Expectations, International Business Cycles and the Balance of Payments

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1. INTRODUCTION AND SUMMARY

THIS PAPER DEVELOPS a stochastic version of the monetary approach to the balance of payments (MABP) that incorporates the rational expectations hypothesis. Within the framework cyclical movements of the balance of payments are attributable to the occurrence of country-specific shocks and to endogenously determined differences in expectations of unobserved world variables. With perfect contemporaneous information, the model yields the long-run results of the standard monetary approach. However, in the presence of uncertainty and imperfect information, these long-run results no longer obtain. The analysis stresses the importance of capital mobility in the form of a centralized world capital market that contrasts with the decentralized production and exchange of commodities. This represents an attempt at capturing the popular idea that assets markets may adjust faster than commodity or factor markets. An outcome of this fixed exchange rate model is that prices and activity levels are contemporaneously positively correlated across countries. As such, the analysis is a prelude to an equilibrium theory of the international business cycle and, in particular, the role of alternative monetary institutions, including alternative exchange rate regimes.

A number of the results in this paper are similar to propositions in Lucas [5] and Barro [1] relative to closed economies. This is not surprising since, on the one hand,

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there is a common rational expectations equilibrium framework and on the other, the world viewed as a whole is a closed economy. The major common results are: (a) with full information the world economy (or closed economy analogue) real equilibrium is invariant to the monetary sector—this reflects an absence of built-in nonneutrality effects and that quantity decisions are dependent on perceived movements in relative prices and real rates of return; (b) imperfect current information leads to monetary nonneutrality and procyclical movements in interest rates and prices. Both are desirable outcomes that appear to correspond to broad empirical generalizations.

In addition to these common results, the world economy framework yields a number of new results. First, the money supply process becomes endogenous under fixed exchange rates. This allows a discussion of the nature and transmission of business cycles under a particular monetary standard. The influence of alternative monetary standards and international monetary institutions on the transmission and generation of business cycles has been a neglected subject. Theoretical results derived from a closed economy model with an exogenous statistical process generating the money supply may yield misleading results. With perfect capital mobility and no wealth effects—as in section 4 below—even unanticipated changes in domestic monetary policy do not matter for the determination of the domestic price-output structure. In this example, a competitive economy has a Phillips-curve (or price-output trade-off) that is dominated by movements in world nominal variables and real disturbances. Domestic monetary/portfolio shocks would only affect the balance of payments. To obtain effects of domestic monetary policy under permanently fixed exchange rates would seem to require either some form of a wealth effect (such as discussed in section 5) or allowing for country-specific capital markets and/or the presence of nontraded goods. This would permit domestic prices and interest rates to deviate from their world counterparts. The main issue here is to provide an analytically tractable framework that incorporates the costs, regulations, uncertainty, and imperfect information that lead to the existence of domestic capital markets. This is beyond the limited scope of this paper. Second, the framework embodies an equilibrium rational expectations model of the balance of payments. It is shown that the results derived from an application of the monetary approach obtain only in the special case of full current information. With imperfect current information, the role of expectations as a factor in balance of payments determination becomes crucial. In particular, the distinction between anticipated and unanticipated magnitudes is essential in determining the impact of domestic monetary policy on the balance of payments. Consequently, as an empirical phenomenon, the balance of payments responds to the new information contained in currently observed variables in much the same manner as market determined flexible exchange rates.

2. A STOCHASTIC VERSION OF THE MABP

The analysis below embodies two notions: (i) commodity arbitrage is imperfect, but (ii) countries are linked by the existence of a world capital market. The building

block of the model is a stochastic equilibrium version of the monetary approach to the balance of payments[1] with a Lucas-type aggregate supply function (see [5] or [11]).

Consider a world consisting of a continuum of countries, indexed by θ, operating under a system of permanently fixed exchange rates. Tastes and the production technology are the same across countries. Demand and supply are subject to random disturbances of two varieties, global and country-specific. Prior to trade, all countries share the same ex ante price distribution, representing a common reservation price across all agents. However, the uneven allocation of world demand across countries leads to both aggregate and relative price movements. To agents located in θ, the perceived relative price is the transactions price in θ compared with the expected world price level. The idea here is that commodity arbitrage is imperfect—implicitly, search is costly—leading to a dispersion of prices. This type of effect is discussed in Lucas [4, 6].

In addition to production and exchange, agents also visit a world consump-loan market. In contrast to the decentralization of production, the global loan market clears in an integral sense. There is a world rate of interest that adjusts to maintain world portfolio balance. Agents in any specific country take the world nominal rate as being competitively determined: given the country-specific state of the world, they rearrange their portfolio on the world market at the ruling interest rate. While the nominal rate is the relevant rate of return for portfolio allocation, the relative price affecting intertemporal quantity decisions is the anticipated real rate of return. For agents located in θ, the expected real rate is the current transactions price in θ relative to the discounted—at the world nominal rate—expected average price in the next period. Ex ante, all countries have an identical expected real rate. However, ex post, the allocation of agents and the realization of disturbances will generate a distribution of expected real rates across countries.

More formally, consider the following:

$$y_t^s(\theta) = b_1^s[p_t(\theta) - Ep_t|I_t(\theta)] + b_2^s Er_t(\theta)|I_t(\theta) + u_{1t} + e_{1t}(\theta) \tag{1}$$

$$y_t^d(\theta) = -b_1^d[p_t(\theta) - Ep_t|I_t(\theta)] - b_2^d Er_t(\theta)|I_t(\theta) + u_{2t} + e_{2t}(\theta) \tag{2}$$

$$m_t^d(\theta) - p_t(\theta) = a_1 y_t(\theta) - a_2 i_t + u_{3t} + e_{3t}(\theta) \tag{3}$$

$$m_t^s(\theta) = m_{t-1}^s(\theta) + [R_t(\theta) - R_{t-1}(\theta)] + x_t(\theta) \tag{4}$$

$$m_t^d - p_t = a_1 y_t - a_2 i_t + u_{3t} \tag{5}$$

$$m_t^s = m_{t-1}^s + [R_t - R_{t-1}] + u_{4t} \tag{6}$$

$$x_t(\theta) = u_{4t} + e_{4t}(\theta) \tag{7}$$

$$Er_t(\theta) = p_t(\theta) - (Ep_{t+1}|I_t(\theta) - i_t) \tag{8}$$

$$\theta = 1, 2, \ldots; a_i, b_i, > 0 \ (i = 1, 2);$$

[1]The standard analysis [2, 3, 8] uses a deterministic setting with world variables exogenous. Here, there is an explicit stochastic framework with expectations and world variables endogenous.

where (except for the world nominal rate of interest) all variables are measured in logs, and the a's and b's are elasticities ($d \equiv$ demand, $s \equiv$ supply). Variables with a θ identify representative country θ values. $I_t(\theta)$ refers to the θth information set and is partitioned into local and common information: $I_t(\theta) = \{p_t(\theta); i_t, I_{t-1}\}$, and I_{t-1} contains lagged values of all aggregate (global) variables.

