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EMU, Adjustment, and Exchange Rate Variability[1]

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Abstract

This paper uses a three-country, three-good, factor-specific model of trade with wage rigidities to investigate how European Monetary Union (EMU) is likely to affect exchange rate variability. Focusing on international macroeconomic adjustment under both exogenous and optimizing monetary policies, it shows that the relative variability (against external currencies) of the euro (under EMU) and a basket of present currencies (pre-EMU) depends on relative sizes and specialization patterns of EMU countries and the relative importance of different shocks. EMU is likely to decrease (increase) exchange rate variability for shocks to industries in which large (small) EMU countries are specialized.

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SUMMARY

Previous studies have analyzed how European Monetary Union (EMU) is likely to affect exchange rate variability by focusing on the game-theoretic interactions of monetary authorities or fiscal authorities or both. This paper instead emphasizes the role of the sectoral dimension of international macroeconomic adjustment. It develops a three-country, three-good, factor-specific model of trade in which to investigate the short-run adjustment to demand and supply shocks in the presence of wage rigidities. This framework allows comparisons, for each type of shock, of the response of the exchange rate of the monetary union currency (versus an external currency) with the response of a weighted average of the bilateral exchange rates of each of the two candidates for the union (vis-à-vis the outside one). Three types of exchange rate weights are considered in the comparisons: country-size weights, trade weights, and equal weights. Whether EMU increases or reduces exchange rate variability is shown to depend on the relative importance of different types of shocks (demand or supply), on both the sizes and the specialization patterns of the countries forming the union, and on the weights that are assumed to be relevant for the comparator basket.

The analysis is first carried out under the assumption that money supplies are exogenous. It is then extended to the case of optimizing monetary policies that attach quadratic losses to both inflation and employment variability. For comparisons based on country size or trade weights, the assumptions about monetary policy do not affect the qualitative nature of the results. Thus, in contrast to conjectures by Kenen (1995), Bergsten (1997), and others, the analysis suggests that optimization of policy objectives does not necessarily imply that EMU will lead to greater exchange rate variability.

I. INTRODUCTION

The main aim of this paper is to shed light on the question of whether the move to European Monetary Union (EMU) will make the euro more or less variable than a comparator basket of the present currencies of the countries that participate in EMU. The answer is shown to depend on the relative importance of different types of shocks, on both the sizes and the patterns of specialization of the EMU countries, and on the weights used in defining the comparator basket: for baskets based on country-size or trade weights, EMU is likely to decrease (increase) exchange rate variability for shocks to the industry in which large (small) EMU countries are specialized.

The likely effects of EMU on exchange rate variability—that is, on the variability of the euro against external currencies, compared with the variability of a basket of the present currencies of EMU participants—has been the subject of recent discussion. Focusing on prospective economic policy interactions among the group of EMU participants and third countries, Kenen (1995), Bergsten (1997), and others have argued that "creation of the euro will eliminate one of the EU's chief interests in international cooperation in managing exchange rates,"[2] and lead the EMU countries to attach less weight to exchange rate stability as a policy objective. This "benign neglect effect" is illustrated formally by Benassy-Quéré, Mojon, and Pisani-Ferry (1997), who develop a three-country model in which real exchange rate variability is explicitly included in the policy authorities' loss function, with a smaller weight under EMU than in the pre-EMU regime. Under the latter assumption, the institution of EMU would unambiguously increase exchange rate variability. It is interesting to note, as shown by the authors within the same model, that even when the policy loss is specified more conventionally as a quadratic function of prices and output, a change from the pre-EMU floating exchange rate regime to EMU will increase exchange rate variability in response to all types of shocks, except in the case symmetric European supply shocks.

Cohen (1997) analyzes the issue with a different three-country model, distinguishing between price shocks (i.e., stochastic shifts in Phillips curves) and demand shocks, and emphasizing that the effects of such shocks on exchange rates depend on the reactions of monetary and fiscal policies. Under an assumed model of optimal policy responses, Cohen infers that EMU will increase exchange rate variability in response to price shocks and reduce it for demand shocks. He therefore concludes that there is "no a priori reason to believe that the euro will be a more 'stable' currency than its predecessors...." unless we believe we are entering a world in which price shocks will become less prevalent relative to demand shocks.[3]

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[2]Bergsten (1997), p. 42.

[3]Cohen (1997), p. 409.

Masson and Turtelboom (1997) address the issue by performing stochastic simulations with a version of MULTIMOD that contains 14 separate models for the EU countries. Their results indicate that the effects of EMU on exchange rate variability will depend on the type of policy reaction function adopted by the European Central Bank and on the degree of international policy coordination.

In a model extending the Barro-Gordon setup to two countries, Martin (1997) shows that relative country size affects exchange rate variability in a nonlinear fashion, with the variance of the exchange rate an increasing function of the differential in country size at low levels of this differential and deceasing with the size differential at high levels of the differential. Empirical evidence is shown to support such a nonlinear relationship, and it is argued that EMU will substantially reduce the size differential with the rest of the world, implying a likelihood of reduced exchange rate variability.

These studies emphasize that the analysis of the effect of EMU on exchange rate variability hinges on the nature of policy reaction functions and international policy coordination (as extensively classified by Canzoneri and Henderson, 1991) either in a Mundell-Fleming or in a Barro-Gordon (1983) setup.[4] They also make the restrictive assumption that each country's product is internally homogenous and imperfectly substitutable with foreign output, so that stochastic disturbances are always modeled as aggregate national shocks (whether demand or supply). The range of different results among these papers stems, inter alia, from differences regarding the types of authorities considered (monetary and/or fiscal), the forms of loss functions, and the macroeconomic adjustment underlying the policy interaction.

This paper extends the analysis to focus on the sectoral dimension of international macroeconomic adjustment as an additional important channel through which EMU may affect exchange rate variability.[5] It develops a three-country, three-good factor-specific model of trade, where demand and supply shocks occur in the presence of wage rigidities. This setup allows us to focus on countries production and trade structures when investigating whether the institution of monetary union between two of the countries will alter the international macroeconomic adjustment and lead to a different volatility of their exchange rate vis-à-vis the third country. Following several of the other studies cited above, the pre-EMU regime is

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[4]The model employed by Masson and Turtelboom (1997) differs considerably from those analyzed in the other studies. The structure of MULTIMOD is much richer than that of the other models, but the larger size of MULTIMOD provides less understanding of the underlying intuition.

