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THE TERMS OF TRADE, THE REAL EXCHANGE RATE, AND ECONOMIC FLUCTUATIONS*

BY ENRIQUE G. MENDOZA[1]

This paper examines the relationship between terms of trade and business cycles using a three-sector intertemporal equilibrium model and a large multi-country database. Results show that terms-of-trade shocks account for nearly 1/2 of actual GDP variability. The model explains weak correlations between net exports and terms of trade (the Harberger, Laursen, and Metzler effect), and produces large and weakly-correlated deviations from purchasing power parity and real interest rate parity. Terms-of-trade shocks cause real appreciations and positive interest differentials, although productivity shocks have opposite effects. The puzzle that welfare gains of international asset trading are negligible is left unresolved.

1. INTRODUCTION

Large and recurrent fluctuations in the terms of trade are widely viewed as an important driving force of recent business cycles. Sharp fluctuations in economic activity affected many industrial and developing countries after the large oil-price increases of the 1970s, and the subsequent abrupt declines the following decade. During the 1980s, there were also marked fluctuations in prices of nonoil primary commodities that resulted in large terms-of-trade shocks for developing countries—the terms of trade rose by 7 percent in 1983–84 for exporters of nonoil primary commodities, and fell by more than 18 percent in 1985–90 (see IMF 1991). Terms-of-trade shocks affected economic activity in industrial countries mainly by rising the relative price of energy, as examined by Hamilton (1983) and Finn (1991), while in developing countries this effect was magnified by dependence on imported capital goods and specialization in commodity exports. Accessibility to world financial markets, which help smooth consumption by financing trade imbalances, also played an important role (see Sachs 1981 and IMF 1991).

This paper conducts an empirical examination of the relationship between terms-of-trade shocks and business cycles from the perspective of an intertemporal general equilibrium framework. The study borrows numerical solution methods from real business cycle (RBC) theory to compute the equilibrium stochastic processes of a three-sector intertemporal model of a small open economy, and compares various features of the model's business cycles with actual business cycles. The model incorporates transmission mechanisms via international capital mobility, the cost of imported inputs, and the overall purchasing power of exports.

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Despite extensive theoretical work on the macroeconomic effects of terms-of-trade shocks based on equilibrium models, actual comovements between terms of trade and other macro-aggregates have not been examined in detail, nor have they been compared with theoretical predictions.[2] Thus, the paper begins by documenting some key empirical regularities. The statistical evidence for the group of seven largest industrialized countries (G-7) and 23 developing countries (DCs) highlights four facts:

1) Terms-of-trade shocks are large, persistent, and weakly procyclical.
2) Net exports-terms of trade correlations are low and positive, and independent of terms-of-trade autocorrelations.
3) Cycles are larger in DCs, but all countries have similar variability ratios, autocorrelations, and GDP correlations.
4) Real exchange rate fluctuations are large and procyclical.

The paper shows that business cycles in model economies driven by terms-of-trade shocks identical to those observed in the data, together with rough estimates of domestic sectoral productivity shocks, are generally consistent with these observations. Moreover, terms-of-trade shocks account for 45 to 60 percent of the observed variability of GDP and real exchange rates, although productivity shocks still play an important role. Macroeconomic dynamics in response to terms-of-trade shocks differ significantly from those induced by domestic productivity shocks; in particular, real exchange rates and real interest differentials are procyclical in response to the former, but countercyclical in response to the latter. In both cases, labor supply effects are negligible.

There is growing interest among international business cycle researchers in exploring issues similar to those studied here. Recent studies for small open economies examine models in which all goods are tradable and insurance markets are incomplete (Lundvik 1991, Mendoza 1991a, and Correia, Neves, and Rebelo 1993). These models explain several business cycle facts, but they impose purchasing power parity (PPP) and real interest rate parity (RIRP), and hence induce near-perfect correlation between consumption and GDP and cannot explain the observed breakdown of parity conditions. In theory, neoclassical models explain the breakdown of these conditions by introducing nontraded goods, as in Greenwood (1984), but little is known about the quantitative implications of this approach.[3] Mendoza (1992a) introduced nontraded goods into a quantitative model of a small open endowment economy. The resulting consumption-GDP correlations are more realistic because the domestic real interest rate varies with the terms of trade and the relative price of nontradables. However, absence of investment and production decisions produced unrealistic dynamics for net exports and real exchange rates. These restrictive assumptions are relaxed in this paper with the result that net exports- and consumption-GDP correlations are brought in line with observed stylized facts. Moreover, the model explains observed low positive

[2] Frenkel and Razin (1987) and Razin (1993) review the theoretical literature. Recently, Backus et al. (1992b) and Mendoza (1992a) examined some stylized facts of the terms of trade in G-7 countries.

[3] Tesar's (1993) analysis of risk-sharing implications of nontraded goods is an early contribution in this area.

correlations between real exchange rates and real interest rate differentials at business cycle frequencies, as documented by Baxter (1994), without limiting capital mobility or imposing price stickiness.

International RBC research has also examined two-country world equilibrium models with complete insurance markets following Backus et al. (1992a) and Baxter and Crucini (1993). Backus et al. (1992b) and Stockman and Tesar (1990) studied three-sector extensions with trade specialized in either capital or consumption goods, and found that, although the models explain key empirical regularities, terms of trade in the data fluctuate 2 to 6 1/2 times more than in the models. Thus, although terms of trade in these models are endogenous and reflect productivity shocks, the effects of changes in relative prices of traded goods are not fully captured. In contrast, by focusing on the small open economy, this paper introduces shocks to terms of trade of the magnitude observed in the data directly as an input for model simulations. While this strategy implies that terms-of-trade shocks are exogenous, it is consistent with McCallum's (1989) view that RBC models should incorporate terms-of-trade effects to reduce their reliance on controversial measures of productivity shocks, and to isolate effects of changes in key imported input prices such as oil. As Finn (1991) showed, energy price shocks can account for 1/3 of GDP variability in a closed-economy RBC model of the U.S. economy, and they bias conventional measures of Solow residuals. The model examined here also departs from the two-country framework in two respects. First, risk-free bonds are the only claim exchanged internationally, and hence insurance markets are incomplete.[4] Second, both capital and consumption goods are traded internationally to be consistent with the fact that 2/3 of a typical country's imports are inputs and 1/3 are consumption goods (see Mendoza 1992b for details).

International and closed-economy RBC models share the puzzling feature that welfare costs of business cycles are minimal—less than 1/10 of a percent in terms of compensating variations in stationary consumption streams (Lucas 1987). Moreover, costs of limiting trade in goods or assets in open-economy models are also minimal (see Mendoza 1991b and Backus et al. 1992a). Since these puzzles originated in models where risk sharing and consumption smoothing are facilitated by the fact that there is only intertemporal trade in a single homogenous good, extensions in which importables, exportables, and nontradables are differentiated were viewed as a potential solution. However, this paper shows that in such a three-sector setting, costs of business cycles or restricted asset trading are still minimal, although costs for developing economies exceed those for G-7 countries.