Equations (1)–(8) capture the physical environment discussed above. In (1), (2) aggregate demand and supply in country θ respond to the perceived relative price of the country θ commodity and to the expected real rate of interest as defined in (8). The $e_k(\theta)$, $k = 1, 2$, are country-specific real shocks, while the u_k denote global real disturbances which affect all countries equiproportionately by shifting global aggregate demand and supply schedules. By contrast, the country-specific disturbances sum to zero. Note that wealth effects are absent from (1), (2), a restriction which is relaxed in section 5 below.

Equations (3) and (5) are, respectively, standard portfolio balance schedules for the representative θ country and the world. The common world interest rate implies perfect capital mobility or perfect substitutability of bonds issued by different countries. Given the world nominal rate, i_t, and the representative country's price-output combination (3) determines the level of the domestic money stock. Further, given the time path of transfers (domestic credit) by the monetary authorities—as determined by (7)—equations (3) and (4) determine the level of international reserves $R_t(\theta)$ held by the representative country.[2] With a fixed exchange rate policy rule the monetary authorities in the representative small country can only determine the composition of the monetary base as between domestic credit and international reserves. Note that the world portfolio balance schedule only involves aggregate variables. Given the world price level, income, and the global portfolio shock, the world rate of interest adjusts so that the world money stock is willingly held. The latter—an unweighted geometric average of individual country stocks—evolves according to (6), growing at the same rate as world reserves except for the average transfer, u_{4t}.

In sum quantity decisions in the individual country are based on perceived ments in relative prices and are affected by expectations of the time path of the world price level. This will imply that agents will be forming expectations of the world variables—world money stock, portfolio shifts, real income—that are the determinants of movements in the world price level.

3. PRELIMINARY SOLUTION

From (5) impose world portfolio balance and invert to obtain the equilibrium value of i_t:

$$i_t = [p_t + a_1 y_t + u_{3t} - m_t]\, a_2^{-1}, \tag{9}$$

[2]The reserves multiplier is normalized to one, as are exchange rates. The effects of allowing for multiplier differences across countries can be captured by varying the stochastic process generating monetary transfers.

where the bracketed variables are currently unobserved. Given the equilibrium value of i_t in (9), portfolio equilibrium for the representative country determines the evolution of the stock of international reserves. Equating (3) to (4), using (6) and the definition of $x_t(\theta)$ from (7) we get

$$\begin{aligned}[R_t(\theta) - R_{t-1}(\theta)] = (p_t(\theta) - p_t) + a_1(y_t(\theta) - y_t) \\ - (m_{t-1}(\theta) - m_{t-1}) + (R_t - R_{t-1}) \\ + (e_{3t}(\theta) - e_{4t}(\theta)).\end{aligned} \tag{10}$$

The global portfolio shock u_{3t} does not affect the relative excess demand for money and consequently has no implications for the determination of the behavior of reserves for the individual country. Expression (10) summarizes the essential content of the MABP (see Johnson [3], Mussa [8], and the papers in [2]). The representative small country gains (loses) reserves relative to the world, to the extent that its price level and real income are higher (lower) than the corresponding world averages. Positive country-specific portfolio shocks ($e_{3t}(\theta) > 0$), which imply higher desired real balance holdings, are directly related to international reserve holdings, while monetary transfers in excess of the world average imply a loss of reserves.

To solve for the representative country price-output combination, equate (1) to (2) and substitute for $Er_t(\theta)|I_t(\theta)$ using (8) and (9). This will involve the aggregate pair, p_t, y_t. Aggregate with respect to the country-specific shocks to obtain the latter. Finally, substituting back into the equilibrium expressions for $p_t(\theta)$ and $y_t(\theta)$, yields solutions such that domestic and world portfolio balance hold, as well as world commodity balance. The resulting expression for the representative country price level is

$$\begin{aligned}p_t(\theta) = A_1 Ep_t|I_t(\theta) + A_2 Ep_{t+1}|I_t(\theta) + A_3 Ep_t|I_t + A_4 Ep_{t+1}|I_t \\ + A_5(m_t - u_{3t}) + A_6 u_{1t} + A_7 u_{2t} + A_8[e_{2t}(\theta) - e_{1t}(\theta)].\end{aligned} \tag{11}$$

In (11) the terms $Ep_t|I_t$ and $Ep_{t+1}|I_t$ denote world average across countries of the current and next period's expected world prive level.[3] Equation (11) implies that, ex ante, all countries have the same expected price so that there would be no deviations of the local price in θ from either the world average or from that in another representative country. Further, the deviation of country θ's price from the world average is accounted for by two factors: differential information—as embodied in the terms $[Ep_t|I_t(\theta) - Ep_t|I_t]$ and $[Ep_{t+1}|I_t(\theta) - Ep_{t+1}|I_t]$—and the zero mean

[3]In (11),

$$A_1 = b_1 A_8,\ A_2 = b_2 A_8,\ A_3 = -b_2 B_1 A_8,\ A_4 = -b_2 B_2 A_8,\ A_5 = -b_2 B_3 A_8$$
$$A_6 = -[1 + b_2 B_4]A_8,\ A_7 = [1 - b_2 B_5]A_8,\ A_8 = [b_1 + b_2]^{-1}$$
$$b_1 \equiv b_1^s + b_1^d,\ b_2 \equiv b_2^s + b_2^d, \text{ and the } B\text{'s arise in (12)}$$
Note that $A_1 + A_2 = 1, A_3 + A_4 + A_5 = 0.$ (A.1)

relative excess demand shock. Finally, country-specific portfolio and/or monetary disturbances do not appear in (11) indicating that unless such shocks influence expectations of the world price level, they possess no implications for the time path of the home price level.