[5]International macroeconomic adjustment is at the heart of the cost-benefit analysis of an optimum currency area (OCA), as it constitutes the key factor in assessing the costs. For models of OCA, see Bayoumi (1994) and Ricci (1997a); for surveys and reviews of the main arguments, see De Grauwe (1992), Masson and Taylor (1993), Tavlas (1993, 1994).

treated as a regime of flexible exchange rates; although this obviously exaggerates reality, it provides a valid benchmark for the types of qualitative results on which the paper focuses. The analysis is carried out with and without optimizing monetary policy, in order to control for whether international monetary policy interaction alters the results. In characterizing the pre-EMU regime, three weighting schemes are considered for the exchange rate of the external country versus the two countries forming the union: country-size weights, trade weights, and equal weights. Analytic derivations and simulations suggest that the effects of EMU on exchange rate variability is likely to depend on the relative sizes and specialization patterns of EMU countries, as well as the relative importance of different types of shocks and the particular weighting scheme adopted for measuring the weighted average exchange rate of EMU participants in the pre-EMU regime. The analysis also concludes, in contrast to the suggestions of Kenen (1995), Bergsten (1997), and others, that optimizing monetary policies do not necessarily imply that EMU will lead to greater exchange rate variability.

The rest of the paper is organized as follows. Section 2 lays out the model. Section 3 presents the equilibrium that would occur in the absence of shocks and rigidities, which can be considered as the long-run equilibrium. Section 4 describes the adjustment to demand and supply shocks in the presence of wage rigidities; the analysis also distinguishes between the cases of exogenous and endogenous (optimizing) monetary policy behavior. Section 5 analyzes the exchange rate response to shocks, both under flexible rates and in the presence of a monetary union, and provides the intuition for the results. Section 6 describes the results of simulations that explore, among other things, the implications of different relative sizes of the two countries forming the union. Section 7 draws conclusions.

II. THE MODEL

This Section describes a monetary model of trade with wage rigidities. The trade structure is given by a factor specific framework, with three countries (I=1,2,3) and three tradable goods (D_k, with k=A, B, C).

Good D_k in country I (sector ki) is produced with a Cobb Douglas production function that is homogeneous of degree one in labor (L_{ki}) and a sector-specific factor (F_{ki}), augmented by a sector-specific technology parameter[6] (γ_{ki}):

$$D_{ki}^s = \gamma_{ki} \, L_{ki}^{\delta_k} \, F_{ki}^{1-\delta_k} \tag{1}$$

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[6]Such productivity parameters may differ for a variety of reasons, including natural advantages, industrial policies, taxation, and unmodeled externalities.

Given that the focus will be on the short-run adjustment where only one factor will be allowed to vary (labor) and that sectoral differences are anyway captured by the technology parameter, the sector-specific factor is assumed to have identical size across sectors and is normalized to one.[7]

Firms take the local wage (w_i) as given. Perfect competition generates the following profit maximizing relation between sectoral employment and price (p_{ki}):

$$p_{ki} = \frac{w_i}{\gamma_{ki}\, \delta_k}\, L_{ki}^{1-\delta_k} \qquad (2)$$

Free trade ensures price equalization for each commodity:

$$p_{k1} = e_{12}\, p_{k2} = e_{13}\, p_{k3} \quad , \qquad \text{with} \quad e_{12}\, e_{23}\, e_{31} = 1 \qquad (3)$$

where e_{ij} is the exchange rate measured in units of currency I per one unit of currency j (j=1,2,3). The previous two equations provide an equilibrium relation between employments in different locations, but in the same industry:

$$\frac{L_{ki}}{L_{kj}} = \left(\frac{e_{ij}\, w_j}{w_i}\, \frac{\gamma_{ki}}{\gamma_{kj}} \right)^{\frac{1}{1-\delta_k}} \qquad (4)$$

Hence, employment in industry k is larger in the location where productivity is higher and the nominal wage is lower.

World agents share identical homothetic preferences in the three goods and money. A representative agent q of country I maximizes:[8]

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[7]The sector specific factor is necessary only to generate homothetic production functions, so as to make pricing independent of actual firm size and to preserve the perfect competition assumption together with decreasing returns to scale (DRS) for labor. Hence, the sectoral price depends on aggregate sectoral labor (the usual perfect competition assumptions). If the production function exhibited DRS in all factors, firms would have infinitesimal size, each pricing according to its own labor employment.

[8]Money in the utility function to investigate comparative statics in a one period model has been used by Blanchard and Kiyotaki (1987), among others.

$$U_{kq} = \left(D_{Akq}^{\alpha_A} \, D_{Bkq}^{\alpha_B} \, D_{Ckq}^{\alpha_C} \right)^{\lambda} \left(M_{kq}' \, / \, P_i \right)^{1-\lambda} \qquad , \quad with \quad \alpha_A + \alpha_B + \alpha_C = 1 \qquad (5)$$

subject to:

$$p_{Al} \, D_{Alq} + p_{Bl} \, D_{Blq} + p_{Cl} \, D_{Clq} + M_{kq}' = Y_{kq} + M_{kq} \qquad (6)$$

where $\mathbf{M'_{kq}}$, $\mathbf{M_{kq}}$, and $\mathbf{Y_{kq}}$, are respectively: money demand, money endowment, and per capita GDP (i.e., the sum of the sectoral revenues within location I) of agents q in location I, while $\mathbf{P_i}$ is the price index of that location.

Utility maximization delivers the following *aggregate* demands of consumers of location I for good k and for money:

$$p_{ki} \, C_{ki}^{d} = \alpha_k \, \lambda \, (Y_l + M_l) \qquad , \qquad M_i' = \frac{1-\lambda}{\lambda} Y_i \qquad (7)$$

In order to simplify the framework and reduce the number of parameters, the following conditions are imposed:

$$\lambda = .5 \qquad \frac{Y_{Al}}{Y_{A2}} = \frac{Y_{Al}}{Y_{A3}} = \sqrt{Y_A} > 1 \qquad \frac{Y_{B2}}{Y_{Bl}} = \frac{Y_{B2}}{Y_{B3}} = \sqrt{Y_B} > 1 \qquad \frac{Y_{C3}}{Y_{Cl}} = \frac{Y_{C3}}{Y_{C2}} = \sqrt{Y_C} > 1 \qquad (8)$$

The first condition sets velocity of money to one and is completely inconsequential for the purposes of the paper. The other three conditions imply that each country has an absolute advantage in the production of one good. Such advantage is of identical size with respect to each of the other two countries. However, countries may differ in the extent of the absolute advantages that they have. These assumptions provide a source of asymmetry across countries, which will be reflected in the relative sizes of countries, and in the pattern of production and specialization (see the next section).