This paper also seeks to integrate the RBC framework with the intertemporal equilibrium approach to the analysis of terms-of-trade effects originated in the seminal work of Obstfeld (1982) and Svensson and Razin (1983). These studies, and the extensive literature that followed (see Persson and Svensson 1985 and Razin 1993), criticized the Keynesian analysis of the effects of terms-of-trade shocks on

[4] Market incompleteness limits the agents' ability to insure away country-specific shocks and strengthens the wealth effects of these shocks. This could induce excessive consumption variability, but Mendoza (1991a) showed that it is not always the case. Moreover, Backus et al. (1992a) and Baxter and Crucini (1993) found that complete markets result in excessive risk sharing and exaggerate international consumption correlations.

net exports by Harberger (1950) and Laursen and Metzler (1950). The Harberger-Laursen-Metzler (HLM) effect argued that, when terms-of-trade worsen, net exports and savings decline because a fall in the purchasing power of exports is a reduction in income, and marginal propensities to consume and save are less than unitary. In contrast, the Obstfeld-Svensson-Razin framework showed that, under conditions of perfect capital mobility and competitive world capital markets, the effect of terms-of-trade shocks on net exports depends on the perceived duration of those shocks. In general, with a fixed rate of time preference, transitory shocks result in the HLM effect, as agents borrow from abroad to finance a temporary trade deficit and hence smooth consumption, but permanent changes tend to leave net exports unaffected.

Although this literature questioned Keynesian analysis, it did not examine the link between terms of trade and business cycles because it focused on deterministic, endowment-economy models. It also did not provide evidence on the size of actual terms-of-trade shocks, the extent to which persistence of these shocks explains net exports-terms of trade correlations, and the fraction of real exchange rate movements accounted for by real factors. In fact, the data cast doubt on the predictions of intertemporal models. Net exports and terms of trade are positively correlated (i.e., there is a HLM effect), but the correlations are low and independent of the persistence of terms-of-trade shocks. Moreover, observed real exchange rate variability seems too large to be accounted for only by real shocks affecting the relative price of nontradables (see Mussa 1990). This paper shows, however, that the intertemporal equilibrium framework accounts for both the observed cross-country pattern of net exports terms of trade correlations and for large fluctuations in real exchange rates driven by real shocks.

The rest of the paper is organized as follows. Section 2 reviews empirical regularities. Section 3 presents the model. Section 4 discusses parameter values. Section 5 presents results of benchmark simulations. Section 6 undertakes impulse response and sensitivity analysis. Section 7 concludes.

2. EMPIRICAL REGULARITIES

The study of industrial-country business cycles has received much attention recently, but less work has focused on developing economies.[5] One reason for this imbalance is that documenting business cycles for a large set of countries involves dealing with international databases created with country data of uneven quality, short samples, and limited coverage. In order to combine available information efficiently to construct comparable statistics for the 30 countries examined here, data were obtained from the IMF's WEO Database and *International Financial Statistics Yearbook 1993* and the World Bank's World Tables included in the *Socio-economic Time-series Access and Retrieval System* (STARS) as of October 1993. The data are annual series of U.S. dollar import and export unit values; U.S. dollar credits and debits in the trade balance and factor payments accounts of the

[5] See Backus and Kehoe (1992), Backus et al. (1992a), and Baxter and Crucini (1993). Costello and Praschnik (1992) and Mendoza (1992b) report some stylized facts for developing economies.

balance of payments; real and nominal GDP, consumption, and investment from national accounts; the average U.S. dollar exchange rate; the CPI-based, trade-weighted real effective exchange rate; and total population. The sample varies slightly with country and variable, but in general it covers 1955–90 for G-7 countries and 1960–90 for DCs.

Imports are selected as ''numeraire'' and hence terms of trade are the ratio of export to import unit values and all variables are measured at constant *import* prices.[6] This ensures consistency in the manner in which wealth effects, caused by variations in the purchasing power of exports, influence all endogenous variables in the model (see Frenkel and Razin 1987, 171–182). For instance, given a fixed exportable endowment and imports determined by wealth and the terms of trade, a terms-of-trade gain widens the trade deficit defined as real exports minus real imports—each deflated using the corresponding price index—but does not always widen the trade deficit defined as exports at import prices minus real imports. The latter measure of net exports falls or not depending on the persistence of the terms-of-trade gain and hence on its effect on permanent income or wealth.

The measure of terms of trade based on unit values does not reflect ''direct'' price indexes based on price surveys taken from exporters and importers. Instead, unit values are indexes obtained by dividing an index of current values of imports or exports over a corresponding volume index, both constructed using balance-of-payments data. However, as noted in IMF (1993), only a few countries compute direct trade price indexes and use them to construct trade deflators for national accounts. In most DCs these deflators do not reflect direct pricing, and balance-of-payments data are more reliable than national accounts. Thus, unit values are commonly used to measure terms of trade (see IMF 1991 and 1993, and UNCTAD 1989). Nevertheless, differences resulting from the use of unit values instead of national accounts deflators do not seem significant if one compares moments in Table 1 with moments reported by Stockman and Tesar (1990) and Backus et al. (1992b), as explained below.

Tables 1 to 6 list business cycle indicators for terms of trade (TOT), trade balance (TB), gross domestic product (GDP), private consumption (C), fixed investment (I), and the real effective exchange rate (RER). Moments reported in the tables correspond to cyclical components of Hodrick-Prescott (HP) filtered data. Figure 1 plots actual observations and HP trends for GDP and TOT in two randomly selected countries, Canada and Kenya. These charts illustrate the magnitude of terms-of-trade shocks and provide an informal indication of their relationship with GDP fluctuations. The charts also suggest a positive link between GDP growth and the rate of change in terms of trade, the study of which is beyond the scope of this paper.

Despite the controversy surrounding filtering methods, there is evidence suggesting that filters other than the HP filter produce similar results for some of the statistics used in this study. An earlier version of this paper (Mendoza 1992b) applied a quadratic time trend to similar data; HP standard deviations are smaller,

[6] Empirical regularities for standard real national accounts are documented in a Statistical Supplement available from the author on request.