The implied solution for the world nominal rate of interest, given that both world portfolio balance and commodity market equilibrium prevail, is[4]

$$i_t = B_1 Ep_t|I_t + B_2 Ep_{t+1}|I_t + B_3[m_t - u_{3t}] + B_4 u_{1t} + B_5 u_{2t}. \tag{12}$$

Equation (12) only involves aggregative variables, with the cross-parameters restriction that a rise in all nominal variables leaves the rate of interest unchanged: $B_1 + B_2 + B_3 = 0$. If expectations were exogenous, so that $Ep_t|I_t$ and $Ep_{t+1}|I_t$ could be held constant, (12) would imply that an increase in the world money stock would depress the interest rate, a liquidity-type effect. However, as will be seen below, foreseen changes in m_t will alter $Ep_t|I_t$ and $Ep_{t+1}|I_t$ to result in a neutral impact on i_t. Further, since global aggregate demand and supply shocks have differential impacts on the world price-output pair, (12) distinguishes between their effects on the world interest rate.[5]

The price solutions in (11) and (12) are associated with equilibrium solutions for the quantity variables in the model. In particular, consider the expressions for relative outputs and the distribution of reserves across countries:

$$\begin{aligned} y_t(\theta) - y_t = {} & (b_1^d b_2^s - b_2^d b_1^s)A_8[Ep_t|I_t(\theta) - Ep_t|I_t) - (Ep_{t+1}|I_t(\theta) \\ & - Ep_{t+1}|I_t)] + [b^d e_{1t}(\theta) + b^s e_{2t}(\theta)]A_8 \end{aligned} \tag{13}$$

$$\begin{aligned} [R_t(\theta) - R_t] = {} & BA_8[B_1(Ep_t|I_t(\theta) - Ep_t|I_t) + B_2(Ep_{t+1}|I_t(\theta) - Ep_{t+1}|I_t) \\ & + B_4 e_{1t}(\theta) + B_5 e_{2t}(\theta)] + [e_{3t}(\theta) - e_{4t}(\theta)] + [\ldots]. \end{aligned} \tag{14}$$

These expressions reveal the importance in this framework of differential information. Given the realization of country-specific shocks, the presence of differential

[4]The reduced-form coefficients are

$$B_1 = [b_1 + a_1(b_1^d b_2^s - b_2^d b_1^s)]B^{-1},\ B_2 = [b_2 - a_1(b_1^d b_2^s - b_2^d b_1^s)]B^{-1}$$

$$B_3 = -(b_1 + b_2)B^{-1},\ B_4 = -(1 - a_1 b^d)B^{-1},\ B_5 = (1 + a_1 b^s)B^{-1}$$

$$B = b_2 + a_2(b_1 + b_2) - a_1(b_1^d b_2^s - b_2^d b_1^s),\ b^s = b_1^s + b_2^s,\ b^d = b_1^d + b_2^d.$$

I assume $(b_1^d b_2^s > b_2^d b_1^s)$, so that demand is relatively more responsive to current substitution opportunities. This implies a commodity market equilibrium locus that is upward sloping in interest rate–real income space.

[5]The effect of u_{1t} on i_t depends on the sign of $(1 - a_1 b^d)$, the total elasticity of aggregate demand. Supply shocks imply opposing movements in price-income space. To the extent that aggregate demand is highly elastic, the aggregate supply shock implies a relatively larger output response. Hence, given the world money stock, world portfolio balance equilibrium might require an upward movement in i_t in response to a positive value of u_{1t}. On the other hand, as long as the aggregate supply schedule is upward sloping, aggregate demand shocks would imply positively correlated movements in p and y. Hence, the interest rate effects of u_{2t} are unambiguous.

information leading to a distribution across countries of estimates of the contemporaneous and future world price level results in a deviation of output in the representative country from the world average. Further, note that only the structural parameters of the demand and supply schedules enter the expression in (12) for the distribution of output. Hence, monetary/portfolio factors and associated parameters only matter to the extent that they impact on the formation of expectations. Similarly, output deviations between any two countries are accounted for by the occurrence of a different pattern of relative shocks as well as by different expected real rates of interest. In (14), note that, holding $Ep_t|I_t$ and $Ep_{t+1}|I_t$ constant, an expected permanent increase in the world price level (the same proportionate increase in $Ep_t|I_t(\theta)$ and $Ep_{t+1}|I_t(\theta)$) will have a one-to-one impact on the level of reserves in the individual country. However, if each individual country anticipates a permanent increase in the world price, so that $Ep_t|I_t$ and $Ep_{t+1}|I_t$ rise to the same extent, the desired increase in the global demand for reserves cannot be accommodated in the absence of new creation of international reserves. The same basic forces noted above matter in determining the distribution of reserves: first, given country-specific monetary and velocity shocks, local real disturbances impinge on relative prices and incomes, thereby affecting the level of reserves via their implications for domestic portfolio balance. Second, differential information elicits quantity responses disturbing local portfolio balance and requires an adjustment of the level of international reserves. As an example, consider a shift in relative demand in favor of country $\theta(e_{2t}(\theta) > 0)$. To the extent that this disturbance is not confused with global shocks, expectations of the world price level are unaffected and adjustment requires an increase in the local price, the expected local real rate of interest, and home output. The increase in price and real incomes raises the local demand for money. The desired expansion of the money stock occurs via an increase in international reserves with the monetary authorities passively maintaining the exchange rate.

4. RATIONAL EXPECTATIONS AND INFORMATIONAL EQUILIBRIA

To close the model requires assumptions on the formation of expectations, current information available to agents, as well as a specification of the stochastic processes assumed to generate the error structure. For simplicity, assume that (a) the real global disturbances u_{1t}, u_{2t} follow simple random walks, $u_{kt} = u_{kt-1} + \epsilon_{kt}(k = 1,2)$, and (b) the terms $(\epsilon_{1t}, \epsilon_{2t}, u_{3t}, u_{4t}, e_{1t}, e_{2t}, e_{3t}, e_{4t})$ are mutually and serially uncorrelated normally distributed random variables with zero mean. It follows that global monetary and real disturbances persist in their effects into future periods, while the remaining shocks (including global portfolio shifts) are transitory.