Uncertainty arises from both demand and supply shocks. In particular, the share of expenditures devoted to each good (α_k), and the degree of returns to labor in each industry (δ_k) are subject to shocks. In order to make the framework as simple and symmetric as possible, the initial (mean) values of these parameters are set to:

$$\alpha_k = 1/3 \qquad \delta_k = 1/2 \tag{9}$$

III. THE SOLUTION IN THE ABSENCE OF RIGIDITIES: LONG-RUN EQUILIBRIUM

This section describes the model solution for the case in which prices and wages are flexible and labor is internationally mobile. This solution can be considered as the long-run equilibrium. Under such circumstances, money is a veil and the equilibrium is given by the solution of the underlying trade model (which can be closed assuming that the world 'natural' level of employment is 'L'). Country size and specialization depend on the relative sizes of the productivity parameters. In fact, price equalization implies that, within each industry, employment and production are larger in countries with higher productivity. As labor mobility makes country size endogenous, countries with a higher average productivity end up with a larger population and size. Comparative advantage drives specialization, as countries specialize in the goods in which they have a relatively higher productivity advantage.

In general, the solution would be quite cumbersome. A relatively simple solution, which will be used as the initial situation in the next section, can be found when the random parameters assume their mean values. To solve the model, one needs to find the 3x3 matrix of sectoral employments (L_{ki}), given the world 'natural' level of employment 'L'. Goods market clearing and price equalization provide the required conditions.

For the assumed case of identical shares of expenditure on each good and identical shares of labor income in each industry, world wage equalization due to labor mobility implies that world labor employment is identical across industries:

$$L_k = 1/3 \ L \tag{10}$$

Within each industry, sectoral employments of the three countries are given by the relative employment condition imposed by price equalization (equation 4):

$$L_{A1} = \frac{\gamma_A L/3}{2+\gamma_A}, \ L_{A2} = L_{A3} = \frac{L/3}{2+\gamma_A} \ ; \ L_{B2} = \frac{\gamma_B L/3}{2+\gamma_B}, \ L_{B1} = L_{B3} = \frac{L/3}{2+\gamma_B} \ ; \ L_{C3} = \frac{\gamma_C L/3}{2+\gamma_C}, \ L_{C1} = L_{C2} = \frac{L/3}{2+\gamma_C} \tag{11}$$

By summing up sectoral employments in each country, one can derive the country sizes. It is interesting to note that relative country sizes are determined only by productivity parameters:

$$L_1 = \left(\frac{\gamma_A}{2+\gamma_A} + \frac{1}{2+\gamma_B} + \frac{1}{2+\gamma_C} \right) \frac{L}{3} \ ; \ L_2 = \left(\frac{1}{2+\gamma_A} + \frac{\gamma_B}{2+\gamma_B} + \frac{1}{2+\gamma_C} \right) \frac{L}{3} \ ; \ L_3 = \left(\frac{1}{2+\gamma_A} + \frac{1}{2+\gamma_B} + \frac{\gamma_C}{2+\gamma_C} \right) \frac{L}{3} \tag{12}$$

Given that each country has an absolute advantage in the production of one good (equation 8), and that its advantage is identical with respect to both of the other countries, it can be shown that a larger absolute advantage is reflected in a higher average productivity and a larger country size:

$$L_1 > L_2 > L_3 \qquad if \qquad \gamma_A > \gamma_B > \gamma_C \tag{13}$$

Since $\gamma_A, \gamma_B, \gamma_C$ all exceed unity, country 1 (2, 3) exports good A (B, C).

IV. UNCERTAINTY, SHORT-RUN RIGIDITIES, AND SHORT-RUN ADJUSTMENT

This section describes the short-run adjustment to shocks. The short run is assumed to be characterized by a simple Keynesian-style situation, where wages are fixed, employment is driven by the labor demands of firms (no labor market clearing), and labor is internationally immobile. Hence, both employment and prices in each country can fluctuate above or below initial levels; the same holds at the sectoral level[9].

Assume that the world is initially in the long-run equilibrium described in the previous section, where random variables take their mean values. Wages are set before shocks occur, and at the level that would ensure the natural employment rate in the absence of shocks. Demand and supply shocks occur in the form of preference shifts (changes in α_k) and shifts in the exponents of the production functions (changes in δ_k). Menu costs prevent wage adjustment and workers are internationally immobile.

Because of the rigidities, the short-run equilibrium is determined from the clearing of the goods and money markets in nominal terms. Under flexible exchange rates, the trade balance clears, while under fixed rates trade imbalances are associated with opposite money flows. Given the assumption of homogeneous goods, price equalization holds for each good: hence, countries adopting a fixed exchange rate system face the same inflation. The analysis will consider both the case in which money supplies are exogenous and the case in which they are optimally chosen.

A. Employment

This section takes exchange rates and money supplies as exogenous, and allows for goods and money market clearing as well as price equalization. It derives expressions for

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[9]This short-run adjustment is reconcilable with the long-run equilibrium described in the previous section: one may imagine either that shocks are temporary and disappear, or that short-run rigidities (wage rigidity and labor immobility) eventually fade away so that the equilibrium is again given by the fundamentals of the trade model.

changes in sectoral employment as a function of shocks, of exchange rate changes, and of money supply changes.

For each industry, price equalization informs us on the **relative** sectoral employments in each country (equation 4). Goods and money market equilibrium then informs us on the **absolute** sectoral employments compatible with market clearing.

For example, for industry k in location 1, goods and money market equilibrium imply that (see demands in equation 7):

$$p_{k1} (D_{k1}^s + D_{k2}^s + D_{k3}^s) = \alpha_k (M_1 + e_{12}M_2 + e_{13}M_3) \tag{14}$$

By applying the output and the relative sectoral employment relations (equations 1 and 4), one derives employment in sector k in country 1:

$$L_{k1} = \frac{\alpha_k (M_1 + e_{12}M_2 + e_{13}M_3) \delta_k}{w_1 \left[1 + (e_{21})^{\frac{\delta_k}{1-\delta_k}} \left(\frac{\gamma_{k2}}{\gamma_{k1}} \right)^{\frac{1}{1-\delta_k}} + (e_{31})^{\frac{\delta_k}{1-\delta_k}} \left(\frac{\gamma_{k3}}{\gamma_{k1}} \right)^{\frac{1}{1-\delta_k}} \right]} \tag{15}$$

Similar expressions can be found for sectoral employments in the other countries. Total differentiation (in percentage terms) around the initial parameter values then provide expressions for all sectoral employment percentage changes ($\hat{L}_{ki}$, where a hat denotes percentage changes) as functions of each of the shock parameters and the exchange rate and money supply terms. Such expressions are presented in the appendix.