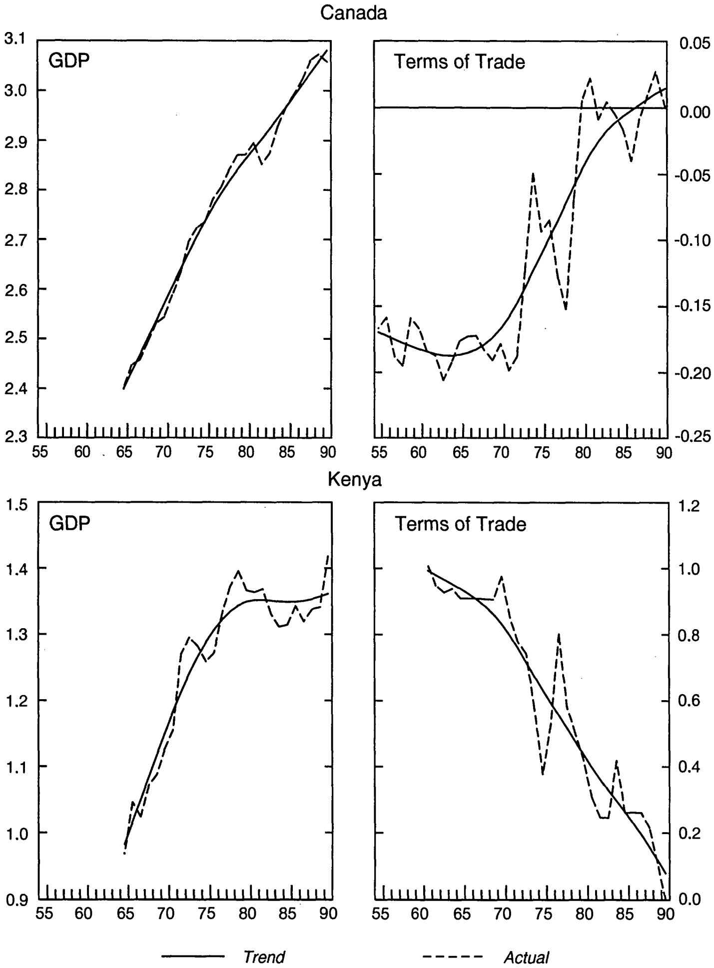

FIGURE 1

but ratios of standard deviations, correlations, and autocorrelations do not differ significantly. Moments computed for terms of trade by Stockman and Tesar (1990) and Backus et al. (1992b) for industrial countries using first difference and HP filters are roughly consistent with those reported in Table 1—taking into account that these authors defined terms of trade as the ratio of import to export deflators and that Backus et al. used quarterly data.

Table 1 reports standard deviations, contemporaneous correlations, and first-order autocorrelations of TOT and TB, and TB-GDP correlations. This table illustrates two important facts: 1) TB-TOT correlations are generally low and positive (the only statistically significant negative correlation is that for the United States), and they are not systematically related to first-order autocorrelations of TOT (see Figure 2). Regressing TB-TOT correlations on the autocorrelation of TOT produces a slope coefficient of -0.15 with a standard error of 0.34, and the fitted

TABLE 1
THE TERMS OF TRADE AND THE REAL TRADE BALANCE: SUMMARY STATISTICS*

	Terms of Trade		Real Trade Balance				
	σ	$\rho(1)$	σ	σ_{tb}/σ_{tot}	$\rho(1)$	$\rho_{tb,tot}$	$\rho_{tb,y}$
A. *Industrialized Countries: Group of Seven*							
United States	4.11	0.505	8.77	2.13	0.389	−0.490	−0.640
United Kingdom	4.05	0.532	7.08	1.75	0.322	0.658	0.375
France	3.30	0.314	6.15	1.86	0.290	0.303	0.338
Germany	4.01	0.460	4.63	1.15	0.432	0.324	0.054
Italy	4.76	0.465	7.85	1.65	0.251	0.415	0.402
Canada	2.87	0.434	4.75	1.66	0.329	−0.100	0.137
Japan	10.04	0.598	11.07	1.10	0.282	0.575	0.607
Mean	4.73	0.473	7.19	1.62	0.328	0.241	0.182
B. *Developing Countries: Western Hemisphere*							
Argentina	8.34	−0.034	24.20	2.90	0.287	0.577	−0.173
Brazil	12.02	0.468	18.65	1.55	0.445	0.136	−0.148
Chile	11.56	0.350	15.83	1.37	0.245	0.182	−0.579
Mexico+	10.52	0.544	20.86	1.98	0.542	0.086	−0.473
Peru	9.79	0.213	24.79	2.53	0.506	0.262	−0.365
Venezuela+	20.44	0.475	26.87	1.31	0.354	0.636	0.026
Mean	12.11	0.336	21.87	1.94	0.397	0.313	−0.285
C. *Developing Countries: Middle East*							
Israel	4.05	0.428	10.18	2.51	0.356	0.533	−0.296
Saudi Arabia+	24.78	0.458	26.53	1.07	0.465	0.432	0.357
Egypt	8.23	0.227	13.66	1.66	0.462	0.132	−0.218
Mean	12.35	0.371	16.79	1.75	0.428	0.366	−0.052
D. *Developing Countries: Asia*							
Taiwan Province of China	7.37	0.296	11.53	1.56	0.416	0.642	0.134
India	8.12	0.475	13.32	1.64	0.541	0.332	0.049
Indonesia+	15.12	0.553	11.37	0.75	0.130	0.152	−0.376
Korea	6.89	0.578	14.70	2.13	0.474	−0.080	−0.199
Philippines	8.20	0.499	12.80	1.56	0.306	0.474	−0.375
Thailand	7.23	0.272	10.59	1.46	0.358	−0.051	−0.578
Mean	8.82	0.446	12.39	1.52	0.371	0.245	−0.224
E. *Developing Countries: Africa*							
Algeria+	20.42	0.396	20.77	1.02	0.213	0.433	−0.054
Cameroon+	12.17	0.569	15.47	1.27	0.397	0.282	0.101
Zaire	12.76	0.307	15.94	1.25	0.604	0.506	−0.113
Kenya	8.99	0.321	15.03	1.67	0.272	0.234	−0.091
Morocco	9.30	0.440	12.13	1.30	0.409	0.167	−0.164
Nigeria+	23.14	0.485	24.01	1.04	0.286	0.328	−0.099
Sudan	9.76	0.651	22.50	2.31	0.310	0.474	−0.069
Tunisia	11.48	0.541	10.80	0.94	0.319	0.412	−0.152
Mean	13.50	0.464	17.08	1.35	0.351	0.355	−0.080
Mean developing countries	11.77	0.414	17.07	1.60	0.378	0.317	−0.168

*Data from the IMF WEO Database for the period 1955–90 for the G-7 and 1961–90 for developing countries. Terms of trade are the ratio of export to import unit values with 1990 = 100. Trade data are current exports and imports in U.S. dollars, deflated by import unit values and divided by total population. Real exports, real imports and the terms of trade are logged and detrended using the Hodrick-Prescott filter with the smoothing parameter set at 100. The real trade balance corresponds to detrended exports minus detrended imports. σ is the percentage standard deviation, $\rho(1)$ is the first-order serial autocorrelation σ_{tb}/σ_{tot}, is the standard deviation of the trade balance relative to the terms of trade, $\rho_{tb,tot}$ is the correlation between terms of trade and the real trade balance, and $\rho_{tb,y}$ is the correlation between GDP at import prices and the real trade balance. A "+" sign identifies countries that are major fuel exporters according to WEO standard.