Given these assumptions on the stochastic structure, consider the problem facing agents in the representative country. Agents observe the local market-clearing price $p_t(\theta)$ as well as the world equilibrium rate of interest i_t. These transactions prices are

both subject to the common global monetary/portfolio and real shocks, while, in addition, the local price is also subject to local random shocks. Given the linear structure of the model and the specific stochastic structure, it is natural to conjecture a bivariate solution for $p_t(\theta)$ and i_t of the form

$$\begin{pmatrix} p_t(\theta) \\ i_t \end{pmatrix} = \begin{pmatrix} \Pi \\ C \end{pmatrix} \xi_t, \quad \Pi = [\pi_{00}, \ldots, \pi_{02}, \pi_{11}, \ldots, \pi_{18}] \equiv [\Pi_0 \Pi_1]$$

$$C = [c_{00}, \ldots, c_{02}, c_{11}, \ldots, c_{14}, 0, \ldots, 0] \equiv [C_0 C_1]$$

$$\xi_t = [m_{t-1}, u_{1t-1}, u_{2t-1}, \epsilon_{1t}, \epsilon_{2t}, u_{3t}, u_{4t}, e_{1t}(\theta) \ldots e_{4t}(\theta)]'$$

$$\equiv [\xi_{t-1}, \xi_t], \tag{15}$$

where the subscript 0 identifies coefficients attached to currently predetermined variables and $\binom{\Pi}{C}$ is the matrix of—as yet—undetermined coefficients. Note that the economic structure of section 3 is incorporated in that the vector C of coefficients pertaining to the interest rate solution is constrained: zeroes appear for coefficients attached to country-specific, relative random terms. From (15), the currently unobserved world price level is obtained by simple aggregation,

$$p_t = \bar{\Pi} \bar{\xi}_t$$

$$\Pi = [\pi_{00}, \ldots, \pi_{02}, \pi_{11}, \ldots, \pi_{14}]$$

$$\bar{\xi}_t = [\xi_{t-1}, \epsilon_{1t}, \ldots, u_{4t}]', \tag{16}$$

where the country-specific shocks have been integrated out to zero.

Equations (15) and (16) express the stochastic processes generating prices as linear combinations of the exogenous variables in the model. This underlying linearity and the normality assumption on errors allows us to replace the expectations of the world price level by the linear least-squares forecasts,

$$Ep_t|I_t(\theta) = Ep_t|I_{t-1} + \phi_p[p_t(\theta) - Ep_t|I_{t-1}] + \phi_i[i_t - Ei_t|I_{t-1}]$$

$$Ep_{t+1}|I_t(\theta) = Ep_{t+1}|I_{t-1} + \lambda_p[p_t(\theta) - Ep_t|I_{t-1}] + \lambda_i[i_t - Ei_t|I_{t-1}]. \tag{17}$$

and the regressions coefficients ϕ_p and ϕ_1 satisfy the least-squares normal equations

$$\begin{pmatrix} \sigma^2_{p(\theta)} & \sigma_{pi} \\ \sigma_{pi} & \sigma^2_i \end{pmatrix} \begin{pmatrix} \phi_p \\ \phi_i \end{pmatrix} = \begin{pmatrix} \sigma^2_{p(\theta)} \\ \sigma_{pi} \end{pmatrix}, \tag{18}$$

where $\sigma^2_{p(\theta)}$, σ^2_i, and σ_{pi} are, respectively, the variance of the local price, interest rate, and their covariance; these are easily derived from (15). λ_p and λ_i have to satisfy similar normal equations. It should be noted that since the regressions coefficients ϕ_p, ϕ_i, λ_p, λ_i have to satisfy the least-squares normal equations (18),

they will not be invariant to the stochastic structure of the model as embodied in the variances of the error terms. This is the basis of Lucas's critique [6].

In (17) I_{t-1} denotes the common, to all countries, information on all lagged variables. For simplicity, I have assumed that lagged values of world variables such as m_{t-1} and p_{t-1} are currently known.[6]

In summary, agents in the representative country utilize all currently available information in forming expectations of the world price and its underlying determinants. Information on lagged variables, common to all countries, includes the lagged history of the world and provides an initial forecast of the world price. This forecast is adjusted for the new, contemporaneous information implicit in the local price and the world interest rate which is known to be determined only by global factors. Although the world rate is an aggregative variable, it is not a sufficient statistic in identifying the separate sources of randomness. In particular, it does not permit an identification of monetary/portfolio shocks independently from the global real disturbances.

To proceed, it is instructive to consider the equilibrium solution that prevails in the absence of a signal-extraction problem. That is, suppose that agents know the separate elements of the vector of random variables ξ. This is equivalent to knowledge of the world price and implies that $EZ_{t+j}|I_t(\theta) = EZ_{t+j}|I_t = EZ_{t+j}|I_t^*$ for any random variable, where I_t^* denotes the full current information set.

Substituting from (15) and (17) into the market-clearing conditions (11) and (12) yields identities in terms of the state variables and unique solutions for Π and C. The resulting values of the price level and the expected real rate of interest in the representative country are

$$\begin{aligned} p_t(\theta) &= m_t + a_2 b_2^{-1}[u_{2t} - u_{1t}] - a_1 b_2^{-1}[b_2^s u_{2t} + b_2^d u_{1t}] - (1 + a_2)^{-1} u_{3t} \\ &\quad + [b_1 + b_2]^{-1}[e_{2t}(\theta) - e_{1t}(\theta)] \\ &= p_t + [b_1 + b_2]^{-1}[e_{2t}(\theta) - e_{1t}(\theta)] \end{aligned} \tag{19}$$

$$\begin{aligned} Er_t(\theta)\,|I_t^* &= Er_t|I_t^* + [e_{2t}(\theta) - e_{1t}(\theta)][b_1 + b_2]^{-1} \\ &= [u_{2t} - u_{1t}]b_2^{-1} + [e_{2t}(\theta) - e_{1t}(\theta)][b_l + b_2]^{-1}. \end{aligned} \tag{20}$$

These deviate from the corresponding world values by the country-specific excess demand disturbance $[e_{2t}(\theta) - e_{1t}(\theta)]$. Further, from (14) we have that international reserves evolve according to

$$[R_t(\theta) - R_t] = B_4 e_{1t}(\theta) + B_5 e_{2t}(\theta) + e_{3t}(\theta) - e_{4t}(\theta). \tag{21}$$

This full information solution embodies characteristics that are typical of equilibrium models with rational expectations and price flexibility (e.g. [1, 7, 11]) and

[6]The average expectation of the world price, $Ep_{t+j}I_t$, is obtained by integration, in (17), with respect to the distribution of country-specific shocks.

