t}.$$

In what follows, we will use the approximation $\log(1 - g_{\mathrm{h}}) \approx g_{\mathrm{h}}$. We have analogous equations describing fiscal policy and private-output behavior for the foreign country.

From the above discussion, the long-term growth rates of private outputs are given by

$$(8) \qquad \Delta y_{it}^{\mathrm{P}} = \Delta y_{it} - \eta_{it} - \phi_i \eta_{jt} \qquad \text{for } i, j = \mathrm{h}, \mathrm{f},\ i \neq j$$

where $y_{\mathrm{h}}^{\mathrm{P}} \equiv \log Y_{\mathrm{h}}^{\mathrm{P}}$ and $y_{\mathrm{f}}^{\mathrm{P}} \equiv \log Y_{\mathrm{f}}^{\mathrm{P}}$.

Consumption, Leisure, and Relative Prices.—Suppose agents in each country maximize the following expected lifetime utility subject to their intertemporal budget constraint:

$$(9) \quad W_t = E_t\left(\sum_{j=0}^{\infty}\left\{\left[\frac{1}{(1+\rho)^{t+j}}\right] \times \left[U(C_{\mathrm{h},t+j}, C_{\mathrm{f},t+j}) + V(\ell_{t+j})\right]\right\}\right)$$

where U and V are instantaneous utility functions with standard properties, C_i is the consumption of the ith good ($i = \mathrm{h},\mathrm{f}$), ℓ represents leisure, and ρ is the pure rate of time preference. Given that we wish to allow for changes in employment, care must be taken in interpreting W_t as the welfare of the typical agent. One might assume that whether an agent is employed or not is determined by a lottery. Then, for unemployed agents, $\ell_{t+j} = 1$ which is *not* a choice variable. Another possibility, more consistent with welfare-maximizing agents, is to assume identical agents with indivisible labor. In this case, individual optimization leads to a corner solution for the labor–leisure choice, with an agent being either employed or unemployed. As Richard Rogerson (1988) shows, given the employment lottery, the aggregate economy in such a model can be characterized by a preference function (of a hypothetical representative agent) of the form given by (9), where V is a linear function. The coefficient on ℓ_{t+j} in V would then be a stochastic variable, changes in which could be thought of as the source of our exogenous employment shocks.

In order to obtain closed-form solutions, we specify the utility function as

$$U(C_{\mathrm{h}t}, C_{\mathrm{f}t}) = \psi_{\mathrm{h}t} \log C_{\mathrm{h}t} + \psi_{\mathrm{f}t} \log C_{\mathrm{f}t}$$

where $\psi_{\mathrm{h}t}$ and $\psi_{\mathrm{f}t}$ are preference parameters allowed to vary over time. With identical preferences in the two countries, the equality of the marginal rate of substitution to the relative price yields

$$(10) \qquad \frac{\psi_{\mathrm{f}t} C_{\mathrm{h}t}}{\psi_{\mathrm{h}t} C_{\mathrm{f}t}} = \frac{\psi_{\mathrm{f}t} C_{\mathrm{h}t}^*}{\psi_{\mathrm{h}} C_{\mathrm{f}t}^*} = \frac{P_{\mathrm{f}t}}{P_{\mathrm{h}t}} = Q_{\mathrm{f}t}^{\gamma}$$

where asterisks denote the foreign country's choices, P_{f} (P_{h}) is the price of good f (good h) in domestic currency units and Q_{f} is the relative price of the foreign good in units of the domestic *composite* consumption good. The relationship $P_{\mathrm{f}}/P_{\mathrm{h}} = Q_{\mathrm{f}}^{\gamma}$ follows from the domestic price level being a fixed weighted index given by $P = P_{\mathrm{h}}^{\gamma} P_{\mathrm{f}}^{1-\gamma}$ and the definition $Q_{\mathrm{f}} \equiv P_{\mathrm{f}}/P$.

With some additional information, we can solve for the long-run growth rate of the

[6]From the government's intertemporal budget constraint, a permanent rise in the size of government would imply a permanent rise in taxes. Since this change is assumed not to affect output in the long run, implicitly it is being assumed that, over the long term, wealth and substitution effects of a change in the tax rate on work effort cancel out. This would hold, for example, in an RBC model with proportional taxes, constant-relative-risk-aversion preferences and Cobb-Douglas production.

relative price Q_f. First, we allow for permanent shocks to the demand for each good. Specifically,

$$\log \psi_{it} = \log \psi_{i,t-1} + \varepsilon_{it} \qquad i = \text{h,f} \tag{11}$$

where ε_{ht} and ε_{ft} are zero-mean, independently and identically distributed preference shocks. Second, along the long-run balanced-growth path, the ratio of world consumption of each good to total private output of that good will be constant. Then, the behavior of private outputs given in (8) together with (10) yields the following:

$$\begin{aligned} \Delta q_{ft} = {} & \gamma(\bar{N}_h - \bar{N}_f) + \gamma(1-\delta_f)\mu \\ & + \gamma(1-\delta_f)\tau_t + \gamma(\tau_{ht} - \tau_{ft}) \\ & + \gamma[(1-\phi_h)\eta_{ft} - (1-\phi_f)\eta_{ht}] \\ & + \gamma(\varepsilon_{ft} - \varepsilon_{ht}) \end{aligned} \tag{12}$$

where $q_f \equiv \log Q_f$. This equation has a straightforward interpretation. A relative domestic supply shock $(\tau_h - \tau_f > 0)$, a relative increase in the size of the foreign government $[(1-\phi_h)\eta_{ft} - (1-\phi_f)\eta_{ht} > 0]$, or a relative preference shock toward the foreign good $(\varepsilon_f - \varepsilon_h > 0)$ will create excess demand of good f relative to good h and hence deteriorate the domestic terms of trade (i.e., $\Delta q_f > 0$). A world productivity disturbance $(\tau > 0)$ has an ambiguous effect, depending on which good's supply rises by more (i.e., whether $\delta_f > 1$).

Money.—Up to now, money does not appear in our model, an omission that can be potentially damaging for our empirical work. Whether real-business-cycle theory is a good approximation for *short-run* behavior is something that should be tested, rather than imposed a priori. Therefore, we now augment our long-run model to include money, by adding the following equation, where m_{ht} (m_{ft}) represents the log of the money supply in the domestic (foreign) country, the ω's are fixed parameters and v_h and v_f (labeling the home and foreign money shocks, respectively) are zero-mean independently and identically distributed shocks designed to capture exogenous disturbances originating in each country's money market:

$$\begin{aligned} \Delta m_{ht} - \Delta m_{ft} & \\ = {} & \omega_0 + \omega_1\tau_{ht} + \omega_2\tau_t + \omega_3\tau_{ft} \\ & + \omega_4[(1-\phi_h)\eta_{ft} - (1-\phi_f)\eta_{ht}] \\ & + \omega_5(\varepsilon_{ft} - \varepsilon_{ht}) \\ & + [(1-\pi_f)v_{ht} - (1-\pi_h)v_{ft}]. \end{aligned} \tag{13}$$

Thus, the ratio of money supplies in the two countries reacts permanently to the three supply shocks (τ, τ_h, and τ_f), the relative fiscal shock ($[1-\phi_h]-[1-\phi_f]\eta_{ht}$), the relative demand shock $(\varepsilon_f - \varepsilon_h)$, and the relative money shock ($[1-\pi_f]v_{ht} - [1-\pi_h]v_{ft}$). The coefficient π_h (π_f) may be interpreted as the feedback reaction of home (foreign) money supply to an exogenous change in the monetary variable of the other country.

Although the specification of (13) is ad hoc, it is nonetheless quite general. For example, given some symmetry restrictions, it is consistent with a variety of views on how money supply is determined, such as countercyclical monetary policy, interest-rate smoothing, and "reverse-causation" (the RBC view that inside money responds to the same real shocks as the rest of the economy, as in King and Charles Plosser [1984]).[7] For fixed-exchange-rate regimes, since foreign-exchange reserves are endogenous, the quantity of nominal money is, of course, demand-determined; but our specification (13) is also consistent with many commonly used methods of introducing money demand through optimization problems, such as cash-in-advance, money-in-

[7]The symmetry restrictions are that the responses of each country's money supplies to own and foreign fiscal and preference shocks are symmetric.

$$(14)\quad \begin{bmatrix} \Delta n_{ht} \\ \Delta y_{ht} \\ \Delta y_{ft} \\ \Delta y_{ht}^{P} - \Delta y_{ft}^{P} \\ \Delta q_{ft} \\ \Delta m_{ht} - \Delta m_{ft} \end{bmatrix} = \begin{bmatrix} \bar{N}_h \\ \mu + \bar{N}_h \\ \delta_f \mu + \bar{N}_f \\ (\bar{N}_h - \bar{N}_f) + (1-\delta_f)\mu \\ \gamma\left[(\bar{N}_h - \bar{N}_f) + (1-\delta_f)\mu\right] \\ \omega_0 \end{bmatrix}$$

$$+ \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & \delta_f & 1 & 0 & 0 & 0 \\ 1 & 1-\delta_f & -1 & 1 & 0 & 0 \\ \gamma & \gamma(1-\delta_f) & -\gamma & \gamma & \gamma & 0 \\ \omega_1 & \omega_2 & \omega_3 & \omega_4 & \omega_5 & 1 \end{bmatrix} \begin{bmatrix} \tau_{ht} \\ \tau_t \\ \tau_{ft} \\ (1-\phi_h)\eta_{ft} - (1-\phi_f)\eta_{ht} \\ \varepsilon_{ft} - \varepsilon_{ht} \\ (1-\pi_f)v_{ht} - (1-\pi_h)v_{ft} \end{bmatrix}$$

the-utility-function, and transactions-costs approaches.[8]

It is not the purpose of our paper to distinguish between these alternative interpretations of (13). Rather, our goal in introducing money is to examine to what extent money has effects on real variables in the short run and whether relative money supplies behave differently across exchange-rate regimes.