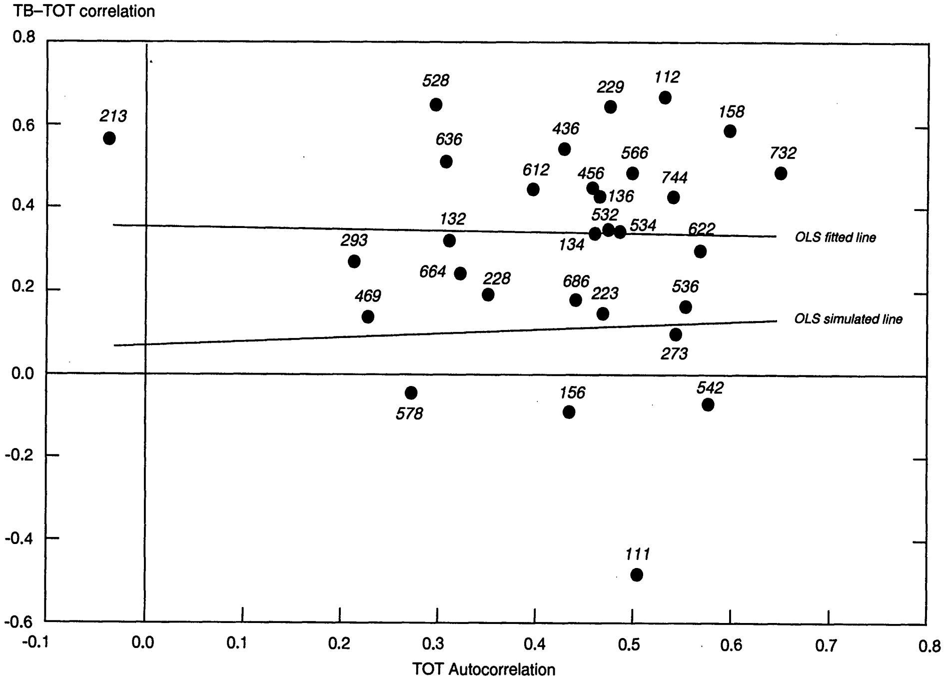

FIGURE 2

OLS line—as plotted in Figure 2—is virtually flat. 2) TB varies more in developing countries, where TOT also fluctuates more, but the ratio of TB variability relative to TOT variability is similar for all countries (1.1 on average). Terms of trade in the G-7 exhibit on average 4.7 percent standard deviation, 2.5 times less than in the DC average. Similarly, trade balances in DCs are 2 to 3 times more variable than in the G-7.

Positive TB-TOT correlations are consistent with the Obstfeld-Svensson-Razin framework, since TOT autocorrelations are generally positive (0.47 for G-7 and 0.41 for DCs on average), but the fact that the correlations do not fall as autocorrelations of TOT rise challenges the theory. The theoretical prediction follows from consumption-smoothing pro-saving and pro-borrowing wealth effects in deterministic, endowment economies that tend to cancel out as shocks become persistent, given the same preferences and technology, perfect international capital mobility, and competitive credit markets.[7] The following sections show that differences in tastes and technology, capital accumulation, and the covariance structure of terms-of-trade and productivity shocks account for this puzzle. Thus, the observation that TB-TOT correlations are low and independent of TOT autocorrelations is not an indicator of credit constraints or lack of capital mobility.

Another key dimension of the co-movement between terms of trade and trade flows is the extent to which the former depend on the latter. This is a crucial

[7] The assumption of incomplete markets is also crucial for this result. As Backus (1989) proved, under complete markets the comovement between TOT and TB is independent of country-specific shocks.

empirical question for small open economy models in which prices of traded goods are assumed to be determined in world markets. A rough first approximation to answer this question is obtained by studying Granger-Sims statistical causality. Table 2 presents results of Granger-Sims tests for the hypothesis that imports or exports cause the terms of trade. Except for the United States and a few major fuel exporters, the results show that exports and imports do not cause the terms of trade. Although caveats of causality tests apply—particularly the fact that causality between contemporaneous innovations is ignored—these results cannot reject the hypothesis of exogeneity of terms of trade for small open economies. Section 4 documents further evidence showing that contemporaneous innovations in terms-of-trade and productivity are weakly correlated in industrial countries.

The moments for GDP, C, and I reported in Tables 3 to 5 support the view that there is qualitative uniformity in business cycles across countries. C and I tend to fluctuate more than TOT and about as much as GDP in most countries. For standard real national accounts at domestic prices, C is generally less variable than TOT and slightly more variable than GDP,[8] while I varies about as much as TOT in many countries and more than GDP in all countries. Regardless of deflators, C and I are procyclical, and Y, C and I are positively autocorrelated. The correlations with TOT are generally positive for variables at import prices and only weakly positive for variables at domestic prices, and they tend to be stronger in G-7 countries. Qualitative features of business cycles in DCs are similar to those reported for industrial countries by Backus and Kehoe (1992).

There are also quantitative similarities in business cycles across countries. Although the G-7 exhibit less variability in GDP, C, and I than DCs, the ratios of variability relative to the standard deviation of TOT do not differ significantly. Comparing averages of regional means for the G-7 and the regions of DCs, the ratio of the standard deviation of GDP to the standard deviation of TOT at import prices (domestic prices) ranges from 1 to 1.69 (0.37 to 0.49), the ratio for C ranges from 1.08 to 2.21 (0.49 to 0.68), and the ratio for I is between 1.1 and 2.59 (1.03 and 2.02). First-order autocorrelations of TB, TOT, GDP, C, and I are also similar across countries. For the G-7 (DCs), averages of autocorrelations of these variables range from 0.33 (0.37) to 0.56 (0.51).

Table 6 reports business cycle regularities for RER. Because the sample covers only ten years, these moments must be interpreted with caution. RER fluctuates 5.8 and 12.4 percent on average for G-7 and DCs respectively, with autocorrelations for all countries generally near 0.4. Ratios of standard deviations are again uniform across countries and the RER-TOT correlation in DCs is smaller than that in G-7 countries. RER is also generally procyclical in terms of GDP at import prices, while correlations with GDP at domestic prices are near zero.

[8] These moments are reported in the Statistical Supplement. Consumption includes durables, if these are taken out C is usually less variable than GDP.