yields the long-run results of the MABP. In particular, (a) innovations in world excess demand induce a higher real and nominal rate of interest and a positive correlation between the price level(s) and the nominal rate of interest; (b) quantity-theoretic results obtain for the world monetary disturbances: monetary surprises ($u_{4t} \lesseqgtr 0$) are neutral in that neither the nominal nor real rates of interest are affected. There are corresponding one-to-one effects on all prices. It follows that the level and the probability distribution of real activity in the representative country and the world are invariant to monetary innovations. (c) The world nominal rate of interest is directly related to global portfolio shocks ($u_{3t} \lesseqgtr 0$). However, the level and probability distribution of the real rate(s) is invariant to portfolio shocks. Consider, for example, the occurrence of a positive value of u_3 indicating a rightward shift in the world demand schedule for real balances. The world nominal money stock is fixed so that additional nominal balances are not forthcoming. World portfolio balance therefore requires an upward adjustment of the world interest rate, which partially stems the initial increase in demand. However, the attempt by all countries to achieve a larger stock of real balances can only be accommodated by the same proportionate decline in individual prices and, hence, the world price. The decline in prices offsets the increase in the nominal rate. Hence, global portfolio shocks are neutral with respect to the real equilibrium of the world economy. Further, since the global velocity disturbance affects all countries proportionately but leaves the real equilibrium unchanged, the individual country's money stock and the associated level of international reserves are unaffected.

(d) Country-specific excess-demand shocks require an adjustment of relative prices and expected real rates of return. These real shocks induce deviations in country price levels relative to the world average and in relative outputs. As an example, consider a negative excess-demand disturbance, a relative shift in world excess-demand away from country θ's product. This shift induces a decline in equilibrium output since both $p_t(\theta)$ and the expected real rate fall. With the world nominal rate unaffected, domestic monetary equilibrium requires either a decline in the money stock or a redistribution of international reserves away from country θ.

(e) Country-specific monetary transfers (domestic credit movements) and relative portfolio shocks have no impact on the domestic price level, the expected real rate of interest, or output. They only affect the balance of payments and redistribute international reserves between countries. For the representative country, portfolio reshuffling is accommodated at a given interest rate in the world capital market.

In summary, in the presence of complete current information, the level and probability distribution of nominal and expected rates of interest are invariant to changes in the world money stock, which have standard quantity-theoretic implications with respect to prices. Further, expected real rates of interest are invariant to portfolio/velocity shifts. The distribution of international reserves across countries is invariant to global real and monetary or velocity disturbances. For the representative country, movements in the stock of international reserves held by the monetary authority arise from the occurrence of relative (country-specific) real and monetary or velocity shocks. Specifically, monetary transfers that deviate from the world

average transfer generate a redistribution of the given stock of reserves between countries but have no implications for the time paths of prices and real rates of interest. Again, this type of result emerges from models of small open economies in the presence of perfect capital mobility. Finally, the level and probability distribution of activity in the representative country (and hence the world) are invariant to monetary and/or portfolio shocks, so that a separation principle holds.

Consider now the more relevant case in which information is incomplete and in which agents must infer the unobserved world price and global disturbances from the new information contained in $p_t(\theta)$ and i_t. Following the same solution procedure, obtain the following set of nonlinear restrictions on the individual elements of Π and C:

$$\begin{aligned}
&\pi_{11}[1-\alpha_p] = \alpha_i c_{11} + A_6,\ \pi_{12}[1-\alpha_p] = \alpha_i c_{12} + A_7 \\
&\pi_{13}[1-\alpha_p] = \alpha_i c_{13} - A_5,\ \pi_{14} = -\pi_{13} \\
&\pi_{15}[1-\bar{\alpha}_p] = -A_8,\ \pi_{16} = -\pi_{15},\ \pi_{17} = \pi_{18} = 0 \\
&c_{11}[1-\beta_i] = \beta_p \pi_{11} + B_4,\ c_{12}[1-\beta_i] = \beta_p \pi_{12} + B_5 \\
&c_{13}[1-\beta_i] = \beta_p \pi_{13} - B_3,\ c_{14} = -c_{13},
\end{aligned} \tag{22}$$

where

$$\begin{aligned}
&\alpha_p \equiv (A_1 + A_3)\,\phi_p + (A_2 + A_4)\lambda_p,\ \bar{\alpha}_p \equiv A_1\phi_p + A_2\lambda_p \\
&\alpha_1 \equiv (A_1 + A_3)\phi_i + (A_2 + A_4)\lambda_i,\ \beta_i \equiv B_1\phi_i + B_2\lambda_i \\
&\beta_p \equiv B_1\phi_p + B_2\lambda_p.
\end{aligned}$$

Note that the coefficients on the predetermined variables (m_{t-1}, u_{1t-1}, u_{2t-1}) are the same as under full current information and are not reproduced.

Given values for the least-squares regression coefficients $\phi_p,\phi_i,\lambda_p,\lambda_i$—which implies assigning values to σ_ξ^2 and hence summarizing the relative importance of various shocks—we can solve explicitly for the individual coefficients in (22) and obtain the equilibrium time paths for prices, real rates, and quantities.

In comparison with the full information results, (22) reveals that the response of the representative country's price to the occurrence of country-specific shocks to excess demand will, in general, be larger in absolute value. The full information responsiveness obtains only in the degenerate case in which $\phi_p = \lambda_p = 0$, implying that the domestic price contains no relevant information for predicting the world price. In turn the latter result follows only if global shocks have zero variance. An implication is that expected real rates of return, output, and international reserves respond more than would be the case with full information.

A major result in (22) is that global disturbances bear similar coefficients, a reflection of the fact that they are not separately observed. Although agents know

the structure of the underlying model and perceive—correctly—that the world rate of interest is only subject to global disturbances, the observation of i_t is not a sufficient statistic to infer the separate sources of fluctuations in i_t. Specifically, agents know that observed movements and comovements in $p_t(\theta)$ and i_t are induced by common world factors and, in addition, that $p_t(\theta)$ is subject to local sources of randomness. These insights are incorporated in the proposed solution (15) and in the cross-equation restrictions relating coefficients in (22). Nevertheless, observed fluctuations and covariation of $p_t(\theta)$ and i_t cannot be uniquely attributed to the occurrence of specific monetary/portfolio and real shocks to the world economy. Hence, these global random variables bear common coefficients in the equilibrium price and interest rate solutions.

The implications of this result for the monetary neutrality results derived above are severe. Note first that unexpected global monetary shocks now enter the interest rate solution with a nonzero coefficient, which is opposite in sign to the velocity disturbance coefficient: $c_{13} = -c_{14}$. Similarly, global monetary innovations have a corresponding less than one-to-one impact on prices. The interest rate effects of monetary innovations arise from the fact that the latter can no longer be separately isolated as a source of perceived relative price and expected real rate variations. The confusion of monetary and real factors allows the former to emerge as a source of contemporaneous and intertemporal relative price changes. These perceived relative price changes elicit contemporaneous output fluctuations across all countries and consequently impact on aggregate portfolio balance requiring an adjustment of the world interest rate.