The restriction that we are imposing is the *long-run neutrality of money*, so that v_h and v_f have no long-term effects on the real variables discussed earlier. This restriction is, admittedly, not consistent with some models (e.g., models that display hysteresis), but identification restrictions always come at some cost. As far as long-run properties go, the neutrality of money is a more widely accepted proposition than the alternatives.[9]

B. *Transformed Long-Run Model*

Since our foreign country is an aggregate of many countries, data limitations prevent us from obtaining a good measure of the foreign labor input. Therefore, anticipating the empirical work to follow, our long-run model can be thought of as consisting of the variables Δn_{ht}, Δy_{ht}, Δy_{ft}, Δy_{ht}^{P}, Δy_{ft}^{P}, Δq_{ft}, and $\Delta m_{ht} - \Delta m_{ft}$, with their behavior described by equations (6), (7), (8), (12), and (13). The shocks describing the long-run paths of these variables are τ_t, τ_{ht}, τ_{ft}, η_{ht}, η_{ft}, ε_{ht}, ε_{ft}, v_{ht}, and v_{ft}. As the model stands, not all the shocks are separately identified. We can, however, isolate linear combinations of the shocks that are economically interpretable (meaningful) by rewriting the long-run model as equation (14), above.

[8]This generalization, of course, comes at some cost. In particular, without explicitly modeling how money demand arises and how money supply is set, we are unable to examine the effects of various shocks on the nominal exchange rates or differences in the volatility of the price levels across exchange-rate regimes. However, the specification in (6)–(8) and (12), which does not include *aggregate* price levels, goes through, as long as money is neutral in the long run (i.e., does not affect output and *relative* prices).

[9]We cannot imagine an alternative set of identification restrictions that would be less restrictive and still enable us to answer the questions with which this paper is concerned.

The new variable $(\Delta y^{\mathrm{P}}_{\mathrm{ht}} - \Delta y^{\mathrm{P}}_{\mathrm{ft}})$ represents the growth rate of the ratio of private domestic output to private foreign output. The transformed shocks are $\varepsilon_{\mathrm{f}t} - \varepsilon_{\mathrm{h}t}$, a relative preference shock toward the *foreign* good, $(1-\phi_{\mathrm{h}})\eta_{\mathrm{f}t} - (1-\phi_{\mathrm{f}})\eta_{\mathrm{h}t}$, an increase in the relative size of the *foreign* government, and $(1-\pi_{\mathrm{f}})v_{\mathrm{h}t} - (1-\pi_{\mathrm{h}})v_{\mathrm{f}t}$, an exogenous increase in the ratio of domestic to foreign money supply.

The system in (14) is the representation based on economic theory of the first term $[\mathbf{C}(1)\boldsymbol{\xi}_t]$ on the right-hand side of equation (2). Notice how the restrictions implied by our long-run model, which can be viewed as the long-run implications of many different macroeconomic models, translate into zero terms in the $\mathbf{C}(1)$ matrix. Shocks to total hours in each country in the long run are exogenous and country-specific, which is the source of the zeros in the first row and third column, respectively. The zero terms in the fourth row reflect the exogeneity of the ratio of government spending to output in the long run, while those in the fourth and fifth columns result from output being supply-determined over the long term. Finally, the zeros in the last column reflect the long-run neutrality of money.

II. Estimation Strategy

Let $\mathbf{X}_t$ and $\boldsymbol{\xi}_t$, respectively, be the vector of the six dependent variables and the vector of the orthogonal innovations in (14). Consider the moving-average (MA) representation of $\mathbf{X}_t$ [this is just equation (1) of Section I]:

$$\mathbf{X}_t = \mathbf{C}(L)\boldsymbol{\xi}_t. \tag{15}$$

The long-run model discussed in Section I implies that $\mathbf{C}(1)$ is the matrix given on the right-hand side of (14). However, not all the restrictions on $\mathbf{C}(1)$ implied by (14) are needed for identification. What we need is that the disturbances in the vector $\boldsymbol{\xi}_t$ be orthogonal to each other and that $\mathbf{C}(1)$ be lower-triangular. Further restrictions on $\mathbf{C}(1)$ are overidentifying restrictions, and since we believe that they will make the estimated model overly restrictive, we do not impose them. The main purpose of the long-run theoretical model is to enable us to obtain the required long-run causal ordering of the variables from an economic model, rather than imposing it arbitrarily.

We now demonstrate that our structural model, (15), can easily be recovered from its reduced form.[10] In order to see this, first rewrite (15) as a structural vector autoregression (VAR):

$$\mathbf{A}(L)\mathbf{X}_t \equiv \mathbf{A}^*(L)\,\Delta\mathbf{X}_t - \mathbf{B}\mathbf{X}_{t-1} = \boldsymbol{\xi}_t \tag{16}$$

where $\mathbf{A}(L) = \mathbf{C}(L)^{-1}$, $\mathbf{A}(L) = [\mathbf{A}(L) - \mathbf{A}(1)L] + \mathbf{A}(1)L \equiv \Delta\mathbf{A}^*(L) - \mathbf{B}L$. Thus, $\mathbf{B} = -\mathbf{A}(1)$. Since $\mathbf{A}(1)$ is the inverse of $\mathbf{C}(1)$, it inherits the long-run restrictions imposed on the latter and is, therefore, lower-triangular. The system in (16) represents the simultaneous-equations model corresponding to the MA representation of the structural model given by (15). The identifying restrictions are now contained in both $\mathbf{B}$ and the covariance matrix of the innovations; the former is lower-triangular, and the latter is diagonal.[11]

A reduced-form model that conveniently matches with (16) is

$$\boldsymbol{\Gamma}(L)\,\Delta\mathbf{X}_t - \boldsymbol{\Phi}\mathbf{X}_{t-1} = \boldsymbol{\xi}^*_t \tag{17}$$

where $\boldsymbol{\Gamma}(0)$, the leading coefficient matrix of $\boldsymbol{\Gamma}(L)$, is an identity matrix, and $\boldsymbol{\Phi}$ and $\mathrm{Var}(\boldsymbol{\xi}^*_t) \equiv \boldsymbol{\Omega}$ are unrestricted nonsingular matrices. We estimate (17) and recover (16) as follows. First, multiply both sides of (17)

[10] Similar strategies have been used by Shapiro and Watson (1988) and Blanchard and Quah (1989).

[11] Note that rewriting of $\mathbf{A}(L)$ in (16) as $\mathbf{A}(L) \equiv \Delta\mathbf{A}^*(L) + \mathbf{A}(1)L$ is just a convenient way of separating the long run from the short run. In particular, since our variables are not cointegrated, it should not be viewed as an error-correction form. It would be an error-correction model only if the variables were cointegrated, so that $\mathbf{B}$ would be singular and could be written as a product of two rectangular matrices with full column rank (i.e., $\mathbf{B} = \boldsymbol{\beta}'\boldsymbol{\alpha}$, with $\boldsymbol{\alpha}$ representing the matrix of cointegrating vectors and $\boldsymbol{\beta}$ the speeds of adjustment to the equilibrium errors). In our case, $\mathbf{B}$ is triangular and invertible, and there is no cointegration among the variables.

by the inverse of $\mathbf{\Phi}$ to obtain

$$(18)\quad \mathbf{\Phi}^{-1}\mathbf{\Gamma}(L)\,\Delta\mathbf{X}_t - \mathbf{X}_{t-1} = \mathbf{\Phi}^{-1}\boldsymbol{\xi}_t^{*}.$$

Next, multiply (18) by the inverse of the Cholesky factor of $\mathbf{\Phi}^{-1}\mathbf{\Omega}\mathbf{\Phi}^{-1\prime}$. It is well known that the Cholesky factor is unique up to the signs of the diagonal elements. Since, in our theoretical model, **B** is lower-triangular and the signs of the diagonal elements are fixed, the above process uniquely recovers (16) from (17).