Once the sectoral employment changes are known, one can infer the sectoral inflation levels (by differentiation in percentage terms of equation 2), as well as the aggregate national inflation levels and employment percentage changes (respectively $\hat{p}_i$ and $\hat{L}_i$):

$$\hat{p}_{ki} = -[1+\delta_k \ln(L_{ki})]\hat{\delta}_k + (1-\delta_k)\hat{L}_{ki} \tag{16}$$

$$\hat{p}_i = \frac{\sum_k \hat{p}_{ki}}{3} \quad , \quad \hat{L}_i = \sum_k \left(\frac{L_{ki}}{L_i} \hat{L}_{ki} \right) \tag{17}$$

B. Exchange Rate Regimes

The paper compares behavior under two exchange rate regimes. The first (FX) is characterized by separate currencies for each country with flexible exchange rates between all three currencies; in this regime trade imbalances are corrected by exchange rate movements. The second (MU) involves a monetary union between country 2 and 3, where the trade imbalance of country 1 versus the union is corrected by changes in the exchange rate between country 1 and the union while the trade imbalance between 2 and 3 is matched by a bilateral money flow. Although the situation prior to EMU is not characterized by completely flexible exchange rates between prospective EMU participants (countries 2 and 3), comparison of behavior under the FX and the MU regimes seem quite appropriate for analyzing the likely effects of EMU. (In the absence of EMU, some countries—namely, those with historically high inflation rates—might turn to flexible rates.)

There are two independent trade balances, which are initially in equilibrium. By differentiating the sum of the sectoral excess supplies of goods in countries 1 and 2 around the initial equilibrium (from equations 1, 2, 14), one can derive expressions for the changes in the trade balances of these countries:

$$dtb_1 = \frac{\gamma_A}{2+\gamma_A}(\hat{L}_{A1}-\hat{\delta}_A) + \frac{1}{2+\gamma_B}(\hat{L}_{B1}-\hat{\delta}_B) + \frac{1}{2+\gamma_C}(\hat{L}_{C1}-\hat{\delta}_C) - (\frac{\gamma_A}{2+\gamma_A}+\frac{1}{2+\gamma_B}+\frac{1}{2+\gamma_C})\hat{M}_1 \qquad (18)$$

$$dtb_2 = \frac{1}{2+\gamma_A}(\hat{L}_{A2}-\hat{\delta}_A) + \frac{\gamma_B}{2+\gamma_B}(\hat{L}_{B2}-\hat{\delta}_B) + \frac{1}{2+\gamma_C}(\hat{L}_{C2}-\hat{\delta}_C) - (\frac{1}{2+\gamma_A}+\frac{\gamma_B}{2+\gamma_B}+\frac{1}{2+\gamma_C})\hat{M}_2 \qquad (19)$$

In the FX case, setting both (hence all) trade balances to zero (and substituting for percentage changes in the sectoral employment levels derived in section 4.1) allows one to solve for the equilibrium changes in the exchange rates ($\hat{e}_{12}$, $\hat{e}_{13}$). In the MU case, $e_{12}=e_{13}$ by definition, and $\hat{e}_{12}=\hat{e}_{13}$ can be found through $dtb_1=0$.

C. Optimizing Monetary Policy

Two monetary regimes are analyzed. In the first regime (NM), money supplies are exogenously given;[10] this regime will be adopted in the formal analysis developed in Section 5. In the second regime (OM), changes in money supply reflect optimizing monetary policies

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[10]In a preliminary draft, money shocks were also analyzed, to represent, for example, mistakes in monetary policy.

that minimize quadratic loss functions in inflation (CPI index) and employment fluctuations. Because of the complexity of the model, this regime is analyzed only with simulations, as presented in Section 6.

When optimal monetary policy is pursued under flexible rates (OM-FX), each country controls its domestic money supply and is assumed to minimize a loss function that depends only on domestic inflation and domestic employment:

$$Loss_i = \hat{p}_i^2 + \theta \, \hat{L}_i^2 \tag{20}$$

When optimal monetary policy is pursued in the case of monetary union (OM-MU), countries 2 and 3 jointly control their combined money supply to minimize a weighted average of the loss functions of the two countries (2 and 3):

$$Loss_1 = \hat{p}_1^2 + \theta \, \hat{L}_1^2 \quad ; \quad Loss_{23} = \mu_2 \, (\hat{p}_2^2 + \theta \, \hat{L}_2^2) + \mu_3 \, (\hat{p}_3^2 + \theta \, \hat{L}_3^2) \tag{21}$$

The weights (μ_2, μ_3) can be equal for the two countries (**OM1-MU**) or can reflect relative country size (**OM2-MU**). This second case can be shown to be identical, in our model, to the case where inflation and employment of the whole union directly enter the union loss function.

V. RESPONSES TO SHOCKS UNDER FLEXIBLE RATES AND MONETARY UNION WITH EXOGENOUS MONEY SUPPLIES

This section provides, for the case of exogenous money supply (NM), an analytical solution to the main question of the paper: whether there is a substantial change in the response to shocks of the exchange rate of country 1 versus countries 2 and 3, when 2 and 3 switch between flexible exchange rates and monetary union. The case of optimal monetary policy (OM) will be illustrated by simulation in Section 6: the introduction of optimizing monetary policy affects the results quantitatively, but not qualitatively.

In the presence of world flexible exchange rates (FX), there is no unique measure of the exchange rate of country 1 versus countries 2 and 3 (e_{1FX}), but different weighting schemes can be conceived. When countries 2 and 3 form a monetary union (MU), there is only one exchange rate (e_{1MU}). In percentage changes:

$$\hat{e}_{1FX} = x_2 \, \hat{e}_{12FX} + x_3 \, \hat{e}_{13FX} \quad with \quad x_2 + x_3 = 1 \quad ; \quad \hat{e}_{1MU} \equiv \hat{e}_{12MU} \equiv \hat{e}_{13MU} \tag{22}$$

Three different sets of weights (x_2, x_3) are analyzed: equal weights (**EW**); country size weights (**SW**), based on relative initial employment levels; and trade weights (**TW**), given by the initial shares of the bilateral trade of 1 with 2 and 3 in the total trade of 1 (as measured by the ratios of the imports of 1 from each of the two other countries to the total exports of 1). The emphasis is on the last two measures, which appear to represent the most reasonable ways of weighting. The first case is presented for completeness as a benchmark, but it is not discussed in detail.

