MICHAEL T. BELONGIA
PETER N. IRELAND

The Own-Price of Money and the Channels of Monetary Transmission

Traditionally, the effects of monetary policy actions on output are thought to be transmitted via monetary or credit channels. Real business cycle theory, by contrast, highlights the role of real price changes as a source of revisions in spending and production decisions. Motivated by the desire to focus on the effects of price changes in the monetary transmission mechanism, this paper incorporates a direct measure of the real own-price of money into an estimated vector autoregression and a calibrated real business cycle model. Consistent with the RBC view of the monetary transmission mechanism, both approaches reveal that movements in the own-price of money are strongly related to movements in output.

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TRADITIONALLY, THE EFFECTS of monetary policy actions on output are thought to be transmitted via monetary or credit channels. In the former, changes in the nominal quantity of money affect spending directly, whereas, in the latter case, open market operations induce changes in interest rates that affect spending; in some models, credit rationing can have a secondary effect on output as well. All of these traditional models rely on some form of nominal price or wage rigidity to draw the hypothesized links between money, interest rates, and output.

Flexible-price real business cycle models, in contrast, emphasize that changes in real prices can be a consequence of monetary policy actions and that economics

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MICHAEL T. BELONGIA *is the Otho Smith Professor of Economics at the Department of Economics, University of Mississippi* (*E-mail:* mvpt@earthlink.net). PETER N. IRELAND *is a professor of economics at the Department of Economics, Boston College* (*E-mail:* irelandp@bc.edu).

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most naturally focuses on these price changes as the source of revisions in spending and production decisions. Unfortunately, estimation or calibration of real business cycle models to illustrate this theoretical proposition has been handicapped by the apparent absence of a continuous time series of price data that would reflect changes in the stance of monetary policy. Thus, the perceived lack of any price data flowing directly from actions taken by the Federal Reserve's Open Market Committee (FOMC) has led authors to examine proxies and isolated incidents rather than directly observable price changes over a broad span of time. For example, Romer and Romer (1989) extracted anecdotal evidence from transcripts of FOMC meetings to identify six episodes of negative monetary policy shocks associated with attempts to reduce inflation; the dummy variable that marks these decisions explains a substantial portion of the variation in output. In a similar vein, Plosser (1991) treated increases in reserve requirements between 1937 and 1939 as an increase in the cost of deposit creation and examined that period for fluctuations in output associated with this change in the setting of one monetary policy lever.[1]

Motivated by the desire to focus on the effects of price changes on output as a consequence of monetary policy actions, this paper studies two closely related models of the monetary transmission mechanism. One of these models is empirical, the other theoretical. In both models, neither the nominal quantity of money nor interest rates is linked directly to output but, instead, changes in the real own-price of money are associated with aggregate fluctuations. To this end, we first discuss how the own-price of money can be measured in a manner consistent with results in modern aggregation theory and, in so doing, produce a continuous time series of real prices that can be used in the empirical work. The characteristics of the resulting data then are examined, in overview, within an empirical VAR framework that allows changes in the two traditional measures of monetary policy—the nominal money stock and the nominal interest rate—and changes in the real price of money to affect output separately.

We then discuss a theoretical real business cycle model and modify it to incorporate the real price of money as well. Our model includes features used previously by King and Plosser (1984), Freeman (1986), Freeman and Huffman (1991), Coleman (1996), and Freeman and Kydland (2000) to explain the observed money-output correlations without appealing to any form of nominal price rigidity. In our model as in theirs, policy-induced movements in the monetary base (or "outside money") have only small effects on output; technology shocks, however, generate demand-induced movements in demand deposits (or "inside money") that lead in turn to a positive correlation between a broad monetary aggregate and output. But while our model shares these features with those used previously, it also goes beyond existing

1. Although some might regard the policy stance index of Boschen and Mills (1995) as being representative of this concept, it is arbitrary in its construction and does not focus directly on a single real concept, such as reserve requirements. Also see Kydland and Prescott (1990) for another study motivated by the idea that variables other than the nominal quantity of money are primarily responsible for fluctuations in real activity.

models by specifically highlighting a role for financial-sector shocks that give rise to large movements in the own-price of money and, simultaneously, large movements in output as well. Once specified, this model is calibrated and time paths for data generated by it are compared against actual output data. We find that the synthetic and actual data evolve along similar paths and that a direct measure of the real own-price of money appears to offer a new channel of monetary policy transmission, consistent with real business cycle theory, but apart from either the monetary or credit views.

1. MEASURING THE OWN-PRICE OF MONEY

Empirical work in monetary economics typically uses measures of the aggregate quantity of money produced by central banks. These data are called simple sum aggregates because they are unweighted, arithmetic summations of the deposits in the various categories subsumed within the aggregate. The theoretical implications of simple sum aggregation are that each asset in the index is a perfect substitute for every other asset in the group and, as such, the representative consumer is assumed to have a linear utility function.[2] Alternatively, an aggregate quantity of money also can be constructed as an index of the superlative class. Here, the Törnqvist approximation to the Divisia index weights the components of the aggregate by their shares of total expenditure on monetary services.[3] And even though the form of the sub-utility function for money holdings is unknown, the index number will track its value over time as changes in the relative prices of alternative forms of money induce substitutions that alter the expenditure share weights of the components and the quantities held of those deposit categories within the aggregate.