An additional implication of interest is with respect to the covariance of the price level and the nominal rate of interest, σ_{pi}. With full information, p_t and i_t would be positively correlated for shocks to global excess-demand, but a negative correlation would obtain for portfolio disturbances. Hence, the covariance between price and the nominal rate would depend on—given that the random shocks are mutually uncorrelated—the variance of portfolio shifts as compared to the variance of excess demand. The variance of monetary innovations did not matter. However, with incomplete current information, the variance of monetary shocks affects the result. In particular, the possibility of confusing monetary and velocity disturbances implies that the covariance of price and the nominal rate now depends on the variance of monetary innovations.

Finally, note that the price coefficients π_{17}, π_{18} attached to domestic portfolio and monetary transfer shocks are zero. Hence, even in the presence of imperfect current information monetary and/or portfolio shocks in the representative economy play no role in the determination of the time paths of local price and the expected real rate of return. These shocks only affect the balance of payments. The absence of effects on the domestic price level, real interest rate, and output is due to two reasons. First, the model of this section does not allow for any real balance effects on demand and supply forcing domestic monetary variables to operate via the channels of interest rates and price movements. Since country-specific portfolio and monetary shocks are uncorrelated with world disturbances, they do not matter for global portfolio balance; there are no possible world interest rate movements, only

portfolio reshuffling. Second, the production and financial structure of the model does not allow for the existence of nontraded goods or for country-specific assets. Allowing for domestic asset markets with locally determined rates of interest would alter the irrelevance proposition for domestic monetary or portfolio disturbances. Suppose that local demand and supply depend on the rate of return on a domestic asset and that the latter is an imperfect substitute—due to domestic capital controls or imperfect information about prospects—for the international asset. Then, monetary and/or portfolio disturbances would affect the relative return on the domestic asset and potentially induce local price and output movements. Such movements would affect the demand for real money balances and we would lose the one-to-one offset on the balance of payments. Further, some interesting effects could also be derived from the potential confusion between global and country-specific sources of disturbances to domestic interest rates. We leave this for future research.

5. UNANTICIPATED MONEY AND THE BALANCE OF PAYMENTS

The assumption of perfect capital mobility and an absence of wealth effects implied that domestic monetary/portfolio disturbances were irrelevant for the determination of the representative country's price-output structure. This section retains the notion that world asset markets are fully integrated but discusses the implications—particularly for the balance of payments—of a wealth effect. Specifically, following the specification in Barro [1], aggregate demand is assumed to be directly related to the unanticipated rate of monetary transfers. To incorporate this effect (2) is written as

$$y_t^d(\theta) = \{\ldots\} + b_3[x_t(\theta) - Ex_t(\theta)\,|I_t(\theta)], \tag{2'}$$

where the dotted term in brackets is the unchanged part of (2) and $b_3 > 0$ is the wealth elasticity of aggregate demand with respect to unanticipated monetary transfers.[7] To the extent that transfers exceed the anticipated rate, the aggregate demand schedule is shifted out and along the given supply schedule.

It is clear from this specification that with full current information so that $x_t(\theta) = Ex_t(\theta)\,|I_t(\theta)$, the real equilibrium of the system is unchanged. For the more relevant imperfect information case, the occurrence of unexpected monetary transfers that are confused with other sources of demand shocks affects the equilibrium values of p_t and y_t and portfolio equilibrium. The main effect is to alter the coefficients attached to monetary variables, namely π_{14}, π_{18}, and c_{14}. With an identical solution procedure it is easy to obtain[8]

$$\pi_{14}(1-\eta_p) = \eta_i c_{14} + A_5 + A_9 + A_{10},\ \pi_{18}(1-\bar{\eta}_p) = A_9$$
$$c_{14}(1-\gamma_i) = \gamma_p \pi_{14} + B_3 + B_6, \tag{23}$$

[7]Recall that $x_t(\theta) = u_{4t} + e_{4t}(\theta)$, so that (2)′ incorporates both an aggregate and a country-specific wealth effect, but with the same elasticity of demand.

[8]The details can be found in the Appendix.

where η_p, $\bar{\eta}_p$, η_i, γ_p, and γ_i incorporate the regression coefficients resulting from the projection of u_4 and e_4 on the observed values of $p_t(\theta)$ and i_t. The presence of an (unexpected) wealth effect destroys the block-recursive character of the model. Since unexpected transfers directly impinge on aggregate demand, these shocks have an impact similar to that of real aggregate demand disturbances. The resulting common expansion in output raises i_t with feedback to the demand and supply schedules. Further, this structural change alters the rationally formed expectations of the world price level as evidenced by the coefficients in (23). As a consequence, the responsiveness of p_t and i_t to global real shocks is reduced, and world output is less responsive to real disturbances.

Given (2′) the reduced-form expression for the balance of payments (BoP) becomes $\Delta R_t(\theta) = \{. \; . \; .\} + B_6[(x_t - Ex_t|I_t(\theta)) - (u_{4t} - Eu_{4t}|I_t)]BA_8$, the dotted terms in brackets denoting the unchanged part of (14). Given expectations of the world price level, and to the extent that the unanticipated domestic transfer exceeds the average unanticipated common transfer $(u_{4t} - Eu_{4t}|I_t)$, the home country will tend to have a BoP surplus (or a smaller deficit). The reason is that country θ's output level will tend to rise relative to the world average implying a relative increase in the demand for real balances. With a fixed exchange rate and given the value of e_4, the tendency will be to generate a smaller BoP deficit. This type of effect can be derived from versions of the MABP that posit the presence of a real balance effect affecting expenditures. However, with rational formation of expectations, this is not the end of the story since expectations are endogenous and adjust to observed changes in $p_t(\theta)$ and i_t. To see this, substitute for the expectational variables to obtain

$$\Delta R_t(\theta) = BA_8(B_1\phi_p + B_2\lambda_p - B_6\phi_{pu4})[p_t(\theta) - p_t] + B_4e_{1t} + B_5e_{2t} + B_6(e_{4t} - Ee_{4t}|I_t(\theta)) + (e_{3t} - e_{4t}), \tag{24}$$

and note that $p_t(\theta) - p_t = \pi_{15}e_{1t} + \pi_{16}e_{2t} + \pi_{17}e_{3t} + \pi_{18}e_{4t}$. This expression for $\Delta R_t(\theta)$ incorporates two important facts. First, the availability of new information will alter expectations and affect the BoP in much the same manner that expectations affect the determination of flexible exchange rates.[9] Hence, BoP time series will be volatile to the extent that new information alters expectations about the time paths of domestic and world variables. Second, it is only to the extent that country θ's expectations differ from average expectations that these matter for BoP determination. Further, these differences are attributable to the occurrence of relative, country-specific shocks that average out to zero. To derive the effects of various shocks, consider the following conjectural solution:

$$\Delta R_t(\theta) = Z_1\epsilon_{1t} + Z_2\epsilon_{2t} + Z_3u_{3t} + Z_4u_{4t} + Z_5e_{1t} + Z_6e_{2t} + Z_7e_{3t} + Z_8e_{4t}. \tag{25}$$