III. Empirical Analysis

A. *Data*

The sample consists of quarterly data from 1960:1 to 1986:4 with 1960:1–1973:1 treated as fixed-exchange-rate regime observations and with 1973:2–1986:4 treated as flexible-exchange-rate observations. Data for each country on GDP, government purchases of goods and services, exchange rates and implicit price deflators (to be used in constructing some weights described later), and money stock (except for the United Kingdom) are from the *OECD Main Economic Indicators*. The data on U.S. hours and the U.S. import price index come from the *National Income and Product Accounts*, (NIPA). U.K. money data are taken from Michael R. Darby et al. (1983) and from the *Bank of England Quarterly Reports*. The relative price of the foreign good is defined as the ratio of the U.S. import price index to the U.S. GNP deflator. The foreign output growth rate is a weighted average of the growth rates of the outputs of individual countries that constitute the rest of the world. The weights are the shares of each country's GDP in total GDP of the rest of the world expressed in units of Japanese yen.[12]

Private output growth rates are the growth rates of real GDP less government spending on goods and services. Foreign private outputs and foreign money growth rates are aggregated in a manner analogous to that described above for foreign total output. The levels of all the variables are in logs. The plots of the data in levels and differences (not reported for the sake of brevity) indicate that the variables are likely to be nonstationary in levels and stationary in differences. This is consistent with our specification of the variables as containing unit roots. Formal augmented Dickey–Fuller (ADF) tests confirm this for all the variables except total hours, for which the unit-root results are sensitive to the sample period. We later discuss results from an alternative specification in which hours are trend-stationary.

For expository convenience, we next redefine the variable names in (14), providing the corresponding algebraic expressions in the parentheses:

(i) Structural shocks:
- TW: common world supply shock (τ)
- TH: home-country labor-supply shock ($\tau_{\rm h}$)
- TF: foreign-country labor-supply shock ($\tau_{\rm f}$)
- SF: relative fiscal-policy shock ($[1-\phi_{\rm h}]\eta_{\rm f} - [1-\phi_{\rm f}]\eta_{\rm h}$)
- SP: relative preference shock ($\varepsilon_{\rm f} - \varepsilon_{\rm h}$)
- SM: relative money shock ($[1-\pi_{\rm f}]\upsilon_{\rm h} - [1-\pi_{\rm h}]\upsilon_{\rm f}$)

(ii) Endogenous variables (all in logs):
- NH: domestic hours ($n_{\rm h}$)
- YH: home output ($y_{\rm h}$)
- YF: foreign output ($y_{\rm f}$)
- YHF: ratio of domestic to foreign private outputs ($y_{\rm h}^{\rm P} - y_{\rm f}^{\rm P}$)
- QF: relative price of foreign good ($q_{\rm f}$)

[12]We calculate the weights quarter-by-quarter. The weights seem to be invariant to the choice of the numeraire currency. For example, the relative weight of U.K. output in the rest-of-the-world output is the same whether we use yen or deutsch marks as the numeraire. Even though our weights are not sensitive to the choice of numeraire currency, it might be questionable whether we should use purchasing-power parity in assigning the weights. Why not use the procedure of Robert Summers and Alan Heston (1988) for aggregation? The reason is that their method implies weights that do not vary over time. This would be a shortcoming in that they would not allow for changes in the relative importance of the individual countries in the aggregate.

MHF: ratio of domestic to foreign money stocks $(m_h - m_f)$

The first differences of the endogenous variables will be indicated by attaching an initial D to these names.

B. *Tests of Shifts Across Exchange-Rate Regimes*

The theoretical model does not provide much guidance on the appropriate lag length in our VAR. We have chosen the lag length using the Akaike information criterion (AIC), by estimating the VAR, (17), over the whole sample period with dummy variables for observations corresponding to the flexible-exchange-rate period for both the slopes and intercepts. The AIC achieves its minimum when the lag length is two. The likelihood-ratio (LR) test (using the Sims degrees-of-freedom correction) also indicates a lag length of two.

In estimating the model, we have paid special attention to possible structural shifts that may have occurred, due to the breakdown of the Bretton Woods system. These shifts may have arisen in two different ways: volatility shifts (i.e., heteroscedasticity, defined as changes in the variance of the structural shocks) and changes in the dynamic responses of the dependent variables to these shocks (i.e., regression parameter instability).

Volatility-Shift Tests.—After fixing the lag length at two, we test for stability. We first test for the constancy of the variances, as this logically precedes the tests for constancy of the coefficients. Maintaining the dummy variables, we obtain the ratios of the estimated variances in the floating-exchange-rate period to those in the fixed-exchange-rate period. We then test for the homoscedasticity of each of the six error terms in (17). The test statistics for the first through sixth elements of the error vector, are 1.41, 1.73, 1.10, 2.21, 1.00, and 2.28, respectively, indicating a higher volatility of the system under the floating-exchange-rate regime. The upper 5-percent critical value of the $F_{[37,42]}$ statistic is about 1.70. Thus, in equations where domestic output and the ratios of private outputs and money supplies are the dependent variables, the error terms do not display constant variances.[13]

A natural question that arises at this point is: where does the nonconstancy of the variances of the error terms in the three reduced-form equations highlighted above show up in the structural disturbances? The structural disturbances are retrieved according to the procedure described in Section II. The ratios of the variances of the fundamental disturbances in the floating-exchange-rate period to those in the fixed-exchange-rate period (in the order home labor-supply shock [TH], world supply shock [TW], foreign labor-supply shock [TF], relative fiscal shock [SF], relative preference shock [SP], and relative money shock [SM]) are 1.72, 2.49, 0.90, 1.93, 1.26, and 0.77. Using the 5-percent upper critical value of 1.70, these statistics indicate that, of the six fundamental disturbances, the home supply, the world supply, and the relative fiscal-policy shocks display significantly higher volatility in the post-Bretton Woods flexible-exchange-rate period. The latter two are consistent, respectively, with the higher volatility of oil-price changes since the 1970's and the conjecture in Frenkel (1987) that differences in fiscal policy across regimes are partly responsible for the observed increase in the variance of some macroeconomic variables in the post-Bretton Woods period.

Regression-Parameter-Instability Tests.—We now investigate whether the change of the exchange-rate regime has induced other structural changes, leading to instability in the regression coefficients. Due to the differences in the volatility of some of the structural disturbances, we use weighted least squares. Thus, the parameter-instabil-

[13] It is noteworthy that the error term in the relative price equation is stable across exchange-rate regimes. This result seems to be in contrast to that in Baxter and Stockman (1989) who find that the real exchange rate displays higher volatility in the flexible-rate period. Yet the reason for the difference is the different measure used: we use the relative price of imports in the United States, rather than the real exchange rate.

ity tests are conditioned on nonconstant variances across regimes.

First, we test whether the long-run responses in the system as a whole are the same for both periods. This amounts to testing for the significance of the slope dummies associated with $\mathbf{\Phi}$ in (17). The LR statistic for this hypothesis, which is asymptotically distributed as $\chi^2_{[36]}$, is 28.96, which is much less than the approximate 5-percent critical value. Thus, there appears to be no significant structural change in the long-run responses.

Next, we test whether the short-run responses are the same. The test is the same as above but includes both the long-run and the short-run slope dummies. The LR statistic (distributed as $\chi^2_{[72]}$) is 82.28, again less than the 5-percent critical value. Thus, the short-run interactions among the variables have also been the same across exchange-rate regimes.

In considering possible structural shifts, the final hypothesis we want to examine is whether the average growth rates have changed. This can be done by testing for the significance of both the slope and the intercept dummies. The LR statistic (distributed as $\chi^2_{[78]}$) is 96.50. The null hypothesis of no change, therefore, cannot be rejected at the 5-percent significance level.

In a VAR system with six variables and two lags, the number of parameters is quite large, and therefore a question may arise as to whether the tests for regression-coefficient shifts reported above for the system as a whole are powerful enough. In addition, due to the different behavior of money across exchange-rate regimes predicted by almost all models, the stability of the coefficients in the money equation (or lack thereof) is interesting in its own right.

Therefore, we also conducted equation-by-equation tests of parameter stability using weighted least squares. We omit the relevant test statistics for the sake of brevity. The null hypothesis of no shift in the long-run and short-run coefficients, as well as mean growth rates, clearly is not rejected for any equation at the 5-percent significance level (or even at much higher significance levels). Of course, our money variable is expressed in relative terms, and therefore, the results do not preclude the possibility that the dynamic interactions of the individual countries' nominal variables with other variables are different across exchange-rate regimes. Yet our results do indicate that, for this to be the case, the changes in the interactions must be very similar across countries.

Given nonconstant variances of the fundamental disturbances, we find no evidence whatsoever of any structural shift between the pre-1973 fixed-exchange-rate period and the post-1973 flexible-exchange-rate period in the estimated regression coefficients. The long-run responses, the short-run dynamic interactions, and the mean growth rates of all our endogenous variables are stable across exchange-rate regimes. We thus find support for the view that, *for the variables that we focus on*, there are no differences across regimes in the transmission properties of economic disturbances.

C. *Structural VAR Estimates*

Conditional on nonconstant variances but regression coefficient stability, we now turn to the results from the retrieval of the structural VAR, (16). We present below the estimated $\mathbf{C}(1)$ matrix, plots of the impulse responses, and variance decompositions.