No matter what type of index is chosen to measure the aggregate quantity of money, principles of duality require that each, as a matter of internal consistency, is paired with a precise expression for the corresponding own-price of money. For the case of a linear utility function, the Leontief unit cost function is the price dual. Because the perfect substitution assumption of simple sum aggregation implies that the coefficients of the linear utility function are equal, so too are the coefficients of the Leontief unit cost function.[4] And because of perfect substitutability, maximizing agents will be expected to hold only that monetary asset with the lowest price; as will be shown below, this own-price will take the form of a minimum user cost.[5]

2. Moreover, such an index does not internalize pure substitution effects so that the index value may change even though the value of the monetary service flow from a stock of money holdings is unchanged.

3. As will be seen below, the actual weights are average expenditure shares across periods t and $t-1$.

4. These results and others can be found in the collection of papers in Barnett and Serletis (2000).

5. While it is true that the asset with lowest user cost also will be that earning the highest rate of return, the nonlinear transformation in the user cost formula does not permit simply using maximum rates of return.

In contrast, when the quantity of money is measured by a Divisia index, the own-price of aggregate money will be the share-weighted sum of each asset's user cost.[6] In neither case, however, is the own-price of money merely an interest rate chosen to represent the opportunity cost of foregone interest on a single alternative to money holdings.

To illustrate these points, the construction of a superlative index number begins by calculating total expenditures on the components of the aggregate. That expenditure (E_t) can be written as $E_t = \Sigma x_{it} p_{it}$. When aggregation is over monetary assets, x_{it} is the nominal quantity of monetary asset i at t and p_{it} is its real price; equivalently, one can construct the expenditure magnitude by using real quantities and nominal prices. Because monetary assets are durables that do not perish during the period from use, their prices are their user costs. The formula for the real user cost of a monetary asset, derived by Barnett (1978), can be written as:

$$p_{it} = (R_t - r_{it})/(1 + R_t) \,,$$

where R_t is a benchmark rate of return and r_{it} is the own rate of return on the ith component at time t.[7]

With the user cost and quantity data, the expenditure share on asset i is $s_{it} = x_{it} p_{it}/E_t$. A Divisia quantity index in continuous time (and its Tornqvist discrete time approximation) computes the growth rate of the aggregate as the share-weighted average of its components and satisfies[8]

$$\text{dlog}\, X_t = \sum 0.5^*(s_{it} + s_{it-1}) d \log x_{it} \,,$$

while the Divisia price index P_t in continuous time satisfies

$$\text{dlog}\, P_t = \sum 0.5^*(s_{it} + s_{it-1}) d \log p_{it} \,.$$

2. BEHAVIOR OF THE SIMPLE SUM AND DIVISIA PRICE DUALS

Figure 1 illustrates the behavior of percentage changes in the real price of money as measured by nominal price duals deflated by the geometric mean of the GDP

6. Goldfeld (1987, p. 135) intuited as much when he pointed out that:
"Measuring this implicit rate of return is no easy matter. Matters are considerably more complicated when broader definitions of money are used and some components of money bear explicit interest, especially when there are several components each carrying a different rate of return. The aggregate own rate of return would then be a complex function of interest rates, shares, and elasticities of each of the components."

7. In principle, the benchmark rate of return would be the return on a completely illiquid asset with the example being the return on human capital in a world without slavery. As a matter of practice, the benchmark rate has been chosen such that it produces nonnegative user costs. A more general explanation of the issue is offered in Barnett, Fischer, and Serletis (1992).

8. Notice that the Divisia index formula is not self-dual because (X_t,P_t) are not a dual pair; this result was reported by Theil (1967) and occurs because the weights in a Divisia index are *average* expenditure shares across two periods. Because the differences between the Törnqvist approximation to Divisia and the Divisia index are of a third-order magnitude in the changes, studies still use a Divisia index both for quantity and for price and ignore the tiny violation of Fisher's factor reversal test.