[9]For a discussion that focuses on business cycles aspects, see [9] and [10]. In particular, [9] singles out the aggregate information content of market determined exchange rates and their role in the international transmission of business cycles.

Substituting into (24) yields the following set of nonlinear restrictions on the Z's:

$$Z_k = -BA_8B_6[\phi_{pe4}\pi_{1k} + \phi_{ie4}c_{1k}],\ (k = 1, \ldots,4],\ Z_5 = BA_8\{B_4 + \phi_B\pi_{15}\}$$

$$Z_6 = BA_8\{B_5 + \phi_B\pi_{16}\},\ Z_7 = 1 + BA_8\phi_B\pi_{17},\ Z_8 = -1 + BA_8\{B_6 + \phi_B\pi_{18}\},$$

where $\phi_B \equiv B_1\phi_p + B_2\lambda_p - B_6(\phi_{pu4} + \phi_{pe4})$. Note that global shocks enter the BoP solution with common coefficients that depend on the values of the least-squares coefficients ϕ_{pe4} and ϕ_{ie4}. It is only to the extent that these shocks provide additional information (via perceived changes in $p_t(\theta)$ and i_t and their covariation) on the home country transfer, e_4, that they affect the BoP. It is useful at this stage to contrast some of the predictions of a rational expectations approach to the BoP to those resulting from the simple monetary approach. In particular, consider the implications of a positive value of e_4. Note that if the expansion were fully perceived as such, there would be no impact on domestic prices or output and, consequently, there would be a one-to-one loss of international reserves. This is the type of offset result that is familiar from the monetary approach and that was also obtained above. On the other hand, to the extent that the monetary expansion is not fully anticipated, it leads to a rise in country θ's price level relative to the world price level and raises the perceived real rate of return. The result is an expansion of output to the extent that aggregate supply is elastic. Given the value of e_4, both the rise in the domestic price level and the accompanying output expansion induce an increase in the demand for nominal balances and, consequently, a balance of payments surplus and gain of international reserves. This is the effect captured in the bracketed expression for Z_8 in (25). In the absence of other country-specific disturbances, this effect would tend to impart a procyclical bias to the BoP.

More generally and from an empirical point of view, the rational expectations equilibrium has a number of fundamental implications that do not arise in the standard monetary approach. First and foremost is the role of expectations in explaining BoP time series. The BoP—analogously to exchange rates—will respond to new information that affects expectations of the time paths of domestic and world variables. Second, the distinction between anticipated and unanticipated magnitudes is crucial to obtaining unbiased estimates of the effects of domestic monetary movements (domestic credit policy changes) on the BoP.[10] Equations (24) and (25) predict that Z_8, the elasticity of the BoP with respect to country-specific monetary shocks, will typically be different from minus unity. The standard explanation implemented in econometric practice is to posit simultaneity bias arising from a neglect of systematic attempts at monetary sterilization by the monetary authorities. There is however a further source of bias: unanticipated changes in policy induce

[10]For a related discussion and some suggestive empirical evidence, see [12].

movements in domestic prices and output. Consequently, it is necessary on both theoretical and empirical grounds to distinguish between anticipated and unanticipated changes in monetary policy. It is only with respect to fully anticipated changes in credit policy that the one-to-one international reserves offset should be expected. This does not mean that sterilization is unimportant as a source of bias. The argument here is that even in the absence of sterilization, econometric estimates of the offset coefficient would be biased away from unity. How much of the bias in existing estimates is due to simultaneity as opposed to neglect of anticipations is an empirical issue. Third, the rational expectations model presented above predicts that the magnitude of the deviation of Z_8 away from minus one depends on the stochastic structure of relative and global shocks. In particular, as the variance of domestic monetary shocks σ^2_{e4} rises, an increasing fraction of domestic price variance is attributed to domestic money transfers; in the limit, as $\sigma^2_{e4} \to \infty$, it can be shown that $Z_8 \to -1$. The important point is that the extent of bias in estimates of Z_8 is dependent on past monetary variability and consequently will not be the same for all countries or for the same country in different time periods. Hence the prediction is that countries with a past history of high domestic monetary variability (e.g., some Latin American countries) would have offset coefficients (Z_8 values) much closer to minus one than countries with relatively stable domestic monetary policies (e.g., Germany and Japan).

Tables 1 and 2 below provide numerical illustrations of the main predictions of the model.[11] The focus is on the "misinformation" induced by variability in the money supply.

Reading down the individual columns of Table 1 reveals the effect of increasing the variance of world money shocks, σ^2_{u4}. The response of the world price level and the interest rate to global disturbances (π_{1j}, c_{1j}, $j = 1,$,4) tends to converge to the full information response as σ^2_{u4} becomes relatively large. The reason for this is that movements in the world interest rate (which becomes less responsive, $c_{14} \to 0$) isolate the other global disturbances. On the other hand, the response of prices to country-specific shocks diverges from the full information values. Hence, increased world monetary variability distorts the response of prices and quantities to relative shocks. Similarly, while the balance of payments response to global shocks gets reduced to zero, the response to local domestic shocks is distorted and the variance of the BoP increases.

Table 2 displays the effects of varying σ^2_{e4}, the variance of domestic monetary transfer policy. Of particular interest in this case is the responsiveness of the BoP to various shocks. For low values of σ^2_{e4}, the resulting coefficients are distorted away from the (*) values but not excessively so. Note that the offset coefficient Z_8 is well above minus one, although Z_1 through Z_4, which are attached to global shocks, approximate their zero full information values. As σ^2_{e4} increases the response of the world price level to all global disturbances declines. The fraction of observed

[11]Brent Moulton wrote the program and ran the simulation. Each row in the tables displays the fixed point equilibrium solution for the constrained coefficients in (A.1), (23), and (25). The assumed values for the structural parameters are $b^d_1 = 0.7$, $b^d_2 = 0.3$, $b^s_1 = 0.3$, $b^s_2 = 0.7$, $\alpha_1 = 0.5$, $\alpha_2 = 0.8$, $b_3 = 0.6$.