The model is too complex to allow for tractable solutions for $\hat{e}_{1FX}$ and $\hat{e}_{1MU}$. The analysis will therefore compare, for each type of shock, the absolute value of the weighted average of the changes of bilateral exchange rates under FX ($\hat{e}_{1FX}$) with the absolute value of the change in the exchange rate of 1 versus the union under MU ($\hat{e}_{1MU}$):

$$|\hat{e}_{1FX}| - |\hat{e}_{1MU}| \tag{23}$$

This difference between the two responses will in general depend on countries' production structures and specialization patterns as well as on the type of shock. As the relative size of the two countries forming the union (2, 3) is crucial to the analysis, without loss of generality it will be also assumed that:[11]

$$\gamma_B > \gamma_C \tag{24}$$

so that country 2 is larger than country 3. Hence, sector B can be referred to as the sector in which the large country of the union is relatively specialized.

A. Analysis

Note that under FX the changes in e_{12} and e_{13} (hence in e_1) can each be decomposed into two components, which is useful for the analysis of $\hat{e}_{1FX}$:

$$\hat{e}_{12FX} = \hat{e}_{1MU} + \hat{e}_{12AD}, \quad \hat{e}_{13FX} = \hat{e}_{1MU} + \hat{e}_{13AD} \quad \rightarrow \quad \hat{e}_{1FX} = \hat{e}_{1MU} + x_2 \hat{e}_{12AD} + x_3 \hat{e}_{13AD} \tag{25}$$

The first component ($\hat{e}_{1MU}$) is the *identical* change in e_{12} and e_{13} that would clear the trade balance of country 1 under MU. The other terms ($\hat{e}_{12AD}$ and $\hat{e}_{13AD}$) are the additional (AD) opposite movements in e_{12} and e_{13} that would clear also the trade balances of the two other

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[11]This is in addition to the condition $\gamma_k > 1$ (for k=1,2,3) imposed in Section 2, which implies that each country has an absolute advantage in one of the goods and hence is relatively specialized in that good.

countries, while maintaining the trade balance equilibrium of country 1. These terms generate the difference between e_{1MU} and e_{1FX}, the focus of the paper.

According to equation 25, switching from the MU regime to the FX regime increases the response of the exchange rate of country 1 to shocks ($|\hat{e}_{1FX}| > |\hat{e}_{1MU}|$) if the weighted average of $\hat{e}_{12AD}$ and $\hat{e}_{13AD}$ ($=\hat{e}_{1FX}-\hat{e}_{1MU}$) has the same sign as $\hat{e}_{1MU}$. Investigation of such cases can be pursued in steps.

Proposition I: $\{\hat{e}_{1FX} -\hat{e}_{1MU}\}$ has the same sign as $\hat{e}_{12AD}$ under the SW and TW weights and the opposite sign under the EW weights.

Trade balance equilibrium of country 1 must hold before and after the simultaneous occurrence of $\hat{e}_{12AD}$ and $\hat{e}_{13AD}$. Hence, these changes must have opposite sign and their relative size can be found by differentiation of the trade balance of 1. From equation 18 and the appendix, one can derive that:

$$\frac{d(dtb1)}{d(\hat{e}_{12})}\hat{e}_{12AD}+\frac{d(dtb1)}{d(\hat{e}_{13})}\hat{e}_{13AD} = 0, \text{ with } \frac{d(dtb1)}{d(\hat{e}_{12})}>\frac{d(dtb1)}{d(\hat{e}_{13})}>0 \text{ if } \gamma_A>1 \text{ and } \gamma_B>\gamma_C>1 \quad (26)$$

where the relative size of the derivatives depends on the fact that the trade balance of country 1 is more sensitive to changes in the bilateral exchange rate with the large country of the union.

Equations 25 and 26 imply that, for a given shock, $|\hat{e}_{1FX}| > |\hat{e}_{1MU}|$ if the following expression

$$\hat{e}_{1FX} - \hat{e}_{1MU} = x_2\,\hat{e}_{12AD}+x_3\,\hat{e}_{13AD} \equiv \left[x_2\frac{d(dtb1)}{d(\hat{e}_{13})} - x_3\frac{d(dtb1)}{d(\hat{e}_{12})}\right]\frac{\hat{e}_{12AD}}{\frac{d(dtb1)}{d(\hat{e}_{13})}} \quad (27)$$

has the same sign as $\hat{e}_{1MU}$. As discussed below, the sign of the expression in square brackets depends on the sizes and production structures of the two countries forming the monetary union, while the sign of $\hat{e}_{12AD}$ depends on the type of shock.

It can be shown that if the usual conditions on γ_k hold,[12] the expression in square brackets is positive with equal weights (EW) and negative for country-size or trade weights (SW or TW). This is because, $\hat{e}_{12AD}$ always moves less than $\hat{e}_{13AD}$, due to the relative magnitudes of the derivatives of dtb1 with respect to such exchange rates (see equation 26),

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[12] $\gamma_A>1$ and $\gamma_B > \gamma_C > 1$.

implying that with equal weights, the average of the additional exchange rate changes is dominated by the sign of $\hat{e}_{13AD}$. Under the country size or trade weighting schemes, the smaller movements of $\hat{e}_{12AD}$ are more than compensated for by the larger weights, and the sign of $\hat{e}_{12AD}$ determines the sign of the weighted average of the additional exchange rate changes.

Proposition II: Following a demand or supply shock to good B (C), $\hat{e}_{12AD}$ ($\hat{e}_{13AD}$) has the same sign as $\hat{e}_{1MU}$.

Whether $\hat{e}_{12AD}$ or $\hat{e}_{13AD}$ has the same sign as $\hat{e}_{1MU}$ depends on the type of shock. For each shock, the effect on $\hat{e}_{1MU}$ depends on the effect of the shock on the trade balance of country 1, while the effect on $\hat{e}_{12AD}$ ($\hat{e}_{13AD}$) depends on the effect on the trade balance of country 2 (3), once trade equilibrium of country 1 is reached (due to $\hat{e}_{1MU}$).

The analysis of demand shocks is pretty straightforward. A shift in demand from good C to good A ($\hat{\alpha}_A > 0$) induces dtb1>0 (hence $\hat{e}_{1MU} < 0$) and $dtb3_{dtb1=0} < 0$ (hence $\hat{e}_{13AD} < 0$). A shift in demand from good C to good B ($\hat{\alpha}_B > 0$) induces dtb1<0 (hence $\hat{e}_{1MU} > 0$) and $dtb3_{dtb1=0} < 0$ (hence $\hat{e}_{13AD} < 0$).

Regarding supply shocks, one can see from equations 18-19 and the appendix that a positive supply shock in sector k ($\delta_k > 0$) has a positive effect on the trade balance of the country that is a net exporter of good k and a negative effect on the trade balance of the other countries. Hence, the only unknown effect is the one of $\delta_A > 0$ on $\hat{e}_{12AD}$ and $\hat{e}_{13AD}$, as one cannot infer the effect of such a shock on the trade balances of countries 2 and 3 once the trade balance of country 1 is in equilibrium.