TABLE 2

EXPORTS, IMPORTS AND THE TERMS OF TRADE: *F*-STATISTICS FOR GRANGER-SIMS CAUSALITY TESTS*

	Exports Cause the Terms of Trade	Imports Cause the Terms of Trade
A. *Industrialized Countries: Group of Seven*		
United States	5.848††	1.167
United Kingdom	1.876	1.047
France	0.527	0.312
Germany	2.757	0.169
Italy	0.643	0.099
Canada	0.300	1.014
Japan	1.750	0.397
B. *Developing Countries: Western Hemisphere*		
Argentina	1.797	0.482
Brazil	1.119	0.102
Chile	1.171	0.393
Mexico†††	1.572	0.590
Peru	1.180	1.215
Venezuela†††	1.419	4.717†
C. *Developing Countries: Middle East*		
Israel	2.336	0.544
Saudi Arabia†††	4.611†	2.621
Egypt	1.727	0.105
D. *Developing Countries: Asia*		
Taiwan Province of China	0.436	0.821
India	0.515	0.816
Indonesia†††	1.350	1.262
Korea	1.574	0.489
Philippines	0.894	2.897
Thailand	0.926	0.021
E. *Developing Countries: Africa*		
Algeria†††	3.525†	0.796
Cameroon†††	2.080	4.489†
Zaire	0.406	5.547†
Kenya	0.701	1.399
Morocco	1.725	0.228
Nigeria†††	1.840	1.562
Sudan	2.818	1.097
Tunisia	0.777	1.979

*F-Statistics for the null hypothesis that $(\delta_1, \delta_2, \delta_3) = 0$ in the regression:

$$\chi_t = \alpha_0 + \beta_0\chi_{t-1} + \beta_1\chi_{t-2} + \beta_2\chi_{t-3} + \gamma_1 \text{tot}_{t-1} + \gamma_2 \text{tot}_{t-2} + \gamma_3 \text{tot}_{t-3} + \delta_0 \text{tot}_t + \delta_1 \text{tot}_{t+1} + \delta_2 \text{tot}_{t+2} + \delta_3 \text{tot}_{t+3}$$

where χ can be exports or imports. The data used in the regressions are the Hodrick-Prescott filtered deviations from trend. Degrees of freedom in the tests for industrial countries are (3, 19) and in the tests for developing countries are (3, 13).

†Denotes significance at the 5 percent level.
††Denotes significance at the 1 percent level.
†††Denotes a major fuel exporter according to WEO standard.

TABLE 3
REAL GDP AT CONSTANT IMPORT PRICES: SUMMARY STATISTICS

	σ_y	σ_{tot}	σ_y/σ_{tot}	$\rho(1)$	$\rho_{y,tot}$
A. *Industrial Countries: Group of Seven*					
United States	9.61	4.89	1.97	0.597	0.921
United Kingdom	7.53	4.65	1.62	0.521	0.812
France	7.21	3.89	1.85	0.374	0.894
Germany	8.57	4.51	1.90	0.557	0.837
Italy	10.26	5.43	1.89	0.552	0.964
Canada	3.30	3.32	0.99	0.289	0.083
Japan	17.51	10.91	1.60	0.569	0.982
Mean	9.14	5.37	1.69	0.494	0.785
B. *Developing Countries: Western Hemisphere*					
Argentina	28.54	8.91	3.20	0.305	0.090
Brazil	14.40	12.45	1.16	0.444	0.761
Chile	24.18	11.88	2.04	0.691	0.148
Mexico	12.93	11.31	1.14	0.374	0.641
Peru	13.77	10.35	1.33	0.343	0.238
Venezuela	10.10	22.20	0.45	0.432	0.012
Mean	17.32	12.85	1.55	0.432	0.315
C. *Developing Countries: Middle East*					
Israel	9.66	4.32	2.24	0.594	0.136
Saudi Arabia	17.73	26.89	0.66	0.667	0.718
Egypt	17.68	8.73	2.03	0.409	−0.455
Mean	15.02	13.31	1.64	0.557	0.133
D. *Developing Countries: Asia*					
Taiwan Province of China	10.37	5.67	1.83	0.447	0.609
India	11.39	8.70	1.31	0.576	0.813
Indonesia	11.37	15.65	0.73	0.518	0.346
Korea	14.13	7.34	1.93	0.623	0.886
Philippines	8.55	8.87	0.96	0.346	−0.285
Thailand	7.78	7.83	0.99	0.434	0.422
Mean	10.60	9.01	1.29	0.491	0.465
E. *Developing Countries: Africa*					
Algeria	11.47	22.06	0.52	0.512	−0.234
Cameroon	8.61	13.02	0.66	0.541	0.106
Zaire	22.17	13.39	1.66	0.598	−0.107
Kenya	9.02	9.66	0.93	0.473	0.572
Morocco	10.17	9.89	1.03	0.495	0.014
Nigeria	23.78	24.63	0.97	0.597	0.487
Sudan	16.96	10.18	1.67	0.329	0.265
Tunisia	7.18	12.12	0.59	0.533	−0.309
Mean	13.67	14.37	1.00	0.510	0.099
Mean developing countries	14.00	12.44	1.30	0.490	0.255

Note. Real GDP at constant import prices is the U.S. dollar value of GDP deflated using U.S. dollar import unit values. The data are expressed in per capita terms, logged, and detrended using the Hodrick-Prescott Filter with the smoothing parameter set at 100. The data cover the period 1965–90. The moments listed are the percentage standard deviation of GDP (σ_y), the percentage standard deviation of the terms of trade (σ_{tot}), the standard deviation relative to the standard deviation of the terms of trade (σ_y/σ_{tot}), the first-order serial autocorrelation ($\rho(1)$), and the correlation between GDP and the terms of trade ($\rho_{y,tot}$). The source of the data is the IMF WEO Database.

TABLE 4

REAL PRIVATE CONSUMPTION AT CONSTANT IMPORT PRICES: SUMMARY STATISTICS

	σ_{tot}	σ_c	σ_c/σ_{tot}	$\rho(1)$	$\rho_{c,y}$	$\rho_{c,tot}$
A. *Industrialized Countries: Group of Seven*						
United States	5.08	9.15	1.80	0.549	0.948	0.890
United Kingdom	4.89	8.30	1.70	0.527	0.983	0.732
France	4.08	6.82	1.67	0.265	0.968	0.878
Germany	4.61	8.24	1.79	0.527	0.959	0.868
Italy	5.61	9.60	1.71	0.429	0.948	0.942
Canada	3.48	3.36	0.97	0.330	0.953	−0.047
Japan	11.32	17.14	1.51	0.499	0.954	0.938
Mean	5.58	8.94	1.59	0.447	0.959	0.743
B. *Developing Countries: Western Hemisphere*						
Argentina	9.41	31.73	3.37	0.287	0.995	0.090
Brazil	13.14	14.73	1.12	0.400	0.951	0.839
Chile	11.81	22.29	1.89	0.627	0.966	0.136
Mexico	12.05	15.13	1.26	0.349	0.902	0.658
Peru	10.74	15.29	1.42	0.390	0.902	−0.059
Venezuela	23.17	12.35	0.53	0.277	0.930	0.001
Mean	13.38	18.59	1.60	0.388	0.941	0.278
C. *Developing Countries: Middle East*						
Israel	4.54	10.57	2.33	0.454	0.928	0.192
Saudi Arabia	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Egypt	9.27	19.47	2.10	0.416	0.943	−0.424
Mean	6.91	15.02	2.21	0.435	0.936	−0.116
D. *Developing Countries: Asia*						
Taiwan Province of China	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
India	9.17	12.53	1.37	0.535	0.937	0.875
Indonesia	16.37	12.59	−0.77	0.523	0.918	0.336
Korea	7.49	11.67	1.56	0.562	0.919	0.774
Philippines	9.36	8.54	0.91	0.270	0.942	−0.314
Thailand	8.18	6.54	0.80	0.233	0.844	0.328
Mean	10.11	10.37	1.08	0.425	0.912	0.400
E. *Developing Countries: Africa*						
Algeria	23.08	8.11	0.35	0.443	0.710	−0.248
Cameroon	13.70	11.37	0.83	0.411	0.593	−0.007
Zaire	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Kenya	10.22	8.72	0.85	0.420	0.833	0.071
Morocco	10.18	9.33	0.92	0.403	0.913	−0.005
Nigeria	25.97	24.79	0.95	0.550	0.946	0.412
Sudan	10.73	17.15	1.60	0.362	0.912	−0.150
Tunisia	12.47	4.92	0.39	0.493	0.905	0.060
Mean	15.19	12.06	0.84	0.441	0.830	0.019
Mean dev. cts.	12.55	13.89	1.27	0.421	0.894	0.178