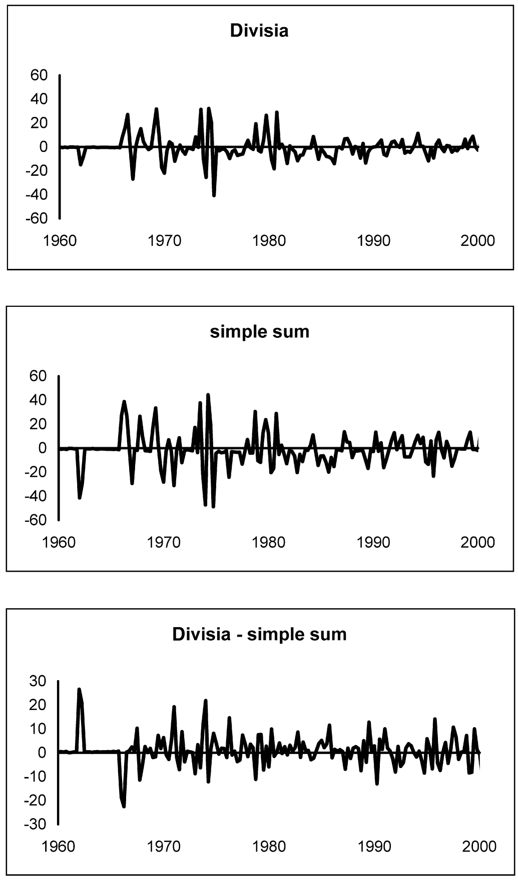

FIG. 1. Growth Rates of Real Divisia and Simple Sum Price Duals for the M1-plus Monetary Aggregate

deflator and the CPI. With a variety of aggregates that might be examined, we have chosen to examine data for simple sum and Divisia measures of an aggregate consisting of M1 assets plus savings deposits. Although this aggregate is not reported by the Federal Reserve, it has been examined by Rotemberg, Driscoll, and Poterba (1995) and named "M1-plus" by Belongia (1996). More important for issues regarding aggregation, however, this grouping possesses the property of weak separability such that it is a candidate for aggregation; by contrast, M2 fails this test.[9] Thus, studies that have created a Divisia measure of M2 still have been in error because they have applied a legitimate index number formulation to a group of commodities that

9. On the basis of parametric (Swofford and Whitney 1987) and nonparametric (Belongia 2000) tests, this asset collection has been shown to be a weakly separable group that meets a sufficient condition for aggregation. In general, rejection of broad aggregates in the U.S., Germany, and Japan appears to be associated with the inclusion of CDs—a *time* deposit—in what is intended to be a *monetary* aggregate.

fails the first test (weak separability) in the construction of an aggregate data series. The simple sum price dual for this asset collection is a mixture of the user costs of other checkable deposits and savings deposits issued by thrifts. An exception to this general result occurred during the period 1983–86, when money market deposit accounts (MMDAs) were reported separately rather than as part of savings deposits; during this interval, the user cost of MMDAs represented the lowest user cost in the simple sum aggregates.

Despite the fundamental differences in the manner each series is constructed, Figure 1 shows that the two follow the same broad patterns; this picture is reinforced by a comparison of values for the means and standard deviations of the series. And, while both series demonstrate considerable variability, augmented Dickey–Fuller tests show that each is stationary. Finally, from an economic standpoint, it is interesting to note that sharp increases in the price of money tend to be associated with the onset of recessions, whereas sharp declines appear to lead economic expansions. A potential explanation for this pattern in the data and more detailed exploration of its economic consequences is the focus of the real business model derived and discussed later.

3. A SMALL VAR MODEL

How the monetary price dual might be associated with aggregate economic activity can be examined using a vector autoregression for three variables: the adjusted nominal monetary base, real gross domestic product, and the real price dual for the Divisia M1-plus aggregate. This model was estimated with quarterly data over a sample spanning 1960:1 through 2001:4. Two lags were used for each variable and experimentation with longer lags did not affect the results in a meaningful way. All variables enter in growth rates.

Before turning to the results, several comments regarding the specification of this small VAR are called for. First, note that here, by including the Divisia price dual in the VAR together with the more conventional measures of real output and nominal money growth, we are doing something fundamentally different from earlier studies, including Rotemberg, Driscoll, and Poterba (1995) and Belongia (1996), that modify popular empirical models by replacing simple sum measures of the money stock with Divisia or similar counterparts: here, by contrast, the addition of the Divisia price dual is intended to capture the effects of changes in the *real price*, rather than the *nominal quantity*, of money, appropriately measured using the theory outlined above.

Second, note that by using the adjusted monetary base as our measure of the nominal money supply, we are implicitly holding reserve requirements fixed throughout all of our experiments. As mentioned above, Plosser (1991) has already identified changes in reserve requirements, interpreted as changes in the tax rate on banking services, as a potential source of output fluctuations in real business cycle models; and, indeed, Manchester (1989) presents VAR evidence consistent with this view.

So here, once again, our focus on direct measures of the real price of money differentiates our work from previous efforts.

Third and finally, to generate variance decompositions and impulse responses described below, we identify structural shocks from reduced form innovations using the recursive ordering scheme suggested above, with the adjusted monetary base listed first, real GDP listed second, and the real price dual listed third. In fact, the covariance matrix for the reduced form innovations comes close to being diagonal, with the largest (in absolute value) correlation between any two innovations being less than 0.07. Hence, permutations of this causal ordering have little impact on the results. Nevertheless, we chose this particular ordering above all others partly to make the links between the empirical model (where the monetary base is listed first in the ordering) and the theoretical model described below (where the monetary base follows a purely exogenous process) as tight as possible and partly to guard against attributing too much influence to the real price dual (listed last in the ordering).