In other words, proposition II states that a shock to the sector in which one of the countries of the union is specialized makes the bilateral exchange rate of that country versus country 1 move more under FX than MU. This is quite intuitive. A positive shock to sector B would induce a trade surplus for country 2 and deficits for countries 1 and 3. Even after the trade balance of country 1 returns to equilibrium (because of $\hat{e}_{1MU} > 0$), the trade balance of country 2 (3) would still be positive (negative). The adjustment of these trade imbalances under FX requires a further depreciation of 1 versus 2 (and an appreciation of 1 versus 3).

B. Results

Tables 1a and 1b summarize the results arrived at with Propositions I and II. With country-size (SW) or trade (TW) weighing schemes, for demand and supply shocks in the industry in which the **large** country of the monetary union is specialized, the response of the average exchange rate of country 1 versus 2 and 3 under flexible rates is larger than the response of the country 1 exchange rate when 2 and 3 create a monetary union. However, with the equal weighting scheme (EW), the response to these shocks is smaller under flexible rates than with a monetary union.

The logic combines two points. First, for these shocks, under flexible rates the exchange rate between the large country of the union and the external country ($\hat{e}_{12AD}$) changes more than it would under monetary union; in fact, these shocks induce a trade imbalance in the large country of the union that is of opposite sign than the trade imbalances of the other two countries. Second, under flexible rates, the SW or TW average of the two bilateral exchange rates of the external country is dominated by the changes in the bilateral exchange rate with the large country of the union ($\hat{e}_{12AD}$), while the opposite holds under the EW scheme. This is because the additional change in the exchange rate of the large country is smaller than the change for the small country, but such difference is more than compensated for by the difference in country size or trade weights.

For shocks to the industry in which the **small** country is specialized, monetary union generates higher variability than the SW or TW average of flexible bilateral rates with the external country. The opposite holds for the equal weighting scheme.

Table 1a. Effects of Shocks on Trade Balances, and Exchange Rates					
	α_A	α_B	δ_A	δ_B	δ_C
dtb1	+	-	+	-	-
e_{1MU}	-	+	-	+	+
$dtb2_{dtb1=0}$	+	+	?	+	-
$dtb3_{dtb1=0}$	-	-	?	-	+
e_{12AD}	+	+	?	+	-
e_{13AD}	-	-	?	-	+

Table 1b. Comparing Exchange Rate Responsiveness Under FX and MU: $\lvert\hat{e}_{1FX}\rvert - \lvert\hat{e}_{1MU}\rvert$ for Different Shocks (α_A, α_B, δ_A, δ_B, δ_C) and Weighting Schemes (EW, SW, TW)					
	α_A	α_B	δ_A	δ_B	δ_C
SW or TW	-	+	?	+	-
EW	+	-	?	-	+

VI. SIMULATIONS WITH BOTH EXOGENOUS AND ENDOGENOUS MONEY SUPPLIES

In order to illustrate the magnitudes of the results described in the previous sections and to extend the analysis to cases of optimizing monetary policy, this section presents simulations of the effects of shocks on exchange rates under the different monetary and exchange rate regimes. By choosing the productivity parameters, one can generate different initial situations (or long-run equilibria), characterized by different patterns of specialization and country sizes. Attention will be limited to two sets of parameters. The first set (S1: γ_A= 2;γ_B=1.33; γ_C=1.1) gives rise to countries that are similar in size and degree of specialization. The second set (S2: γ_A= 20;γ_B=15; γ_C=1.1) generates two large countries (1 and 2) and a small one (3), with all countries highly specialized. The criteria for the choice of parameters are: (a) to ensure that country 1 is always the largest (mimicking the United States); and (b) to focus on the degree of asymmetry of the two countries forming the monetary union (2 and 3), so as to compare a case like Germany-France with a case like Germany-Portugal. Table 2 summarizes the country sizes, production structures, and specialization patterns under the two sets of parameters.

Table 2. Country Size (L_i / L), Country Share in World Production of Good k (L_{ki} / L_k), and Sector Share in National Employment (L_{ki} / L_i), in Percentage Terms, for the Two Parameters Sets					
	S1 (γ_A= 2;γ_B=1.33; γ_C=1.1)			S2 (γ_A= 20;γ_B=15; γ_C=1.1)		
	I=1	I=2	I=3	I=1	I=2	I=3
L_i / L	37	33	30	43	42	15
L_{Ai} / L_A	50	25	25	90	5	5
L_{Bi} / L_B	30	40	30	6	88	6
L_{Ci} / L_C	32	32	36	32	32	36
L_{Ai} / L_i	44	26	28	70	4	10
L_{Bi} / L_i	27	41	33	5	70	12
L_{Ci} / L_i	29	33	39	25	26	78

Tables 3 and 4 summarize the simulated responses of exchange rates under the two sets of parameters. For each of the three monetary regimes (NM, OM1, and OM2),[13] each

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[13]Recall that NM denotes the regime with exogenous money supplies, OM1 the case of optimizing monetary policies when equal weights are placed on each country's welfare, and

(continued...)

table presents: (a) the elasticities of e_{1MU} with respect to the five different shocks, informing us on the sign and size of the response of the exchange rate under MU; (b) the percentage difference between the absolute values of the elasticities of e_{1FX} and e_{1MU} under the three weighting schemes (EW, SW, TW) and the three monetary regimes (NM, OM1, OM2), informing us on whether and by how much a flexible rate regime implies a larger elasticity than monetary union for the exchange rate of the external country[14].

Table 3. Comparing Exchange Rate Responsiveness Under FX and MU, for Parameter Set S1							
Elasticity of e_{1MU} with respect to the different shocks, and percentage difference between the absolute values of the elasticities of e_{1FX} and e_{1MU}, under the three weighting schemes (EW, SW, TW) and the three monetary regimes (NM, OM1, OM2).							
			$\hat{\alpha}_A$	$\hat{\alpha}_B$	$\hat{\delta}_A$	$\hat{\delta}_B$	$\hat{\delta}_C$
$\hat{e}_{1MU}$ (partial derivative)	NM		-0.128	0.016	-0.125	0.025	0.008
	OM1		-0.103	0.012	-0.172	0.061	0.037
	OM2		-0.102	0.013	-0.172	0.063	0.036
$\dfrac{\left(\left|\hat{e}_{1FX}\right|-\left|\hat{e}_{1MU}\right|\right)100}{\left|\hat{e}_{1MU}\right|}$ (Percentage change in partial derivative)	NM	EW	0.26	-7.00	0.06	-3.57	3.64
		SW	-0.03	0.76	0	0.39	-0.40
		TW	-1.16	31.60	-0.18	16.10	-16.45
	OM1	EW	-0.03	0.76	0.01	0.20	-0.17
		SW	-0.31	9.21	0.06	2.43	-2.05
		TW	-1.45	42.77	0.29	11.29	-9.52
	OM2	EW	0.27	-7.17	-0.05	-2.01	1.77
		SW	-0.02	0.61	0	0.17	-0.15
		TW	-1.16	31.53	0.23	8.83	-7.76

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[13](...continued)
OM2 the case of optimizing monetary policies with country-size weights.