Note. Real private consumption at constant import prices is the U.S. dollar value of private consumption deflated using U.S. dollar import unit values (1990 = 100). The data are expressed in per capita terms, logged and detrended using the Hodrick-Prescott filter with the smoothing parameter set at 100. The sample period is 1968–1990 and the source is the STARS database in World Bank (1993). The moments listed are the percentage standard deviation of consumption (σ_c), the percentage standard deviation of the terms of trade (σ_{tot}) the standard deviation relative to the standard deviation of the terms of trade (σ_c/σ_{tot}), the first-order serial autocorrelation ($\rho(1)$), the correlation between GDP and consumption ($\rho_{c,y}$), and the correlation between the terms of trade and consumption ($\rho_{c,tot}$).

TABLE 5
REAL PRIVATE INVESTMENT AT CONSTANT IMPORT PRICES: SUMMARY STATISTICS

	σ_{tot}	σ_i	σ_i/σ_{tot}	$\rho(1)$	$\rho_{i,y}$	$\rho_{i,tot}$	$\rho_{i,s}$
A. *Industrial Countries: Group of Seven*							
United States	5.08	11.04	2.17	0.500	0.894	0.747	0.965
United Kingdom	4.89	7.72	1.58	0.551	0.813	0.441	0.685
France	4.08	8.70	2.13	0.517	0.863	0.685	0.957
Germany	4.61	11.50	2.49	0.550	0.909	0.660	0.922
Italy	5.61	8.62	1.54	0.455	0.890	0.841	0.869
Canada	3.48	6.09	1.95	0.484	0.623	0.390	0.729
Japan	11.32	18.77	1.66	0.540	0.911	0.895	0.987
Mean	5.58	10.35	1.90	0.514	0.843	0.666	0.872
B. *Developing Countries: Western Hemisphere*							
Argentina	9.41	28.26	3.00	0.106	0.842	0.838	0.890
Brazil	13.14	20.76	1.58	0.582	0.880	0.670	0.935
Chile	11.81	23.17	1.96	0.666	0.818	0.205	0.603
Mexico	12.05	20.78	1.72	0.437	0.908	0.674	0.865
Peru	10.74	21.47	2.00	0.470	0.798	0.342	0.675
Venezuela	23.17	17.64	0.76	0.350	0.329	−0.299	−0.163
Mean	13.39	22.01	1.84	0.435	0.763	0.405	0.634
C. *Developing Countries: Middle East*							
Israel	4.54	12.90	2.84	0.506	0.806	−0.135	0.396
Saudi Arabia	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Egypt	9.27	21.64	2.33	0.276	0.830	−0.237	0.855
Mean	6.91	17.27	2.59	0.391	0.818	−0.186	0.626
D. *Developing Countries: Asian*							
Taiwan Province of China	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
India	9.17	11.62	1.27	0.527	0.888	0.911	0.934
Indonesia	16.37	11.58	0.71	0.420	0.671	0.579	0.544
Korea	7.49	16.92	2.26	0.638	0.790	0.671	0.824
Philippines	9.36	17.49	1.87	0.615	0.711	−0.601	0.732
Thailand	8.18	11.12	1.36	0.445	0.681	0.198	0.703
Mean	10.11	13.75	1.49	0.529	0.748	0.352	0.747
E. *Developing Countries: Africa*							
Algeria	23.08	12.09	0.52	0.450	0.599	−0.209	0.630
Cameroon	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Zaire	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Kenya	10.22	15.42	1.51	0.539	0.800	0.450	0.240
Morocco	10.18	17.65	1.73	0.557	0.626	0.055	0.688
Nigeria	25.97	23.06	0.89	0.564	0.708	0.489	0.653
Sudan	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Tunisia	12.47	10.72	0.86	0.642	0.334	0.151	0.463
Mean	16.38	15.79	1.10	0.550	0.613	0.187	0.535
Mean dev. cts.	12.59	17.46	1.62	0.488	0.723	0.264	0.637

Note. Real private investment at constant import prices is the U.S. dollar value of private fixed investment deflated using U.S. dollar import unit values (1990 = 100). The data are expressed in per capita terms, logged, and detrended using the Hodrick-Prescott filter with the smoothing parameter set at 100. The sample period is 1968–1990 and the source is the STARS database in World Bank (1993). The moments listed are the percentage standard deviation of investment (σ_i), the percentage standard deviation of the terms of trade (σ_{tot}), the standard deviation of investment relative to the standard deviation of the terms of trade (σ_i/σ_{tot}), the first-order serial autocorrelation ($\rho(1)$), the correlation between investment and GDP ($\rho_{i,y}$) the correlation between investment and the terms of trade ($\rho_{i,tot}$), and the correlation between investment and savings ($\rho_{i,s}$).