In fact, even under this most conservative identification scheme, a variance decomposition attributes more than 5% of the observed movements in output growth to the real price dual, whereas less than 1% is associated with the nominal monetary base. The impulse response functions displayed in Figure 2 tell the same story. A shock that increases the rate of growth of the nominal monetary base raises output, but only slightly; moreover, 95% confidence bands shown in the same figure indicate that the output response is never statistically significant. A shock that increases the real price dual, on the other hand, generates a more substantial decline in output that appears to be statistically significant as well.

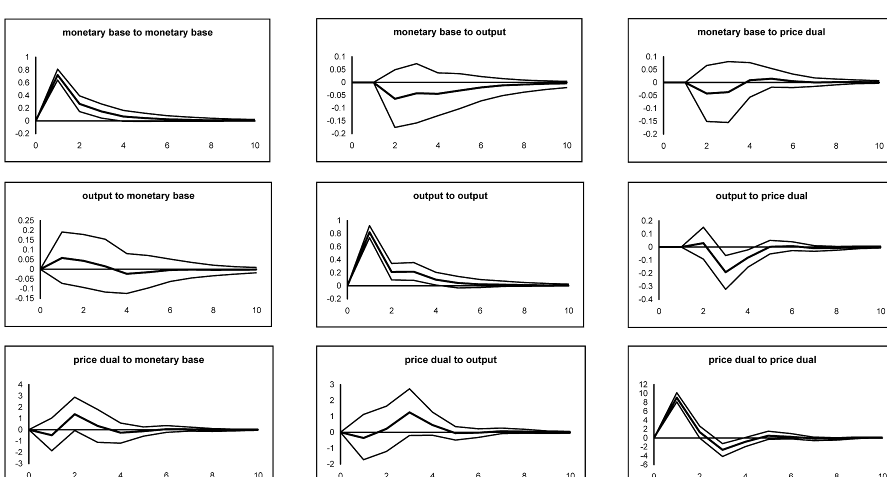

FIG. 2. Impulse Responses from a Three-variable VAR

These empirical findings lend credence to an RBC model, like the one discussed below, that attributes output fluctuations to a change in the real price rather than—or in addition to—the nominal quantity money. Before moving on, however, two modifications are made to the empirical model to highlight the robustness of the results.

First, in Figure 3, the federal funds rate, expressed in percentage point terms, is included as an additional variable in the VAR and is listed third in the causal ordering. Although nominal interest rate movements do not play a direct role in governing the mechanics of the RBC model described below, Bernanke and Blinder (1992), among others, have found an important role for nominal interest rates in forecasting output and, more generally, interest rates play a central role in most Keynesian models of the business cycle. And since the real price dual is constructed using interest-rate data, it is useful to make sure that the effects detected here do not simply reflect the fact that our measure of the real price dual might be a proxy for the nominal interest rate. In fact, Figure 3 confirms Bernanke and Blinder's finding that shocks to the federal funds rate have powerful effects on output; however, the same figure also reveals that shocks to the real price dual have separate effects on output that are of the same order of magnitude and still statistically significant.

Second, in Figure 4, results from our original three-variable VAR are rederived using Anderson and Rasche's (2000) measure of the domestic monetary base in place of our earlier, St. Louis adjusted monetary base measure.[10] The idea behind this check for robustness—quite helpfully suggested by one of the referees—is that foreign holdings of U.S. currency, accounted for in the official St. Louis series but deliberately taken out in the Anderson–Rasche series, would not be expected to influence output domestically: Jefferson (2000), for instance, reports evidence of a stronger association between real GDP and the monetary base once foreign currency holdings are removed. Consistent with Jefferson's findings, shocks to the domestic monetary base appear in Figure 4 to have effects on output that are larger and more significant than those shown previously from the adjusted monetary base in Figure 2. Nevertheless, the output effects of shocks to the real price dual continue to be important—larger and more important than the effects of shocks to the monetary base. Having established the robustness of this key empirical result, we now turn our attention to the theoretical model.

4. THE RBC MODEL

4.1 Overview

The model borrows many elements from real business cycle models with money developed in King and Plosser (1984) and Coleman (1996) as well as from the shopping time model of McCallum and Goodfriend (1987), but extends these earlier

10. Unfortunately, data limitations for the Anderson–Rasche (2000) series limit the sample in this case to the period from 1965:1 through 1999:2.