[14]As there are three measures of $\hat{e}_{1FX}$, depending on the weighting scheme, the percentage change is calculated from MU to FX in order to maintain the same denominator.

Table 4. Comparing Exchange Rate Responsiveness Under FX and MU, for Parameter Set S2							
Elasticity of e_{1MU} with respect to the different shocks, and percentage difference between the absolute values of the elasticities of e_{1FX} and e_{1MU}, under the three weighting schemes (EW, SW, TW) and the three monetary regimes (NM, OM1, OM2).							
			$\hat{\alpha}_A$	$\hat{\alpha}_B$	$\hat{\delta}_A$	$\hat{\delta}_B$	$\hat{\delta}_C$
$\hat{e}_{1MU}$ (partial derivative)	NM		-0.537	0.242	-0.227	0.129	0.010
	OM1		-0.445	0.052	-0.499	0.217	0.145
	OM2		-0.402	0.181	-0.498	0.351	0.081
$\dfrac{(|\hat{e}_{1FX}|-|\hat{e}_{1MU}|)100}{|\hat{e}_{1MU}|}$ (Percentage change in partial derivative)	NM	EW	6.33	-45.70	5.46	-41.84	52.77
		SW	-2.12	15.33	-1.83	14.04	-17.71
		TW	-3.73	26.92	-3.22	24.65	-31.09
	OM1	EW	-2.71	69.09	-0.09	17.35	-12.30
		SW	-11.26	287.35	-0.37	72.16	-51.16
		TW	-12.88	328.78	-0.42	82.56	-58.53
	OM2	EW	7.69	-51.18	0.23	-27.50	56.20
		SW	-1.78	11.85	-0.05	6.36	-13.01
		TW	-3.58	23.81	-0.11	12.79	-26.14

The pattern of signs in Tables 3 and 4 is consistent with the theoretical analysis developed in the previous section:

• Under the country-size or trade weighting schemes (SW, TW), a flexible rate regime implies a larger response of the exchange rate of country 1 versus 2 and 3 to shocks affecting sector B (in which the large member of the union, country 2, is specialized).

• Monetary union implies a stronger response of the external exchange rate to shocks related to the sector in which the small country of the union is specialized (note that $\hat{\alpha}_A$ is a shock between good A and C, the latter being the good in which country 3 is specialized).

- The opposite conclusions tend to hold for the less relevant case in which the average exchange rate of country 1 versus 2 and 3 is calculated with equal weights (EW).[15]

Furthermore, the distinction between exogenous and optimizing monetary policies does not usually alter the rankings of the exchange rate responses under FX and MU, apart from in the relatively uninteresting case of EW-OM1[16].

For both parameter sets (S1, S2), the largest differences between the exchange rate responses in the two exchange rate regimes are usually observed for shocks to sector B. As one might expect, with few exceptions the difference between exchange rate responses to any given shock increases strongly with the difference in the sizes and the degrees of specialization of the two countries forming the union. When the two countries are similar, the difference between e_{12} and e_{13} generates mostly a relative adjustment between countries 2 and 3, and the externality effects on both the adjustment and the trade balance of country 1 are very small.

VII. CONCLUSIONS

This paper has shown on a theoretical basis that the sources of shocks, the patterns of specialization, and the sizes of countries are crucial in determining whether a monetary union will increase or decrease the variability of the exchange rate of the union versus the currencies of outside countries. By focusing on the role of fundamentals in the international adjustment process, this paper complements recent literature that has emphasized the effects of game-theoretical interactions among monetary and fiscal authorities of the various countries.

The paper has developed a three-country, three-good factor-specific model of trade in which to investigate the short-run adjustment to demand and supply shocks in the presence of wage rigidities. It then compared, for each type of shock, the response of the exchange rate of the monetary union versus an external currency, with the response of the average of a weighted average of the bilateral exchange rates of each of the two countries forming the union versus the external currency. Three types of weights were discussed: country-size weights, trade weights, and equal weights.

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[15]Apart from case OM1, in which authorities employ optimal monetary policy and the union minimizes an equal weighted average of the utility function of countries 2 and 3.

[16]When authorities of the union weigh equally the two countries' utility functions (OM1), they respond disproportionately more to shocks to the small country of the union (country 3). This implies that the equilibrium $\hat{e}_{13AD}$ actually needs to move less, in absolute value, than $\hat{e}_{12AD}$. Hence, the equal weight average of the two exchange rates (EW) will automatically be dominated by $\hat{e}_{12AD}$, as in the case of SW or TW.

When the country-size or trade weighting schemes are adopted one finds the following results. For shocks to the sector in which the large (small) country of the union is specialized, exchange rate variability (versus an external currency) is higher (lower) under the pre-union flexible rate regime than after the monetary union is established. In fact, the bilateral exchange rate of the external country versus the large country of the union drives the external exchange rate of the union, and it moves more (less) under flexible rates than under monetary union in response to shocks to the sector in which the large (small) country of the union is specialized.

For the equal weighting scheme, the opposite results emerge, because it is the bilateral exchange rate of the external country versus the small country of the potential union that drives the external exchange rate of the potential union.

The intuition is simple and can be explained in two steps. First, whenever there is a shock to the good in which *one* country of the potential union is specialized, the bilateral exchange rate between that country and the external country moves more under flexible rates than under monetary union, as *that* country drives the potential union trade balance for that shock. Second, under the country-size or trade weighting scheme, the bilateral exchange rate of the external country versus the large country of the union *always* dominates the weighted average of the bilateral flexible rates. The opposite holds for the equal weighting scheme.

Simulations provide three interesting results. First, the difference between the variability of the exchange rate under flexible rates and the variability in the presence of a monetary union widens extensively with differences in the sizes and patterns of specialization of the countries forming the union. Second, shocks to the industry in which the large country of the union is specialized generate much larger differences in variability than shocks to the industry in which the small country is specialized. Third, optimizing monetary policy does not alter the implications for the variability of the exchange rate (apart from in the relatively uninteresting case of equal weights).