Long-Run Responses.—The estimate of the long-run impulse-response coefficient matrix $\mathbf{C}(1)$ is reported in Table 1 along with standard errors which are computed via simulation.[14] There are several interesting features of these results. First, note the asymmetric response of home and foreign outputs to a unit world shock (TW): the response of foreign output growth (0.80) is about half of that for domestic output growth (1.66). Second, the domestic labor-supply shock (TH) has a positive effect on both home (0.70) and foreign (0.29) output growth rates. The latter effect seems consis-

[14]The computer-simulated standard errors reported here and in the rest of the paper involve 1,000 replications.

TABLE 1—ESTIMATES OF LONG-RUN COEFFICIENTS: **C**(1)

	Shocks					
Variables	TH	TW	TF	SF	SP	SM
DNH	1.05 (0.70)	0	0	0	0	0
DYH	0.70 (0.74)	1.66 (0.65)	0	0	0	0
DYF	0.29 (0.61)	0.80 (0.57)	0.66 (0.11)	0	0	0
DYHF	1.13 (0.93)	−0.31 (0.62)	−0.33 (0.16)	0.68 (0.10)	0	0
DQF	0.59 (0.54)	−0.42 (0.35)	0.06 (0.10)	−0.07 (0.08)	0.77 (0.09)	0
DMHF	0.74 (3.41)	−5.06 (2.71)	−0.99 (0.55)	0.37 (0.43)	−1.05 (0.70)	1.31 (0.45)

Notes: Numbers reported in the table indicate the long-run responses of domestic labor growth (DNH), domestic output growth (DYH), foreign output growth (DYF), growth-rate differential of private outputs (DYHF), relative price change (DQF), and growth-rate differential of money balances (DMHF), respectively, to a unit permanent increase in the home supply (TH), the world supply (TW), the foreign supply (TF), the relative foreign fiscal (SF), the relative foreign demand (SP), and the relative money (SM) shocks. Simulated standard errors of the estimates based on 1,000 random draws are in parentheses.

tent with an old assertion that "when the U.S. sneezes, Europe gets pneumonia" and indicates some long-run spillover effects to other countries of U.S. supply shocks. Third, the negative response of the ratio of money supplies to the world shock (−5.06) indicates that foreign money supply is much more sensitive to this shock than domestic money supply. Also, the responses of this same variable to country-specific shocks (0.74 to TH and −0.99 to TF) are consistent with positive long-run money–output comovements.

While most of the signs of the estimated coefficients in the **C**(1) matrix are consistent with the predictions of our theoretical model, there are two puzzles. One is that while domestic relative to foreign output rises in response to the world shock, the ratio of domestic to foreign *private* output (DYHF) falls. The response of the relative price (DQ), though, is consistent with a fall in DYHF. Second, there is hardly any response of the relative price to a change in the size of the foreign government relative to the domestic government.[15]

Two issues with respect to the estimated long-run responses merit further consideration. First, granted the long-run neutrality of money in the theoretical model, is it appropriate to impose the implied zero restrictions on data from 1960–1986? Since the data span 27 years, even if the aggregate supply curve becomes vertical only after a 10–15-year interval or even slightly more, we would argue that the zero restrictions are still correctly imposed. However, there is another consideration. Even if the zero

[15]In principle, it would be interesting to test the overidentifying restrictions on **C**(1) implied by (14) and other interesting hypotheses like symmetric responses (implying $\delta_f = 1$). However, in practice, the standard errors of the off-diagonal elements of the estimated **C**(1) matrix are, in general, fairly large, which makes it impossible to reject any plausible null hypothesis.

elements of **C**(1) are correctly imposed, how sensitive are the estimated values of the off-diagonal elements to the specification of the short-run dynamics?[16] This is certainly a relevant issue, and therefore, we do not focus on the estimates of the **C**(1) matrix to distinguish between alternative theories. Rather, we focus on the impulse-response analysis and variance decompositions. As we report below, our conclusions based on these are not overturned by using a slightly longer lag length.

The second issue has to do with cointegration. Note that the dependent variables in the system given by (14) are in first differences and the **C**(1) matrix is triangular, so that the six variables in levels cannot be cointegrated according to our specification. Is this absence of cointegration consistent with the data? We tested for various possible cointegrating relationships using the method of Robert F. Engle and Clive W. J. Granger (1987).[17] The equations and test statistics are quite numerous, and again, for brevity, we omit them and focus only on the conclusions. We first examined whether the ratio of home to foreign output $(y_h - y_f)$ displays stationarity and whether home and foreign private outputs are cointegrated. We found no evidence for either at the 5-percent significance level. Then we investigated whether the ratio of home to foreign output is cointegrated with the ratio of home to foreign private output, $(y_h^P - y_f^P)$, relative price (q), and the ratio of home to foreign money supply $(m_h - m_f)$, either individually or as a group. There was no evidence for this either. Finally we tested whether the ratio of domestic to foreign private output is cointegrated with the relative price and relative money supply, and whether home output and home hours worked are cointegrated. Once again, no cointegration was found. Thus, it seems reasonable to proceed with a model that assumes our six variables are driven by six stochastic trends.

Short-Run Dynamics.—Next we study the impulse responses of the estimated model. Figure 1 presents the impulse-response functions of the *growth rates* of the endogenous variables in response to a one-standard-deviation world supply shock (TW), along with the estimated one-standard-error bands. The standard-error bands are similar in width for responses of the first differences of the variables to all the other shocks (not reported for the sake of brevity).

The responses of the *level* of the variables can be seen more clearly by accumulating the first-difference responses, such as those in Figure 1. We plot then, in Figures 2–4, the responses of the levels of the endogenous variables to a one-standard-deviation shock for the three supply shocks in the model.

Figure 2, for example, plots the levels responses to a one standard-deviation world supply shock (TW). The similar, smooth and gradual responses of domestic output (YH) and foreign output (YF) are easily discernible. Note that the domestic output response after about 20 quarters is almost equal to the size of the shock, indicating a one-to-one long-run effect on this variable. These estimated smooth dynamic responses of domestic and foreign output are quite similar to the simulated responses to random-walk technology shocks reported in some real-business-cycle calibrations (e.g., King et al., 1988). At first sight, the negative response of the labor input (NH) in the short run appears puzzling, since calibrations discussed above indicate a positive response due to effects on work effort induced by a rise in the anticipated real rate of return. However, such calibrations are in response to an *exact* random-walk disturbance. In response to a gradual (slowly diffusing) permanent improvement in technology, the simulation in King et al. (1989) shows the predicted response of the labor

[16]See Lawrence J. Christiano and Martin Eichenbaum (1990) for a detailed discussion of this point.

[17]The Engle-Granger test for cointegration of a variable Y with a set of variables $\mathbf{Z}$ involves running an ordinary least-squares regression Y on $\mathbf{Z}$ and applying an augmented Dickey-Fuller test for unit roots on the residuals. If the null hypothesis of a unit root in the residuals is accepted there is no cointegration. Because of the first-stage regression, the critical values tabulated by Dickey-Fuller are not valid. Instead, critical values of Engle and Byung Sam Yoo (1987) must be utilized.