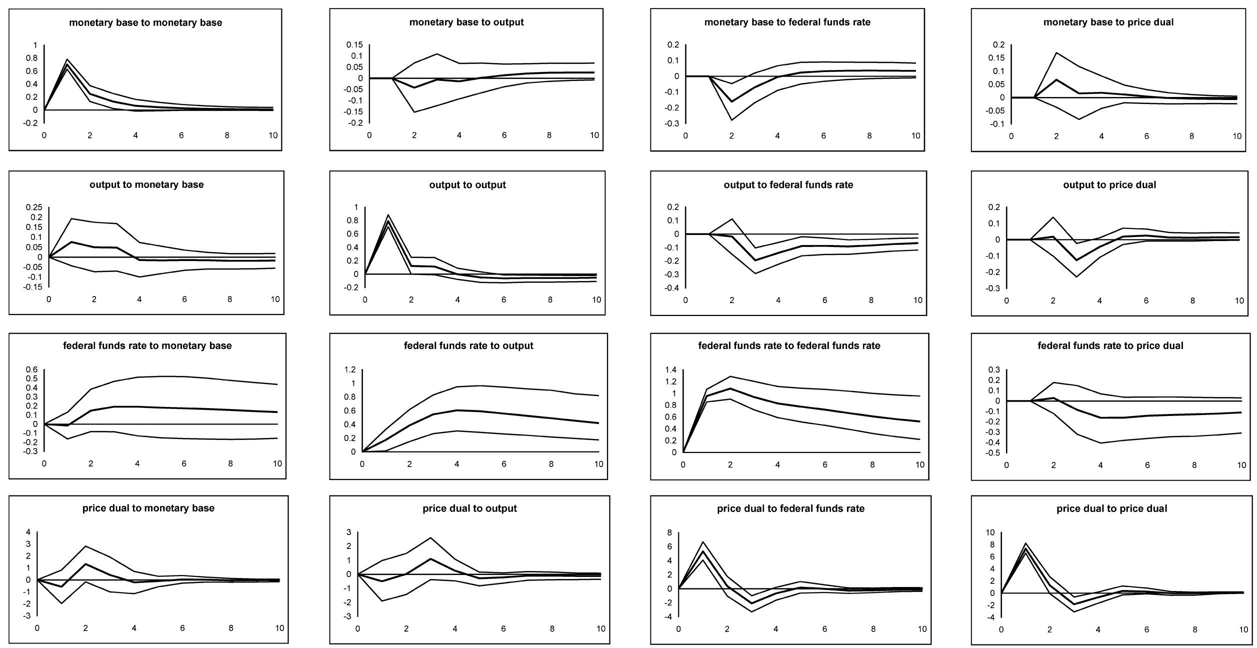

FIG. 3. Impulse Responses from a Four-variable VAR

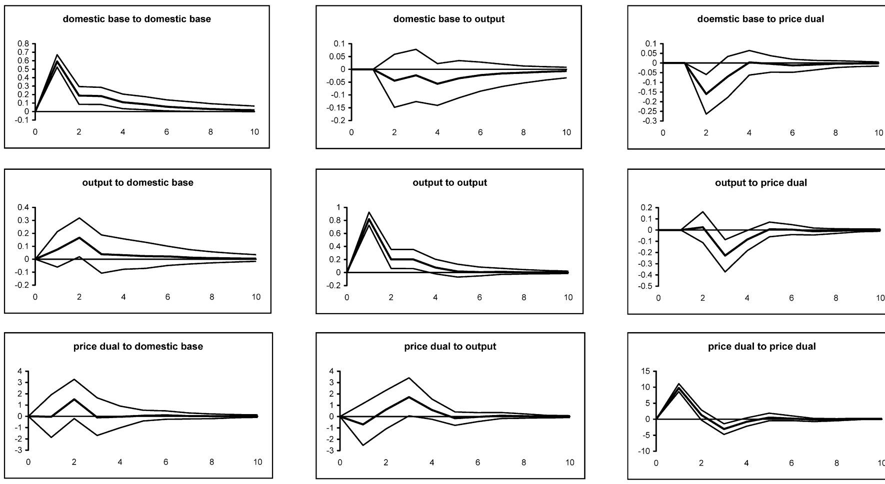

FIG. 4. Impulse Responses from a Three-variable VAR with the Domestic Monetary Base

models to allow for a detailed consideration of fluctuations in the *real price* as well as the *nominal quantity* of money. The economy consists of a representative household, a representative firm, a representative bank, and a monetary authority. The activities of each of these agents are now described in turn.

4.2 The Representative Household

The representative household enters each period $t = 0,1,2,...$ with M_{t-1} units of currency, B_{t-1} bonds, and K_t units of capital. At the beginning of the period, the household receives T_t additional units of currency in the form of a lump-sum transfer from the monetary authority. Next, the household's bonds mature, providing B_{t-1} more units of currency. The household uses some of this currency to purchase B_t new bonds at the price of $1/\ r_t$ dollars per bond, where r_t denotes the gross nominal interest rate between t and $t + 1$.