The latter point deserves emphasis. In particular, insofar as Kenen (1995), Bergsten (1997), and others have argued that the game-theoretic interactions between monetary authorities of different countries are a source of different degrees of exchange rate variability under flexible rates or monetary union, it is important to note that within the general equilibrium framework explored in this paper, the presence of such interactions does not reverse the results derived in the absence of optimizing monetary policy.

If the formation of a euro area does not have first-order effects in the short run on the supply or demand sides of different countries, or on patterns of trade between the euro area and the rest of the world,[17] the analytic framework developed in this paper—including, in particular, the setup with optimizing monetary policies—would appear to provide a

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[17]It may be noted here that Ricci (1997b) finds that countries creating a currency area tend to induce a decrease in their degree of trade specialization.

reasonable basis for making conjectures about the effects of EMU on exchange rate variability.[18] Thus, in considering how the variability of the exchange rate of the U.S. dollar versus the euro after EMU will compare with the variability of the dollar's weighted-average exchange rate against a basket of the present currencies of the countries that participate in EMU, other things equal, the model provides a basis for the following conjectures. For shocks to the industries in which large euro-area countries are specialized, variability is likely to be lower under EMU than under the present regime. For shocks to the industries in which the euro-area countries are specialized, variability is likely to be higher under EMU. Hence, whether EMU will increase the variability of the dollar's exchange rate will depend on the relative importance of shocks to different sectors, as well as on the patterns of specialization and sizes of the countries participating in EMU.

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[18]Although the exchange rates between the present currencies of prospective euro-area members are relatively fixed in the short run, the present regime has involved some degree of short-run flexibility and a considerable degree of medium-run flexibility. Moreover, the future may involve a moderate degree of exchange rate flexibility for European countries that do not participate in EMU. Thus, comparisons of variability under monetary union with variability under completely flexible rates provide relevant benchmarks for making qualitative conjectures about the implications of EMU.

The equations below express the percentage changes in sectoral employments as functions of the various types of shocks. These equations are used in the derivations described in Section 4.1.

$$\hat{L}_{A1} = \hat{\alpha}_A + \sum_{i=1}^{3}\left(\frac{L_i}{L}\hat{M}_i\right) + \left(\frac{L_2}{L}+\frac{1}{2+\gamma_A}\right)\hat{e}_{12} + \left(\frac{L_3}{L}+\frac{1}{2+\gamma_A}\right)\hat{e}_{13} + \left(1+\frac{2\ln(\gamma_A)}{2+\gamma_A}\right)\hat{\delta}_A$$

$$\hat{L}_{B1} = \hat{\alpha}_B + \sum_{i=1}^{3}\left(\frac{L_i}{L}\hat{M}_i\right) + \left(\frac{L_2}{L}+\frac{\gamma_B}{2+\gamma_B}\right)\hat{e}_{12} + \left(\frac{L_3}{L}+\frac{1}{2+\gamma_B}\right)\hat{e}_{13} + \left(1-\frac{\gamma_B\ln(\gamma_B)}{2+\gamma_B}\right)\hat{\delta}_B$$

$$\hat{L}_{C1} = \hat{\alpha}_C + \sum_{i=1}^{3}\left(\frac{L_i}{L}\hat{M}_i\right) + \left(\frac{L_2}{L}+\frac{1}{2+\gamma_C}\right)\hat{e}_{12} + \left(\frac{L_3}{L}+\frac{\gamma_C}{2+\gamma_C}\right)\hat{e}_{13} + \left(1-\frac{\gamma_C\ln(\gamma_C)}{2+\gamma_C}\right)\hat{\delta}_C$$

$$\hat{L}_{A2} = \hat{\alpha}_A + \sum_{i=1}^{3}\left(\frac{L_i}{L}\hat{M}_i\right) - \left(2-\frac{L_2}{L}-\frac{1}{2+\gamma_A}\right)\hat{e}_{12} + \left(\frac{L_3}{L}+\frac{1}{2+\gamma_A}\right)\hat{e}_{13} + \left(1-\frac{\gamma_A\ln(\gamma_A)}{2+\gamma_A}\right)\hat{\delta}_A$$

$$\hat{L}_{B2} = \hat{\alpha}_B + \sum_{i=1}^{3}\left(\frac{L_i}{L}\hat{M}_i\right) - \left(2-\frac{L_2}{L}-\frac{\gamma_B}{2+\gamma_B}\right)\hat{e}_{12} + \left(\frac{L_3}{L}+\frac{1}{2+\gamma_B}\right)\hat{e}_{13} + \left(1+\frac{2\ln(\gamma_B)}{2+\gamma_B}\right)\hat{\delta}_B$$

$$\hat{L}_{C2} = \hat{\alpha}_C + \sum_{i=1}^{3}\left(\frac{L_i}{L}\hat{M}_i\right) - \left(2-\frac{L_2}{L}-\frac{1}{2+\gamma_C}\right)\hat{e}_{12} + \left(\frac{L_3}{L}+\frac{\gamma_C}{2+\gamma_C}\right)\hat{e}_{13} + \left(1-\frac{\gamma_C\ln(\gamma_C)}{2+\gamma_C}\right)\hat{\delta}_C$$

$$\hat{L}_{A3} = \hat{\alpha}_A + \sum_{i=1}^{3}\left(\frac{L_i}{L}\hat{M}_i\right) + \left(\frac{L_2}{L}+\frac{1}{2+\gamma_A}\right)\hat{e}_{12} - \left(2-\frac{L_3}{L}-\frac{1}{2+\gamma_A}\right)\hat{e}_{13} + \left(1-\frac{\gamma_A\ln(\gamma_A)}{2+\gamma_A}\right)\hat{\delta}_A$$

$$\hat{L}_{B3} = \hat{\alpha}_B + \sum_{i=1}^{3} \left(\frac{L_i}{L} \hat{M}_i \right) + \left(\frac{L_2}{L} + \frac{\gamma_B}{2+\gamma_B} \right) \hat{e}_{12} - \left(2 - \frac{L_3}{L} - \frac{1}{2+\gamma_B} \right) \hat{e}_{13} + \left(1 - \frac{\gamma_B \ln(\gamma_B)}{2+\gamma_B} \right) \hat{\delta}_B$$

$$\hat{L}_{C3} = \hat{\alpha}_C + \sum_{i=1}^{3} \left(\frac{L_i}{L} \hat{M}_i \right) + \left(\frac{L_2}{L} + \frac{1}{2+\gamma_C} \right) \hat{e}_{12} - \left(2 - \frac{L_3}{L} - \frac{\gamma_C}{2+\gamma_C} \right) \hat{e}_{13} + \left(1 + \frac{2\gamma_C \ln(\gamma_C)}{2+\gamma_C} \right) \hat{\delta}_C$$

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