TABLE 6
REAL EFFECTIVE EXCHANGE RATE (REER): SUMMARY STATISTICS*

	σ_{tot}	σ_{REER}	$\sigma_{REER}/\sigma_{tot}$	$\rho(1)$	$\rho_{REER,GDP*}$	$\rho_{REER,GDP}$	$\rho_{REER,tot}$
A. *Industrial Countries: Group of Seven*							
United States	4.32	9.30	2.15	0.673	0.366	−0.481	0.681
United Kingdom	2.01	5.92	2.95	0.340	0.175	−0.551	0.730
France	4.49	2.89	0.64	0.484	0.740	0.337	0.492
Germany	5.35	3.43	0.64	0.216	0.949	0.481	0.910
Italy	5.12	2.84	0.55	0.133	0.830	0.094	0.829
Canada	2.42	5.20	2.15	0.484	0.028	−0.671	0.326
Japan	11.19	11.25	1.01	0.325	0.976	−0.051	0.965
Mean	4.99	5.83	1.44	0.379	0.581	−0.120	0.705
B. *Developing Countries: Western Hemisphere*							
Argentina	9.01	23.00	2.55	0.415	0.864	0.141	0.002
Brazil	13.61	13.08	0.96	0.427	0.517	−0.034	0.098
Chile	9.60	13.66	1.42	0.453	0.703	0.080	−0.476
Mexico+	11.64	14.46	1.24	0.276	0.883	0.724	0.800
Peru	6.73	17.22	2.56	0.581	0.679	−0.420	0.242
Venezuela+	21.12	14.18	0.67	0.426	0.911	−0.559	0.569
Mean	11.95	15.93	1.57	0.430	0.760	−0.011	0.206
C. *Developing Countries: Middle East*							
Israel	2.82	3.89	1.38	0.348	0.339	−0.610	0.013
Saudi Arabia+	29.24	9.42	0.32	0.574	0.547	0.048	0.787
Egypt	8.66	14.28	1.65	0.466	0.135	0.366	0.258
Mean	13.57	9.20	1.12	0.463	0.340	−0.065	0.353
D. *Developing Countries: Asia*							
Taiwan Province of China	6.36	5.32	0.84	0.322	0.370	−0.206	−0.226
India	5.10	8.53	1.67	0.493	0.369	0.015	0.131
Indonesia+	15.73	13.47	0.86	0.511	0.960	0.055	0.832
Korea	5.05	8.58	1.70	0.262	0.561	0.266	0.430
Philippines	10.21	8.43	0.83	0.213	0.275	0.173	−0.779
Thailand	5.84	7.14	1.22	0.623	−0.167	0.060	−0.739
Mean	8.05	8.58	1.19	0.404	0.395	0.061	−0.059
E. *Developing Countries: Africa*							
Algeria+	22.69	17.77	0.78	0.632	0.841	0.510	0.066
Cameroon+	7.94	6.49	0.82	0.572	0.189	−0.240	−0.663
Zaire	9.97	19.41	1.95	0.168	0.598	−0.303	0.021
Kenya	7.14	5.17	0.72	0.431	−0.112	−0.585	0.244
Morocco	5.46	3.44	0.63	0.286	0.391	0.364	0.117
Nigeria+	27.44	38.46	1.40	0.555	0.898	−0.387	0.564
Sudan	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Tunisia	7.90	6.24	0.79	0.579	0.715	0.442	0.434
Mean	12.65	13.85	1.61	0.460	0.503	−0.028	0.112
Mean Dev. Cts.	11.33	12.35	1.23	0.437	0.521	−0.005	0.124

Source. International Monetary Fund, *International Financial Statistics*, and Information Notice System.

*The data are for the period 1979–92. Real effective exchange rates are equal to nominal, trade-weighted effective exchange rates adjusted for relative changes in consumer prices. The data have been logged and detrended using the Hodrick-Prescott filter with the smoothing parameter set at 100. σ_{tot} is the percentage standard deviation of the terms of trade in the 1979–92 period. σ_{REER} is the standard deviation of REER in percent, $\sigma_{REER}/\sigma_{tot}$ is the standard deviation of REER relative to the standard deviation of terms of trade, $\rho(1)$ is the first-order serial autocorrelation of REER, $\rho_{REER,GDP*}$ is the correlation between REER and output at import prices, $\rho_{REER,GDP}$ is the correlation between REER and real GDP at constant prices, and $\rho_{REER,tot}$ is the correlation between REER and the terms of trade. A "+" sign identifies countries that are major fuel exporters according to WEO standard.

3. THE MODEL

Preferences. Infinitely-lived representative households consume four goods: nontradables, n, exportables, x, importables, f, and leisure l. Expected lifetime utility is given by[9]

$$(1)\quad U(x, f, n, l) = E\left[\sum_{t=0}^{\infty}\left\{u(x_t, f_t, n_t, l_t) \cdot \exp\left(-\sum_{\tau=0}^{t-1} v(x_\tau, f_\tau, n_\tau, l_t)\right)\right\}\right],$$

$$(2)\quad u(x, f, n, l) = \frac{([(x^a f^{1-a})^{-\mu} + n^{-\mu}]^{-1/\mu} l^{\omega})^{1-\gamma}}{1-\gamma},$$

$$(3)\quad v(x, f, n, l) = \beta \ln (1 + [(x^a f^{1-a})^{-\mu} + n^{-\mu}]^{-1/\mu} l^{\omega}),$$

$$0 \le a \le 1, \quad \mu > -1, \quad \gamma > 1, \quad \beta > 0, \quad \omega > 0.$$

In the instantaneous utility function (2), tradables and nontradables are represented in constant-elasticity-of-substitution (CES) form ($1/(1 + \mu)$ is the elasticity of substitution),[10] tradables are expressed in Cobb-Douglas unitary-elasticity form (a is the share of x in tradables expenditure), and leisure also enters in unitary-elasticity form (ω governs labor supply elasticity). The intertemporal elasticity of substitution in aggregate consumption is $1/\gamma$. The elasticity of the discount factor with respect to the CES-leisure composite is approximated by β.

Production Technology and Financial Markets. Firms produce goods using capital, which is an importable good, and labor services. For simplicity, it is assumed that at business cycle frequencies labor is inelastically supplied to traded-sector industries and capital is inelastically supplied to the nontraded sector. Capital is also perfectly substitutable between the two traded-sector industries. This is an extreme representation of the fact that capital-labor ratios in the traded sector are more variable and larger than those in the nontraded sector (Kravis, Heston, and Summers 1983), which is adopted because of data limitations. The drawback is that this limits sectoral transmission mechanisms of terms-of-trade shocks.

Firms maximize profits facing capital adjustment costs, which help distinguish real from financial capital thereby reducing investment variability under perfect capital mobility (see Mendoza 1991a). Agents trade noncontingent, one-period

[9] Obstfeld (1981) and Engel and Kletzer (1989) discuss the role of the endogenous discount factor present in this utility function on small open economy dynamics. Its use in RBC models was introduced in Mendoza (1991a).

[10] Share parameters in the CES form are omitted without loss of generality. These parameters are implicit in the steady-state determination of p^n, which is calibrated to mimic observed expenditure shares (see Section 4).

bonds paying a fixed interest rate in units of importables in a competitive world bond market, and exports are also sold in competitive world markets. Random shocks affect productivity in all sectors and the terms of trade. Resource constraints are

$$(4)\quad f_t + e_t^p p^x x_t = Q(e_t^p p^x e_t^x (K_t^x)^{1-\alpha x}(L^x)^{\alpha x} + e_t^f (K_t^f)^{1-\alpha f}(L^f)^{\alpha f}) - K_{t+1} + K_t(1-\delta) - \frac{\phi}{2}(K_{t+1}-K_t)^2 - A_{t+1} + A_t(1+r^*)$$

$$(5)\quad n_t = Qe_t^n (K^n)^{1-\alpha n}(L_t^n)^{\alpha n} - K^n + K^n(1-\delta)$$

$$(6)\quad l_t + L_t^n + L^x + L^f = T$$

for $t = 0, \dots, \infty$. Importables are the numeraire, so p^x is the mean world relative price of exportables and p_t^n is the endogenous domestic relative price of nontradables. e_t^i, for $i = x, f, n$, and e_t^p are shocks to sectoral productivity and the terms of trade, which follow stochastic processes to be defined later. Q scales total factor productivity. αi, for $i = x, f, n$, are labor income shares. K_t^x, K_t^f and the time-invariant K^n are capital stocks (since traded-sector capital is homogenous, $K_t = K_t^x + K_t^f$), and L_t^n and the time-invariant L^x and L^f are labor services hired in each sector. ϕ governs the marginal adjustment cost of capital, δ is a depreciation rate uniform across sectors, the net foreign asset position is A_t, the world's interest rate is r^*, and T is total time available for leisure and labor.