After this initial bond-trading session, the household is left with $M_{t-1} + T_t + B_{t-1} - B_t/r_t$ units of currency. It divides this currency into an amount N_t to be used to purchase goods and an amount $M_{t-1} + T_t + B_{t-1} - B_t/r_t - N_t$ to be deposited in the bank. The household also borrows L_t dollars from the bank, bringing the total nominal value of its deposits to

$$D_t = M_{t-1} + T_t + B_{t-1} - B_t/r_t - N_t + L_t\,. \tag{1}$$

During period t, the household supplies h_t units of labor and K_t units of capital to the representative firm, receiving credit for $W_t h_t + Q_t K_t$ in return, where W_t denotes the nominal wage rate and Q_t denotes the nominal rental rate for capital. The household purchases output from the representative firm at the nominal price

P_t; it divides its purchases into an amount C_t to be consumed and an amount I_t to be invested. Making these transactions requires

$$s_t = \gamma_N \left(\frac{C_t + I_t}{N_t/P_t}\right)^{\chi_N} + \gamma_D \left(\frac{C_t + I_t}{D_t/P_t}\right)^{\chi_D} \tag{2}$$

units of shopping time, where $\gamma_N > 0$, $\chi_N > 1$, $\gamma_D > 0$, and $\chi_D > 1$. By investing I_t units of output during period t, the household increases its capital stock during period $t + 1$ according to

$$K_{t+1} = (1 - \delta)K_t + I_t\,, \tag{3}$$

where $1 > \delta > 0$.

At the end of period t, the household owes the bank $r_{Lt}L_t$ dollars, where r_{Lt} is the gross nominal interest rate on loans. At the same time, however, the bank owes the household $r_{Dt}D_t$ dollars, where r_{Dt} is the gross nominal interest rate on deposits. After all of these transactions are settled, the household carries M_t units of currency into period $t + 1$, where

$$M_t = N_t + W_t h_t + Q_t K_t + r_{Dt}D_t - P_t(C_t + I_t) - r_{Lt}L_t. \tag{4}$$

The household, therefore, seeks to maximize the expected utility function

$$E\sum_{t=0}^{\infty}\beta^t[\ln(C_t) - \eta(h_t + s_t)]\,, \tag{5}$$

with $1 > \beta > 0$ and $\eta > 0$, subject to the Constraints (1)–(4), each of which must hold for all $t = 0,1,2,\ldots.$

4.3 The Representative Firm

The representative firm hires h_t units of labor at the nominal wage W_t and K_t units of capital at the nominal rental rate Q_t in order to produce Y_t units of output according to the constant-returns-to-scale technology described by

$$Y_t = K_t^{\alpha}(Z_t h_t)^{1-\alpha}\,, \tag{6}$$

with $1 > \alpha > 0$. In Equation (6), the productivity shock Z_t follows a random walk with positive drift:

$$\ln(Z_t) = \ln(z) + \ln(Z_{t-1}) + \varepsilon_{zt}\,, \tag{7}$$

where $z > 1$ and the zero-mean, serially uncorrelated innovation ε_{zt} is normally distributed with standard deviation σ_z. The firm acts to maximize its profits, equating the marginal product of labor to the real wage W_t/P_t and the marginal product of capital to the real rental rate Q_t/P_t.

4.4 The Representative Bank

During period t, the representative bank makes loans worth L_t dollars and accepts deposits worth D_t dollars. It receives interest on its loans at the gross rate r_{Lt} and pays interest on its deposits at the gross rate r_{Dt}. Let θ, $1 > \theta > 0$, denote the required reserve ratio. Assuming that $r_{Lt} > 1$, the bank will never find it optimal to hold excess reserves; hence

$$L_t = (1 - \theta)D_t , \tag{8}$$

will hold for all $t = 0,1,2,....$

During period t, the bank creates deposits with total real value D_t/P_t using a technology that requires $x_t(D_t/P_t)$ units of output, where the financial-sector cost shock x_t follows the first-order autoregression

$$\ln(x_t) = (1 - \rho_x)\ln(x) + \rho_x \ln(x_{t-1}) + \varepsilon_{xt}. \tag{9}$$

In Equation (9), $1 > \rho_x > 0$, $x > 0$, and the zero-mean, serially uncorrelated innovation ε_{xt} is normally distributed with standard deviation σ_x. Hence, the bank's nominal profits during period t are

$$\Pi_t = (r_{Lt} - 1)L_t - (r_{Dt} - 1)D_t - P_t x_t(D_t/P_t). \tag{10}$$

Since competition in the banking industry drives these profits to 0, Equations (8) and (10) imply that

$$r_{Dt} = 1 + (1 - \theta)(r_{Lt} - 1) - x_t , \tag{11}$$

must hold for all $t = 0,1,2,...$, indicating that the financial-sector cost shock x_t impacts directly on the deposit rate r_{Dt} in equilibrium.

4.5 The Monetary Authority

In equilibrium, $M_t = M_{t-1} + T_t$ and $B_t = B_{t-1} = 0$ for all $t = 0,1,2,....$ Substituting these conditions, together with Equation (8), into Equation (1) confirms that in this economy, the monetary base M_t equals currency N_t plus reserves θD_t. Let $\mu_t = M_t / M_{t-1}$ denote the gross rate of money base growth and assume, for simplicity, that the monetary authority conducts policy so that μ_t follows the first-order autoregression

$$\ln (\mu_t) = (1 - \rho_\mu) \ln(\mu) + \rho_\mu \ln (\mu_{t-1}) + \varepsilon_{\mu t} , \tag{12}$$

where $1 > \rho_\mu > 0$, $\mu > 1$, and the zero-mean, serially uncorrelated innovation $\varepsilon_{\mu t}$ is normally distributed with standard deviation σ_μ.