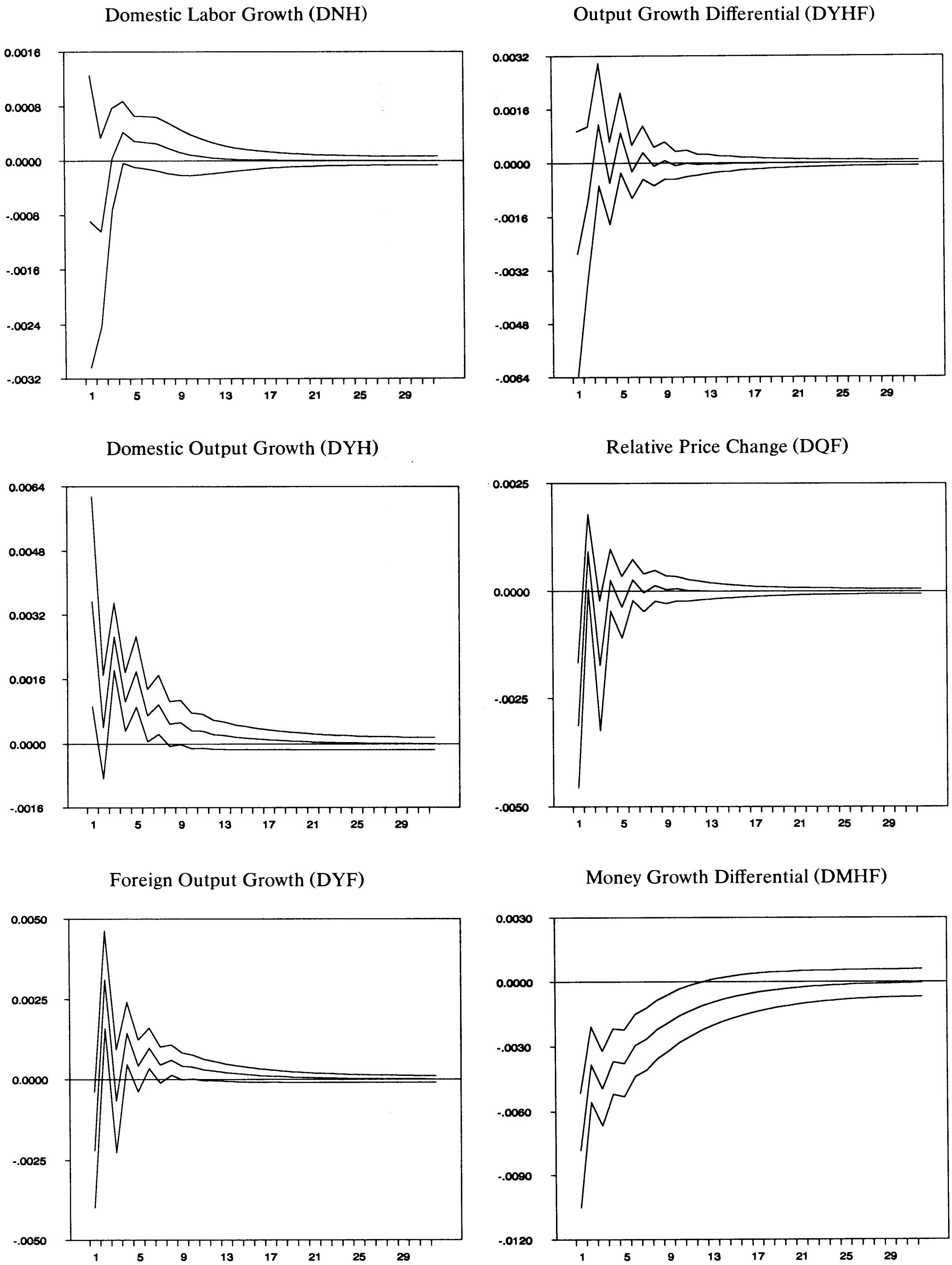

FIGURE 1. IMPULSE RESPONSES OF FIRST DIFFERENCES TO THE WORLD SUPPLY SHOCK

Note: These figures display impulse responses and the associated one-standard-error bands of the first differences of the six transformed variables to a one-standard-deviation world supply shock, TW (the size of which is 0.00354), over a 32-quarter forecast horizon.

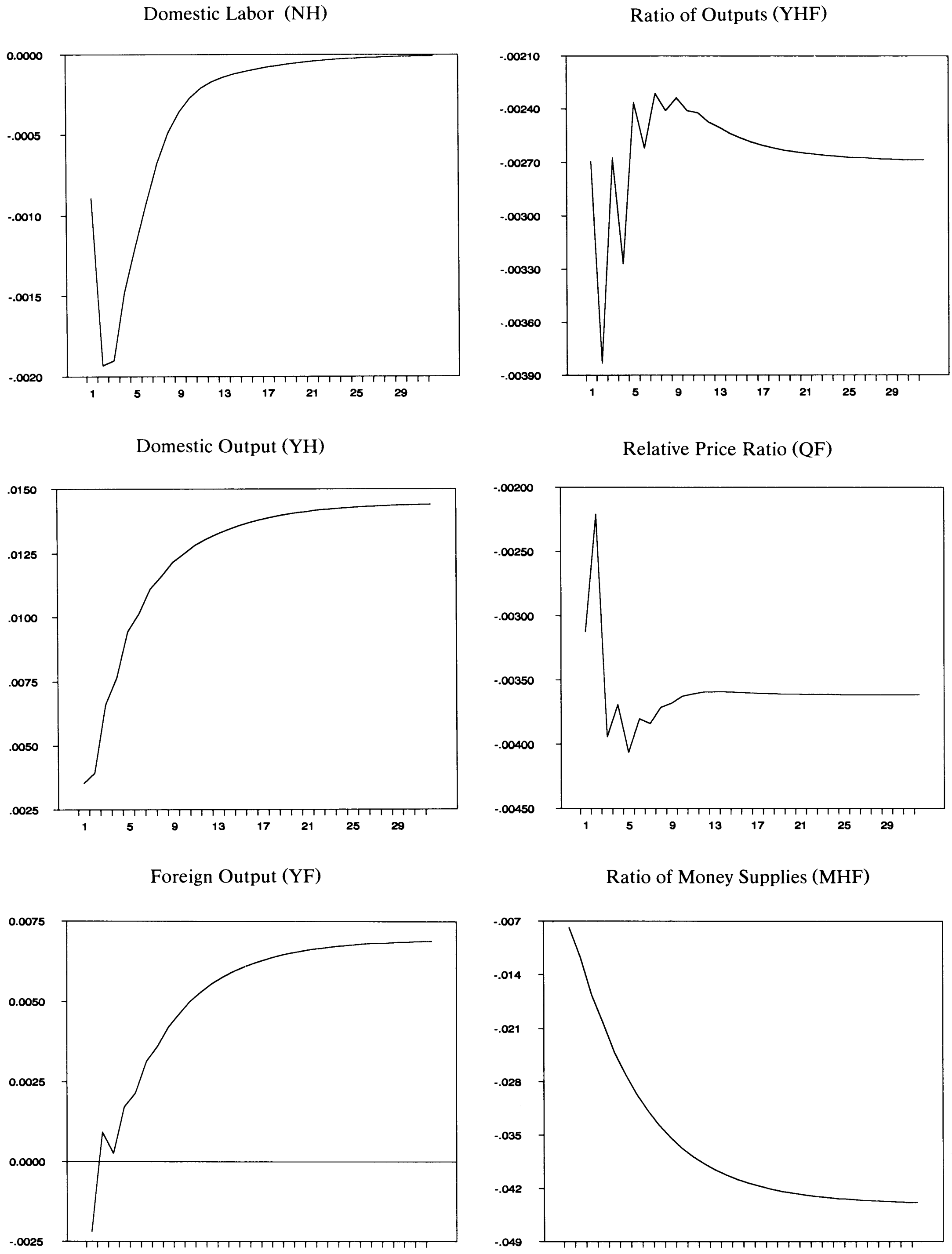

FIGURE 2. IMPULSE RESPONSES OF LEVELS TO THE WORLD SUPPLY SHOCK

Note: These figures display impulse responses of the levels of the six transformed variables to a one-standard-deviation world supply shock, TW (the size of which is 0.00354), over a 32-quarter forecast horizon.

input to be remarkably similar to our estimated response of NH in Figure 2.[18]

Next, consider the response of the variables to a one-standard-deviation domestic supply shock (TH), reported in Figure 3. Two interesting features emerge. First, the domestic labor input (NH) adjusts relatively quickly to its long-run value. Second, the responses of domestic and foreign outputs (YH and YF, respectively) are hump-shaped and reminiscent of the long-swing adjustment of the sort found by Shapiro and Watson (1988) for the United States.

A comparison of Figure 4 with Figure 3 shows that the responses of the variables to a foreign supply shock (TF) do not mirror those to the domestic supply shock (TH), except for the case of the relative money-supply variable (MHF). In particular, the responses to TF (Fig. 4) are much less smooth. The effect on YF is initially big. It then goes down quickly (but remains positive) and approaches its long-run value from below.

The responses of the variables to the three relative shocks are omitted for the sake of brevity. However, three main results are worth mentioning here. First, the responses to an increase in the relative size of the foreign government (SF shocks) are quite consistent with an impact effect of one-to-one crowding out of private spending, and then short-run expansionary effects over time of the type discussed in David A. Aschauer (1989) and Robert J. Barro (1989). Second, an exogenous increase in the ratio of domestic to foreign money supplies (SM shock) has a negative effect on the ratio of home output to foreign output. This seems to indicate either that money is not expansionary even in the short run or that there are substantial spillover effects of monetary policy in one country to output in other countries. Finally, a relative preference shock toward the foreign good (SP) increases the relative price of imports in the United States (QF), as one would expect.

The main results from the impulse responses can now be summarized. They are (i) the smooth and gradual responses of each country's output to the world shock as predicted by modern growth models highlighting stochastic trends; (ii) the "hump-shaped" response of U.S. output to shocks originating in the domestic labor market of the type found by Shapiro and Watson (1988); (iii) the negative and then positive response of U.S. hours to a world supply shock (indicating that technology shocks may be slowly diffusing); (iv) the one-to-one crowding-out on impact and subsequent expansionary effects of fiscal policy changes; and (v) the fairly close correspondence between the relative price and relative private output responses to the various shocks. One puzzling aspect of the results is the negative response of relative outputs to an exogenous relative money-supply change. Given that, for the most part, the responses can be reasonably interpreted, the next question to ask is: which shocks are most important?

Variance Decompositions.—We provide evidence on the relative importance of the various shocks in the model by performing variance decompositions. The results are presented in Table 2. The table presents the percentage of the variance of the k-quarter-ahead forecast error of a particular endogenous variable that is due to each of the shocks, for $k = 1$, 2, 4, 8, 16, and 32, along with the associated standard errors.