TABLE 1

WORLD MONETARY VARIABILITY

$\sigma^2_{u_4}$	π_{11}	π_{14}	π_{16}	π_{18}	c_{11}	c_{14}	Z_4	Z_6	Z_8	σ^2_p	σ_{pt}	$\sigma^2_{p(\theta)}$	σ^2_{BoP}
	−0.95*	1*	0.5*	0*	−1*	0*	0*	0.75*	−1*				
0.00001	−0.558	0.551	0.688	0.481	−0.464	−0.251	−0.091	0.892	−0.376	0.007	0.008	0.016	0.012
0.005	−0.582	0.600	0.742	0.520	−0.470	−0.237	−0.079	0.946	−0.338	0.010	0.007	0.020	0.013
0.02	−0.629	0.694	0.857	0.600	−0.486	−0.200	−0.058	1.043	−0.270	0.018	0.005	0.033	0.015
0.10	−0.724	0.850	1.100	0.770	−0.541	−0.116	−0.025	1.204	−0.157	0.084	−0.002	0.107	0.019
0.50	−0.809	0.953	1.315	0.921	−0.610	−0.039	−0.007	1.319	−0.077	0.469	−0.008	0.502	0.023

NOTES: * denotes full information values. Only $\sigma^2_{u_4}$ is varied in this table. The assumed values of the remaining variances are. $\sigma^2_{\epsilon_1} = 0.01$, $\sigma^2_{\epsilon_2} = 0.02$, $\sigma^2_{u_3} = 0.01$, $\sigma^2_{\epsilon_1} = 0\ 005$, $\sigma^2_{\epsilon_2} = 0.01$, $\sigma^2_{\epsilon_3} = 0\ 002$, $\sigma^2_{\epsilon_4} = 0.008$. σ^2_{BoP} is the variance of the balance of payments

TABLE 2

DOMESTIC MONETARY VARIABILITY

$\sigma^2_{\varepsilon_4}$	π_{11}	π_{14}	π_{16}	π_{18}	c_{11}	c_{14}	Z_4	Z_6	Z_8	σ^2_p	σ_{pi}	$\sigma^2_{p(\theta)}$	σ^2_{BoP}
	−0.95*	1*	0.5*	0*	−1*	0*	0*	0.75*	−1*				
0.00001	−0.654	0.702	0.881	0.617	−0.508	−0.190	−0.000	1.104	−0.227	0.014	0.008	0.025	0.016
0.005	−0.615	0.651	0.808	0.565	−0.485	−0.215	−0.048	1.017	−0.288	0.012	0.007	0.023	0.014
0.020	−0.522	0.538	0.652	0.456	−0.434	−0.270	−0.157	0.830	−0.419	0.009	0.005	0.019	0.013
0.10	−0.291	0.281	0.333	0.233	−0.325	−0.371	−0.416	0.435	−0.695	0.003	0.003	0.010	0.056
0.50	−0.010	0.076	0.010	0.068	−2.63	−0.420	−0.640	0.131	−0.908	0.000	0.001	0.003	0.425

NOTES: Notes to Table 1 applicable here, except that $\sigma^2_{\varepsilon_4}$ is varied, while $\sigma^2_{i_4}$ is held constant at 0.008.

variation in the country price level attributed to common shocks declines. Similarly, since price movements are increasingly attributed to domestic money variability, there is a diminishing response to country-specific real disturbances.

The BoP effects contained in Table 2 are particularly illustrative of the theoretical results. Note that as agents in country θ receive an increasingly distorted perception of world variables, the latter shocks impinge on the BoP. On the other hand, Z_8, the offset coefficient, converges to its full information value of minus one. In this world, the unwary statistician might attribute the small value of Z_8 to simultaneity bias arising from monetary sterilization by the domestic central bank. He would be wrong. For low values of σ^2_{e4} domestic credit policy (transfers) is confused with other relative shocks as well as with global shocks. Hence, we obtain a positive impact on the country's price level (column headed π_{18}) and output relative to the rest of the world. Increasing σ^2_{e4} makes the Phillips-curve slope steeper, lowers the response of the home price level, and increases the offset via the balance of payments.

APPENDIX

Section 5 extends the model to allow for an (unanticipated) wealth effect on demand. From the resulting market-clearing conditions, we can derive the nonlinear restrictions

$$\pi_{11}(1-\eta_p) = \eta_i c_{11} + A_6,\ \pi_{12}(1 - \eta_p) = \eta_i c_{12} + A_7$$

$$\pi_{13}(1\ \eta_p) = \eta_i c_{13} - A_5,\ \pi_{15}(1 - \bar{\eta}_p) = -A_8 = -\pi_{16}(1 - \bar{\eta}_p)$$

$$\pi_{17}(1 - \bar{\eta}_p) = 0,\ c_{11}(1 - \gamma_i) = \gamma_p \pi_{11} + B_4$$

$$c_{12}(1 - \gamma_i) = \gamma_p \pi_{12} + B_5,\ c_{13}(1 - \gamma_i) = \gamma_p \pi_{13} - B_3.$$

Here, $A_9 \equiv b_3 A_8$, $A_{10} \equiv -b_2 B_6 A_8$, $B_6 \equiv B^{-1} b_3(1 + a_1 b^s)$, and

$$\eta_p \equiv \alpha_p - (A_9 + A_{10})\phi_{pu4} - A_9\phi_{pe4} < \alpha_p;\ \bar{\eta}_p \equiv \bar{\alpha}_p - A_9(\phi_{pu4} + \phi_{pe4}) < \bar{\alpha}_p$$

$$\eta_i \equiv \alpha_i - (A_9 + A_{10})\phi_{iu4} - A_9\phi_{ie4} < \alpha_i;\ \gamma_i \equiv \beta_i - B_6\phi_{iu4};\ \gamma_p \equiv \beta_p - B_6\phi_{pu4}.$$

ϕ_{su4}, ϕ_{se4} $(s = p,i)$ are regression coefficients from the projection of u_4 and e_4 on the observed values of $p(\theta)$ and i.

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