5. SOLUTION, CALIBRATION, AND RESULTS

5.1 Solution

Equations (1)–(12), when combined with the first-order conditions describing the optimizing behavior of the representative household and firm, form a large system of nonlinear stochastic difference equations. After these equations are log-linearized around the system's unique steady state, they can be solved using standard methods, such as those described by Blanchard and Kahn (1980). The theory's implications then can be explored numerically once the model is fully calibrated—that is, once specific values are assigned to each of the model's parameters.

5.2 Calibration

Since the model is built around a standard, real business cycle framework, many of its parameters can be assigned values used throughout the literature on real business cycles. For example, the depreciation rate δ is set equal to 0.025; with each model period interpreted as a quarter year in real time, this choice corresponds to an annual depreciation rate for physical capital of 10%. Similarly, the setting $\beta = 0.99$ implies that the representative household's annual discount factor is 4%. The setting $\eta = 2.7$ implies that the household spends about one-third of its time—or eight hours out of twentyfour—working. Finally, the setting $\alpha = 0.33$ dictates that capital receives a one-third share of national income; labor receives the remaining two-thirds.

Values for other parameters can be assigned so that the model matches key statistics that are computed from the postwar U.S. data. For example, the setting $z = 1.00464$ implies that the annualized steady-state growth rate of output in the model is 1.87%, equal to the average annual growth rate of real, per capita GDP in the U.S. from 1959 through 2001. The setting $\sigma_z = 0.0088$ for the standard deviation of the innovation to the productivity shock makes the standard deviation of output growth in the model equal to the standard deviation of real, per capita GDP growth in the U.S. data.

The parameter θ, which measures the required reserve ratio in the model, is set equal to 0.0475, based on the observation that from 1959 through 2001, the average ratio of required reserves to the deposits included in the M1-plus measure of money is also about 4.75%. Similarly, setting $x = 0.011$ for the average marginal cost of creating deposits allows the steady-state user cost of deposits in the model to match the postwar average of user costs of the deposits included in the M1-plus monetary aggregate. With $\gamma_N = 0.00004$ and $\gamma_D = 0.008$, the steady-state currency-output and deposit-output ratios from the model coincide with the average currency-output and deposit-output ratios in the U.S. data. The setting $\sigma_x = 0.145$ for the standard deviation of the financial-sector cost shock allows the model to replicate the standard deviation of the growth rate of the Divisia M1-plus price dual as measured in the U.S. data. Finally, the parameters of the money supply rule (Equation 12) are set to match the results from a regression of the quarterly growth rate of the U.S. adjusted monetary base, 1959:1 through 2001:4, on a constant and its own lagged value: $\mu = 1.0167$, $\rho_\mu = 0.46$, and $\sigma_\mu = 0.007$.

In the absence of any obvious way of linking the model's three remaining parameters to statistics constructed from the U.S. data, values for these parameters are chosen that seem reasonable or, at least, do not seem unreasonable. The settings $\chi_N = 2$ and $\chi_D = 2$ imply that the shopping-time functions for currency and deposits introduced in Equation (2) are both quadratic. The setting $\rho_x = 0.75$, meanwhile, implies that the financial-sector cost shock is more persistent than the shock to the growth rate of the monetary base, but less persistent than the shock to productivity.