The most striking result to emerge is that, even in the short run, supply shocks (TW, TH, and TF) are very important in explaining the behavior of the real variables we consider and the ratio of money supplies as well. Looking at the individual supply shocks more closely, we conclude that, even when a common world shock (TW) is allowed for, country-specific supply shocks (TH and TF)

[18]The intuition behind the negative response of the labor input to a slowly diffusing permanent technological innovation is the following. Even though the anticipated real rate of return rises, it is expected to rise by even more in the near future before returning to its steady-state value. This means that the intertemporal substitution effect from the far future to the present can be overshadowed by the intertemporal substitution effect from the present to the near future. Note that there is nothing in our empirical specification that prevents the world shock from being slowly diffusing. We only impose unit roots on our disturbances, not exact random-walk processes.

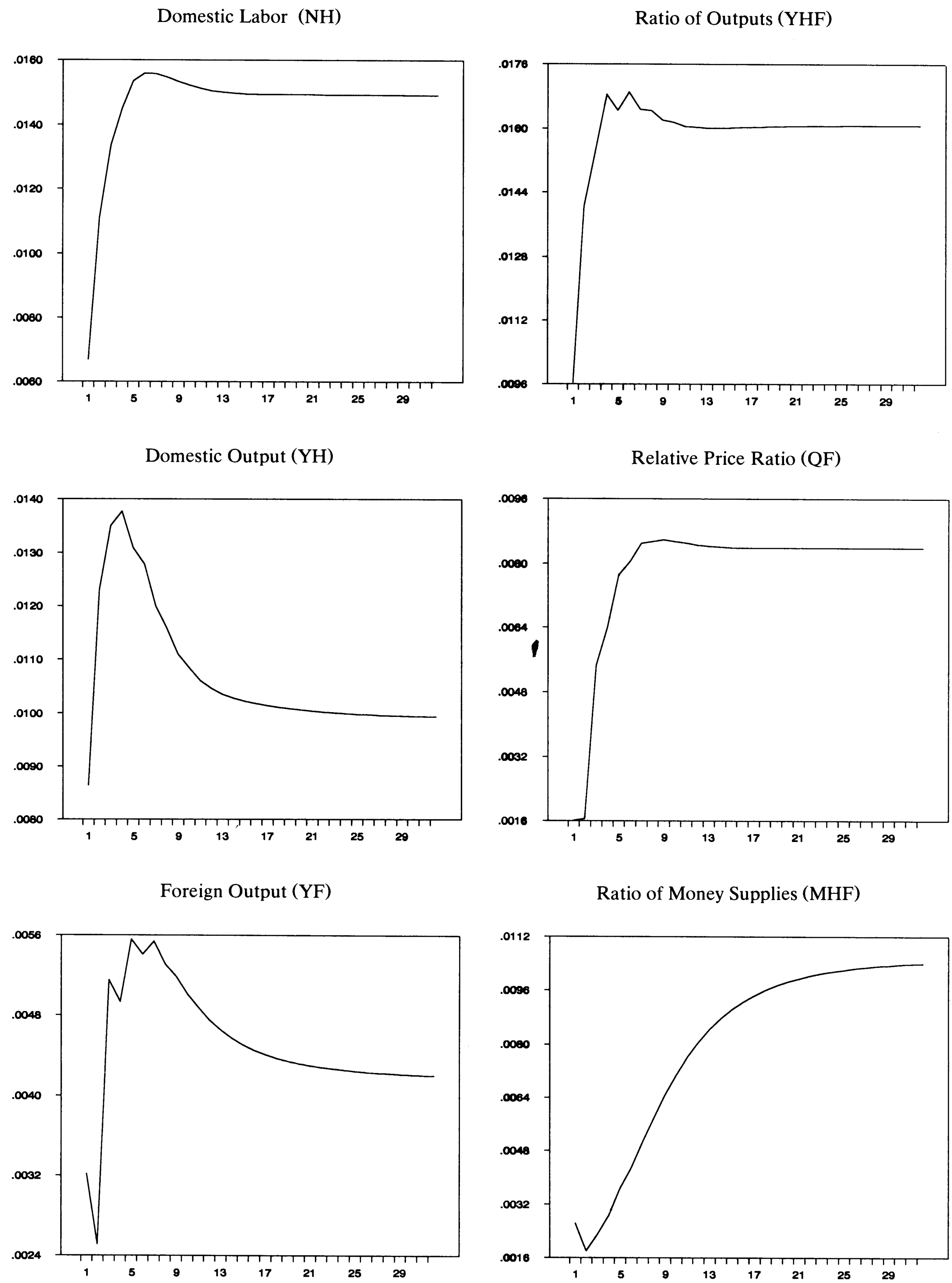

FIGURE 3. IMPULSE RESPONSES OF LEVELS TO THE DOMESTIC SUPPLY SHOCK

Note: These figures display impulse responses of the levels of the six transformed variables to a one-standard-deviation domestic supply shock, TH (the size of which is 0.00669), over a 32-quarter forecast horizon.

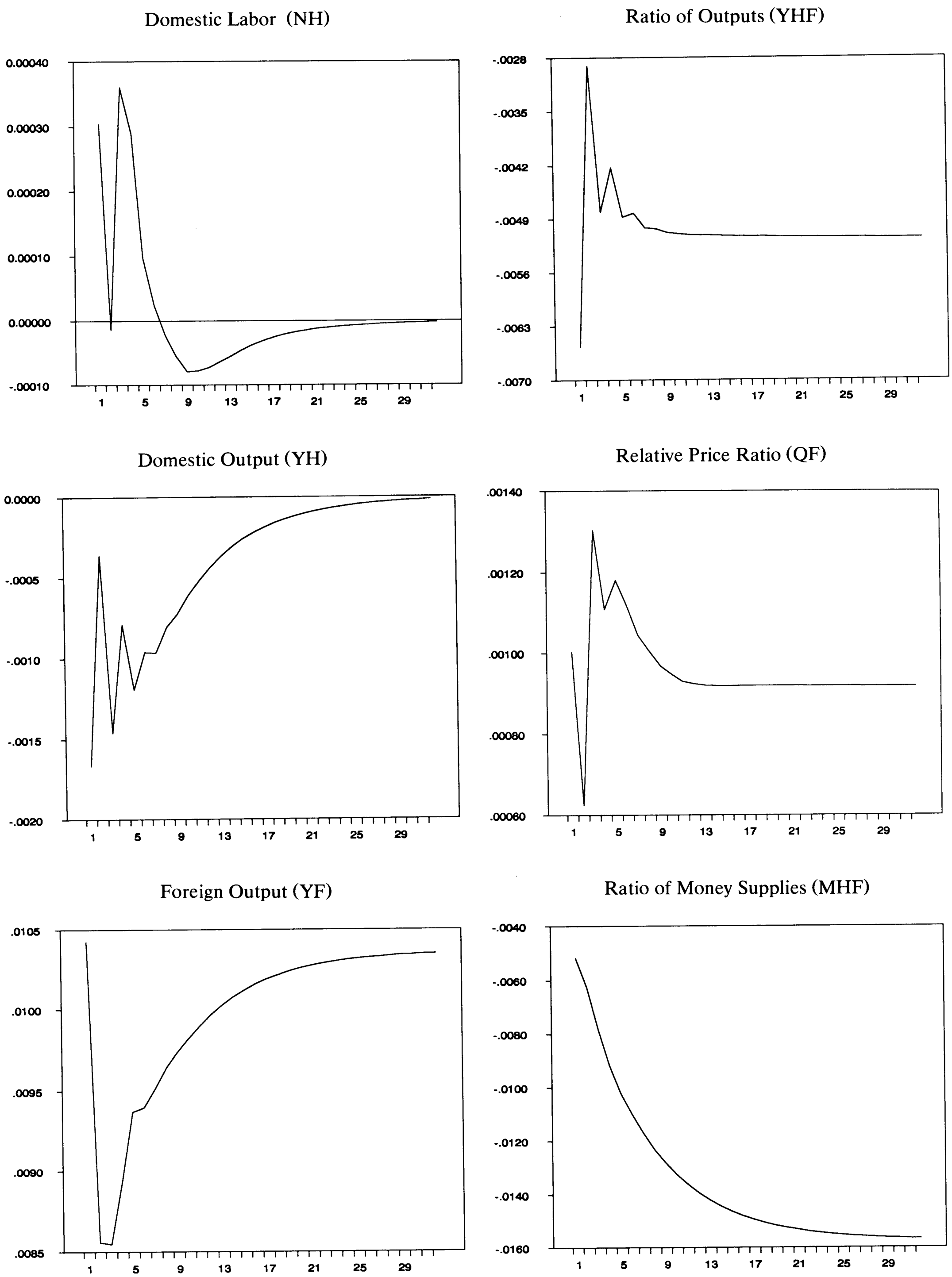

FIGURE 4. IMPULSE RESPONSES OF LEVELS TO THE FOREIGN SUPPLY SHOCK

Note: These figures display impulse responses of the levels of the six transformed variables to a one-standard-deviation foreign supply shock, TF (the size of which is 0.00104), over a 32-quarter forecast horizon.

TABLE 2—VARIANCE DECOMPOSITION OF THE SIX TRANSFORMED VARIABLES (WITH STANDARD ERRORS IN PARENTHESES)

Quarters	TH	TW	TF	SF	SP	SM
	Percentage of variance of the rate of domestic labor growth (DNH) due to:					
1	83.3 (17.1)	1.4 (13.4)	0.1 (4.1)	2.5 (4.9)	1.1 (3.9)	11.3 (11.3)
2	85.8 (15.3)	2.5 (13.3)	0.2 (3.3)	2.1 (3.3)	0.9 (2.8)	8.3 (7.8)
4	83.3 (13.9)	2.4 (11.6)	0.3 (2.9)	2.6 (3.4)	2.0 (3.3)	9.0 (6.8)
8	83.0 (13.4)	2.6 (11.3)	0.4 (2.9)	2.6 (3.3)	2.0 (3.2)	9.1 (6.6)
16	83.0 (13.1)	2.7 (11.3)	0.4 (2.9)	2.6 (3.3)	2.0 (3.2)	9.1 (6.5)
32	83.0 (12.9)	2.7 (11.1)	0.4 (2.9)	2.6 (3.3)	2.0 (3.2)	9.1 (6.5)
	Percentage of variance of the rate of domestic labor growth (DYH) due to:					
Quarters	TH	TW	TF	SF	SP	SM
1	76.9 (16.8)	12.9 (17.5)	2.8 (6.0)	6.3 (6.5)	0.0 (2.7)	0.8 (6.2)
2	77.2 (15.9)	11.1 (15.5)	3.9 (5.0)	6.7 (5.6)	0.1 (2.5)	0.7 (5.2)
4	70.0 (13.9)	16.3 (13.4)	4.8 (4.7)	6.4 (4.7)	0.3 (2.4)	2.0 (4.7)
8	67.2 (12.2)	19.0 (11.2)	4.7 (4.4)	6.2 (4.4)	0.6 (2.3)	2.0 (4.4)
16	66.8 (11.7)	19.3 (10.7)	4.7 (4.3)	6.1 (4.3)	0.6 (2.3)	2.1 (4.3)
32	66.8 (11.6)	19.4 (10.7)	4.7 (4.2)	6.1 (4.3)	0.6 (2.3)	2.1 (4.2)
	Percentage of variance of the rate of foreign output growth (DYF) due to:					
Quarters	TH	TW	TF	SF	SP	SM
1	5.6 (5.3)	2.6 (4.1)	59.3 (18.0)	0.5 (3.9)	1.7 (4.2)	30.0 (16.3)
2	5.0 (5.2)	6.7 (5.3)	52.1 (16.9)	1.1 (4.1)	1.7 (4.1)	33.1 (16.1)
4	7.7 (5.2)	7.3 (5.4)	48.6 (15.1)	1.8 (4.4)	2.7 (4.5)	31.5 (14.1)
8	7.8 (5.3)	8.0 (5.7)	48.1 (14.8)	1.8 (4.3)	2.8 (4.5)	31.2 (13.6)
16	7.8 (5.4)	8.2 (5.8)	47.9 (14.7)	1.8 (4.3)	2.8 (4.4)	31.1 (13.4)
32	7.8 (5.6)	8.2 (5.9)	47.9 (14.7)	1.8 (4.3)	2.8 (4.4)	31.1 (13.4)
	Percentage of variance of the growth-rate differential of private outputs (DYHF) due to:					
Quarters	TH	TW	TF	SF	SP	SM
1	24.0 (11.1)	1.8 (5.7)	11.1 (7.8)	56.0 (13.8)	0.7 (3.3)	6.1 (9.5)
2	25.6 (9.9)	1.9 (5.4)	12.8 (7.4)	52.9 (12.7)	0.7 (3.7)	5.8 (8.9)
4	25.4 (9.4)	2.2 (5.1)	13.1 (7.0)	51.1 (11.8)	1.6 (3.9)	6.3 (8.2)
8	25.3 (9.3)	2.4 (5.3)	13.2 (6.8)	50.8 (11.6)	1.8 (4.0)	6.3 (8.0)
16	25.3 (9.3)	2.4 (5.3)	13.1 (6.8)	50.7 (11.6)	1.8 (4.0)	6.3 (7.9)
32	25.3 (9.5)	2.4 (5.4)	13.1 (6.8)	50.7 (11.7)	1.8 (4.0)	6.3 (7.9)
	Percentage of variance of the rate of change of the relative price (DQF) due to:					
Quarters	TH	TW	TF	SF	SP	SM
1	2.8 (4.6)	10.7 (9.1)	1.1 (3.3)	5.0 (4.9)	80.1 (11.4)	0.1 (5.4)
2	2.7 (4.3)	11.0 (8.6)	1.2 (3.4)	4.9 (4.8)	79.0 (11.3)	0.9 (5.8)
4	15.6 (6.9)	11.8 (8.6)	1.4 (3.5)	4.2 (4.1)	66.0 (9.9)	0.8 (4.9)
8	16.9 (7.6)	11.8 (8.6)	1.4 (3.5)	4.1 (4.0)	64.5 (10.1)	1.0 (4.8)
16	16.9 (7.7)	11.8 (8.6)	1.4 (3.5)	4.1 (3.9)	64.5 (10.2)	1.0 (4.7)
32	16.9 (8.0)	11.8 (8.6)	1.4 (3.5)	4.1 (3.9)	64.5 (10.2)	1.0 (4.7)
	Percentage of variance of the growth-rate differential of money balances (DMHF) due to:					
Quarters	TH	TW	TF	SF	SP	SM
1	4.3 (15.9)	38.5 (17.1)	16.8 (11.9)	5.7 (7.4)	6.6 (6.9)	27.8 (15.5)
2	3.8 (14.1)	38.0 (15.8)	14.0 (10.1)	7.6 (5.6)	5.4 (5.5)	31.0 (13.1)
4	3.1 (14.9)	43.6 (16.1)	12.3 (9.3)	6.4 (4.4)	6.0 (5.2)	28.4 (11.9)
8	3.3 (16.1)	47.5 (16.8)	11.1 (8.9)	5.9 (4.0)	5.4 (4.8)	26.7 (11.4)
16	3.6 (17.0)	48.3 (17.2)	10.7 (8.8)	5.7 (4.0)	5.2 (4.7)	26.2 (11.4)
32	3.6 (17.3)	48.3 (17.4)	10.7 (8.8)	5.7 (4.1)	5.1 (4.7)	26.2 (11.5)

originating in the labor market comprise the single most important source of output fluctuations. Specifically, even over very short forecast horizons, about 70–75 percent of the variance of U.S. output growth and 50–60 percent of foreign output growth are due to own supply shocks. In addition, the world shock explains about 20 percent of U.S. output growth, but very little of foreign output growth.[19] The standard errors indicate that the confidence intervals associated with these results are not too wide.

Another notable aspect of the results in Table 2 is that the relative money-supply shock (SM) is important for the rest of the world and explains about 25–30 percent of foreign output fluctuations in the short run but is not important at all for U.S. output. This result is somewhat troublesome, since it is difficult to come up with an economic model in which money would be important in one country but not in others. One possible explanation might be that money has expansionary effects in the short run in both countries but that the relative money-supply shock is dominated by foreign money shocks in our sample. Since nominal shocks at the individual-country level are not separately identified in our model, it is beyond the scope of this paper to attempt to examine this explanation formally. By way of casual empiricism, though, it is noteworthy that our aggregate of the foreign money growth has a substantially higher variance than that of domestic money growth.

Finally, although statistical criteria indicated a lag length of two, we also estimated the model with four lags to allow for richer dynamics. The findings are quite similar, except for two items. Specifically, in the four-lag model the foreign supply shock becomes less influential as a source of changes in the ratio of domestic to foreign outputs, whereas the relative fiscal shock is now more important in explaining the movements of the relative price of foreign goods. These two differences do not affect any of our important results, and our overall conclusions are unchanged.

[19]According to our theoretical model, in the long run the variance of Solow residuals should correspond to the variance of our world technological innovation (τ), as can be seen from (3) and (4). Our calculations show the standard deviation of τ to be substantially lower than that of Solow residuals calculated by others (see e.g., Donna M. Costello, 1990). This is not as surprising as it appears, since, in our model, short-run productivity changes as measured by conventional Solow residuals can be a function of all the different fundamental disturbances to which the economy is subject.