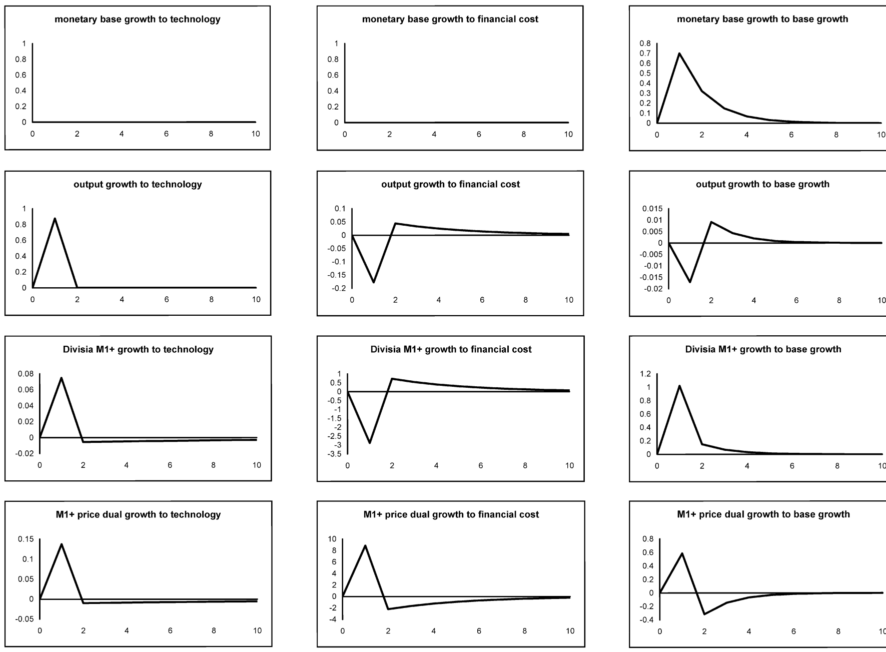

FIG. 5. Impulse Responses from an RBC Model

5.3 Results

Figure 5 displays the theoretical impulse responses of four of the model's variables—output growth, monetary base growth, Divisia M1-plus growth, and the growth rate of the real Divisia M1-plus price dual—to each of the model's three shocks: to productivity, to the cost of creating deposits, and to the growth rate of the monetary base.

In this flexible-price monetary model, as in the basic real business cycle model, productivity shocks represent the dominant source of output fluctuations.[11] A positive technology shock (z_t) permanently increases the level of output; hence, in Figure 5, it temporarily increases the growth rate of output. Under the simple monetary policy rule described by Equation (9), the monetary base is an exogenous variable; hence, it does not respond at all to the productivity shock. Nevertheless, the positive technology shock and the resulting increase in output lead to an endogenous rise in the deposit-currency ratio, just as they do in the previous studies by King and Plosser (1984), Freeman (1986), Freeman and Huffman (1991), Coleman (1996), and Freeman and

11. If, in the VARs presented above, the shock to output growth is interpreted as a productivity shock, then these shocks dominate in the data as well: the three-variable VAR for the adjusted monetary base, real GDP, and the Divisia M1-plus price dual implies that almost 94% of the variance of output growth is attributable to productivity shocks.

Kydland (2000). Here, this rise in the endogenous deposit-currency ratio causes the growth rate of Divisia M1-plus to increase endogenously as well. Therefore, a positive correlation between the growth rates of output and the Divisia monetary aggregate emerges from this model, even in the case where productivity shocks are the sole force driving business cycle dynamics. The nominal interest rate movements set off by the productivity shock lead to an increase in the user costs of both currency and deposits, also leading to a rise in the Divisia M1-plus price dual.

The financial-sector cost shock (x_t) represents the model's closest analog to the innovation in the growth rate of Divisia M1-plus price dual identified earlier in the U.S. data. Just as in the data, this shock generates a decline in output growth. Remarkably, the 0.18 percentage point decline in output growth for the model, shown in Figure 5, coincides almost exactly with the decline in output growth in the data, shown in Figure 2.

In this flexible-price model, which includes none of the traditional Keynesian or monetarist sources of monetary nonneutrality, shocks to the rate of monetary base growth μ_t affect real variables through inflation-tax effects alone.[12] Hence, in Figure 5, the shock to the monetary base leads to a small decline in output growth. Growth in Divisia M1-plus increases, reflecting the increase in currency, reserves, and deposits facilitated by the policy-induced increase in the monetary base. Once again, interest rate movements following the policy shock cause the Divisia M1-plus price dual to rise.

Overall, these impulse responses give rise to the impression that, while the model produces little or no correlation between the exogenous growth rate of the monetary base and the growth rate of output, it does show a positive correlation between the endogenous growth rate of the Divisia M1 monetary aggregate and the growth rate of output. In the model, in fact, the correlation between monetary base growth and output growth is −0.0116; the correlation between Divisia M1-plus growth and output growth is 0.2175. Moreover, the impulse responses from the model and the data suggest that large changes in the real value of the Divisia M1-plus price dual play a key role in generating this endogenous money-output relationship.

6. CONCLUSIONS

While most macroeconomic models incorporate a link between changes in the nominal quantity of money and aggregate fluctuations, real business cycle models emphasize the role of price changes on spending and production decisions. Empirical evaluation of this role has been difficult, however, because it has not been clear how the effects of monetary policy actions could be summarized in a single price variable, especially if the rate of interest is viewed as the price of credit rather than the price of money. This paper offers a solution to the measurement problem by introduction of the economic price dual to the monetary quantity aggregate.

12. A recent study by Kakkar and Ogaki (2002) suggests that inflation-tax effects such as these are important in the U.S. data.

Evaluation of this measure's impact on output growth within an empirical VAR framework indicates that it exerts a stronger influence than that of the monetary base and, in particular, that increases in the own-price of money are associated with declines in output. Meanwhile, a version of the real business cycle model, when suitably modified to allow for an analysis of fluctuations in the same Divisia price dual, has quantitative implications that are remarkably consistent with the data as summarized by the VAR. Taken together, therefore, we believe that these empirical and theoretical results constitute the first body of direct evidence that speaks to the relevance of the RBC view of the monetary transmission mechanism.

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