D. *Alternative Interpretation and Model*

One of the striking features of our results (which are reminiscent of Shapiro and Watson's [1988] benchmark model) is the apparently negligible role played by aggregate demand disturbances, even in the very short run. Following the work of Edward F. Denison (1974) and others, it might be regarded as plausible that most of the long-run growth in output is due to permanent shocks originating in the labor market. However, the finding that the latter also account for a large fraction of the short-term variation in output is quite surprising. Another surprising result from our variance decompositions is that, while relative preference shocks explain a large faction of the movements in relative prices, they do not have much predictive power for explaining short-run movements in relative quantities. These concerns raise a general question: is it possible that what we interpret as aggregate supply disturbances may be capturing, somewhat at least, the effects of aggregate demand (AD) disturbances? This possibility can arise in two ways, each of which we discuss below.

Common Aggregate Demand Shocks.— One problem might arise because our AD disturbances (the fiscal and money shocks) are expressed in relative terms. If shocks to fiscal policy and money supply show little independent movement across countries (i.e., ϕ_f, ϕ_h, π_f, and π_h close to unity), the short-run effects of these would appear as responses to what we have termed the world technology shock. In that case, the world shock could be interpreted as some linear combination of world aggregate supply and world AD disturbances. Thus, strictly speaking, our results indicate that country-specific AD shocks are not very important. However, if such shocks form a substantial proportion of AD disturbances, our results then do provide evidence against the importance of short-run movements in aggregate demand.[20] Moreover, our results indicate no statistically significant differences across exchange-rate regimes in the responses to our world shock, which we would not expect if this shock was primarily representing world aggregate demand changes.

Model with Trend-Stationary Hours.—The second possible source of misspecification is the treatment of the total hours variable. Whether total hours contain a unit root or are trend-stationary is a controversial issue: the formal statistical tests for this variable give borderline results and are sensitive to the choice of sample period. If hours are in fact trend-stationary and we difference them, then we create a moving-average component which may bias the results.

Shapiro and Watson (1988) argue that this bias is unlikely to be large, and they predict that similar results would be obtained if the growth rate of hours were replaced by detrended hours as a variable. Indeed they do broadly find the same results when this is done, as do we. In our case, the importance of the labor-input shock in explaining domestic output movements in the short run goes down from about 65–75 percent to about 40–50 percent, but is still large, while the importance of the technology shock goes up to about 35–45 percent from 10–20 percent.

However, the interpretation of the results can be completely different. For example, Shapiro and Watson assume that, in the case where hours are trend-stationary, the entire short-run deviation from the trend value can be attributed to AD disturbances. If we make the same assumption, AD disturbances (which cause movements along a given labor-demand schedule) explain about 40–50 percent of the short-run movements in output over a 1–8-quarter horizon. This is a strong assumption, however, since technology shocks and short-run labor-supply shocks can also cause hours to move around the long-run trend value.

Our structure is rich enough to enable us to relax this strong assumption, although with some sacrifice in terms of a clear-cut distinction between world and country-specific productivity shocks. Thus, consider an alternative model with a slightly different long-run causal ordering, when hours are assumed to be trend-stationary. The model is still given by the system in (1), but now the variables in $\mathbf{X}_t$ (in order) are Δy_{h}, Δy_{f}, $\Delta(y_{\mathrm{h}}^{\mathrm{P}} - y_{\mathrm{f}}^{\mathrm{P}})$, Δq, $\Delta(m_{\mathrm{h}} - m_{\mathrm{f}})$, and $n_t - d_0 - d_1 t$, where $d_0 + d_1 t$ refers to the time trend in total hours. The fundamental disturbances in $\boldsymbol{\xi}_t$ now are τ_1, τ_2, $(1-\phi_{\mathrm{h}})\eta_{\mathrm{f}} - (1-\phi_{\mathrm{f}})\eta_{\mathrm{h}}$, $\varepsilon_{\mathrm{f}} - \varepsilon_{\mathrm{h}}$, $(1-\pi_{\mathrm{f}})v_{\mathrm{h}t} - (1-\pi_{\mathrm{h}})v_{\mathrm{f}t}$, and τ_{h}. The $\mathbf{C}(1)$ matrix is still assumed to be lower-triangular. The innovation τ_1 now has the interpretation that it is a permanent technological disturbance that represents both world technology shocks and permanent productivity disturbances specific to the United States. The τ_2 innovation is a permanent productivity disturbance in the rest of the world that is orthogonal to U.S. technical innovation. The relative fiscal, relative preference, and relative money shock have the same interpretation as before while τ_{h} is an exogenous short-run shock to the labor input.

In this alternative specification, τ_{h} can have one of two interpretations. It represents either a short-run labor-supply shock, or the component of the AD disturbance (say, a movement along the labor-demand curve) that is correlated across countries, since the effects of relative policy shocks have been kept fixed separately.

The noteworthy results from this alternative specification are as follows (tables omitted for the sake of brevity): over a 1–8-

[20]Although our fiscal and monetary shocks for individual countries are not separately identified, some casual empiricism does support the conjecture that the bulk of aggregate demand changes are independent across countries. The simple correlations between the U.S. and rest-of-world growth rates of money and between U.S. and rest-of-world changes in the ratios of government purchases to output are only -0.16 and 0.14, respectively.

quarter horizon, (i) the labor input shock (τ_h) explains about 45 percent of short-run domestic output growth, while the technology shock and relative money shock account for about 15 percent and 20 percent, respectively; (ii) 45–55-percent of foreign output growth is explained by the own country-specific supply shock (τ_2), and about 35 percent by the relative money shock; (iii) the relative preference shock is still important for explaining relative price behavior, but not relative quantity movements; and (iv) about 50–75 percent of the deviations from trend in hours are accounted for by own shocks (τ_h), and up to 20 percent by relative money shocks. Overall, the stability results across exchange-rate regimes for this model are the same as before. The one exception is that the null hypothesis of constant mean growth rates across regimes is now rejected at the 5-percent significance level. Since the interactions between variables are still stable across exchange-rate regimes, the employment-supply-shock interpretation of the τ_h disturbance seems more plausible than the world-aggregate-demand-disturbance interpretation.

There are two conclusions we reach based on the estimation of the alternative model. First, our results on the importance of supply shocks appear to be reasonably robust to the trend-stationary specification of hours. Second, even if we consider a scenario most favorable for the importance of aggregate demand disturbances (namely, all of the exogenous shock to total hours, τ_h, consists of movements along the labor demand curve, and there are *no* differences across exchange-rate regimes in the transmission properties of AD changes), the importance of productivity shocks in the short run is still not trivial (about 25 percent for domestic output).

IV. Conclusions

This paper has used a structural macroeconometric model to study the sources of international economic fluctuations in an open-economy setting. The model allows country-specific supply shocks originating in the labor market and a common world supply shock, as well as relative fiscal, relative money, and relative preference shocks, to affect the two countries. These fundamental disturbances are identified by using long-run restrictions. The restrictions are not arbitrary causal orderings but are motivated by a simple real-business-cycle model of the world economy with exogenously given fiscal sectors in each country. The effects of the fundamental shocks on the endogenous variables in the short run are left unrestricted and are estimated using quarterly postwar data on the U.S. economy and an aggregate of five large OECD countries.

An important set of our empirical findings relates to the role of exchange-rate regimes. Our results in this respect go beyond previous studies that have focused exclusively on the statistical properties of the data across regimes. Two results based on a pre- and post-1973 division of the data emerge. First, the null hypothesis that the variances of the fundamental differences we identify are the same across exchange-rate regimes cannot be accepted. Specifically, the U.S. country-specific and world supply shocks and the relative fiscal-policy shock display higher volatility in the post-1973 floating-rate period. In contrast to this, the foreign supply shock, relative preference shock, and relative money shock have constant variances. Second, all the coefficients in the structural VAR we estimate are invariant to the exchange-rate regime. This latter result indicates that the interactions between outputs, relative prices, and the ratios of fiscal and monetary variables in the United States and the rest of the world have been the same across the pre-1973 fixed-exchange-rate period and the post-1973 flexible-exchange-rate period. Thus, we find no evidence of differences in the transmission properties of economic disturbances across exchange-rate regimes.

We have also presented evidence on the relative contribution of the various shocks we identify to economic fluctuations in the United States and our five-nation OECD aggregate. Our results strongly suggest that supply shocks are very important in generating international economic fluctuations. When we consider the contribution of the individual supply shocks separately, it is apparent that, even though the world shock is important, own country-specific supply shocks originating in the labor market are the leading source of output fluctuations. The importance of the labor-input shock goes down somewhat when the trend-stationary specification of hours is used, but it still remains high. We take this finding to imply that macroeconomists need to pay much more attention to the labor market—in particular, to identifying sources of permanent and country-specific changes in the natural rate of unemployment—to explain economic fluctuations in open economies. The evidence on the role of money in generating short-run fluctuations is less clear-cut: it seems to matter for the rest of the world, but not for the United States.

Finally, we wish to point out that our study has looked at a limited number of variables. In particular, analyzing the behavior of nominal exchange rates and the price levels in individual countries is beyond the scope of our paper, since the only nominal variable we consider (money supply) is expressed as a ratio of one country's value to the other. It would be interesting to extend our results to examine interactions between countries and across exchange-rate regimes for these individual nominal variables and other real variables, such as consumption, investment, and trade flows.

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