Equilibrium and Dynamic Programming Formulation. The competitive equilibrium is defined by stochastic processes $\{K_{t+1}, A_{t+1}, K_t^x, K_t^f, L_t^n, x_t, f_t, n_t, p_t^n, l_t\}_0^\infty$ that maximize (1) subject to (4) to (6). The optimality conditions are

$$(7)\quad \frac{\mathbf{U}_f(t)}{\exp(-v(t))E_t[\mathbf{U}_f(t+1)]} = (1+r^*),$$

$$(8)\quad \frac{\mathbf{U}_x(t)}{\mathbf{U}_f(t)} = e_t^p p^x,$$

$$(9)\quad \frac{\mathbf{U}_n(t)}{\mathbf{U}_f(t)} = p_t^n,$$

$$(10)\quad \frac{\mathbf{U}_l(t)}{\mathbf{U}_n(t)} = Qe_t^n \alpha n (K^n)^{1-\alpha n}(L_t^n)^{\alpha n - 1},$$

$$(11)\quad (e_t^p p^x) e_t^x (1-\alpha x)(K_t^x)^{-\alpha x}(L^x)^{\alpha x} = e_t^f (1-\alpha f)(K_t^f)^{-\alpha f}(L^f)^{\alpha f},$$

$$(12)\quad \exp(v(t))\mathbf{U}_f(t)[1+\phi(K_{t+1}-K_t)] = E_t[\mathbf{U}_f(t+1)((e_{t+1}^p p^x)Qe_t^x(1-\alpha x)(K_{t+1}-K_{t+1}^f)^{-\alpha x}(L^x)^{\alpha x} + (1-\delta) + \phi(K_{t+2}-K_{t+1}))].$$

Lifetime marginal utilities of consumption of $f(\mathbf{U}_f(t))$, $x(\mathbf{U}_x(t))$, $n(\mathbf{U}_n(t))$, and $l(\mathbf{U}_l(t))$, include the effect of the endogenous rate of time preference. Condition (7) sets the intertemporal marginal rate of substitution in consumption of f equal to its intertemporal relative price, $(1 + r^*)$, (8) to (10) set marginal rates of substitution between x and f, n and f, and l and n, equal to the corresponding relative prices, (11) determines sectoral allocations of capital across traded-sector industries by equating marginal products of capital, and (12) sets optimal investment by equating marginal costs and benefits of postponing consumption of f.

The optimization problem is simplified by expressing it as a dynamic programming problem in the state space comprised by K, A, and the shocks. This requires the following simplifications:

1) Using (2), (3), and (8), the equilibrium value of x is

$$\hat{x}_t = \left(\frac{a}{1-a}\right)\left(\frac{f_t}{e_t^p p^x}\right). \tag{13}$$

2) Equations (5), (10), and (13) imply that in equilibrium L^n solves the nonlinear equation

$$\frac{\omega[Qe_t^n(K^n)^{1-\alpha n}(\hat{L}_t^n)^{\alpha n} - \delta K^n]^{1+\mu}}{[(\hat{x}_t^a f^{1-a})^{-\mu} + (Qe_t^n(K^n)^{1-\alpha n}(\hat{L}_t^n)^{\alpha n} - \delta K^n)]^{-1}} = Qe_t^n \alpha n(K^n)^{1-\alpha n}(\hat{L}_t^n)^{\alpha n-1}(T - L^f - L^x - \hat{L}_t^n). \tag{14}$$

3) From (5), (9), (13), and (14), it follows that n and p^n are given by

$$\hat{n}_t = Qe_t^n(K^n)^{1-\alpha n}(\hat{L}_t^n)^{\alpha n} - \delta K^n \tag{15}$$

$$\hat{p}_t^n = \frac{(\hat{n}_t)^{-\mu-1}}{(\hat{x}_t^a f_t^{1-a})^{-\mu-1}(1-a)\hat{x}_t^a f_t^{-a}}. \tag{16}$$

4) Optimal sectoral allocations of capital solve (11), given $K_t = K_t^x + K_t^f$. The solutions are denoted

$$\hat{K}_t^x = k^x(K_t, e_t^p, e_t^x, e_t^f), \tag{17}$$

$$\hat{K}_t^f = k^f(K_t, e_t^p, e_t^x, e_t^f). \tag{18}$$

Given (13) to (18), the maximization of (1) subject to (4) to (6) can be written as

$$V(K_t, A_t, \lambda_t^s) = \max \left\{ \frac{[[(\hat{x}_t^a f_t^{1-a})^{-\mu} + (\hat{n}_t)^{-\mu}]^{-1/\mu}\hat{l}_t^{\omega}]^{1-\gamma}}{(1-\gamma)} + (1 + [(\hat{x}_t^a f_t^{1-a})^{-\mu} + (\hat{n}_t)^{-\mu}]^{-1/\mu}\hat{l}_t^{\omega})^{-\beta}\left[\sum_{u=1}^{4} \pi_{s,u} V(K_{t+1}, A_{t+1}, \lambda_{t+1}^u)\right]\right\}, \tag{19}$$

subject to,

$$(20)\quad f_t = (1-a)\Big[Q(e_t^p p^x e_t^x(\hat{K}_t^x)^{1-\alpha x}(L^x)^{\alpha x} + e_t^f(\hat{K}_t^f)^{1-\alpha f}(L^f)^{\alpha f}) - K_{t+1} + K_t(1-\delta) - \frac{\phi}{2}(K_{t+1}-K_t)^2 + (1+r^*)A_t - A_{t+1}\Big],$$

$$A_t,\ A_{t+1} \geq \Delta \quad \text{and} \quad K_t,\ K_{t+1},\ f_t \geq 0.$$

At any date t, A_t and K_t are given, realizations of all shocks are observed—i.e., a state of nature λ_t given by realizations e_t^i, for $i = x, f, n$, and e_t^p—and stochastic processes governing future realizations of shocks are known. Agents formulate optimal decisions for A_{t+1} and K_{t+1} and, given these, optimal allocations for K_t^x, K_t^f, L_t^n, x_t, f_t, n_t, p_t^n, and l_t are given by (13) to (18) and (20).[11]

Several algorithms are available for solving stochastic dynamic optimization problems like this one. Linear approximation methods are widely used in RBC models, but they may be unreliable in this case because of the large magnitude of terms-of-trade shocks and their interaction with productivity disturbances. Christiano (1989) and Dotsey and Mao (1992) showed that the accuracy of approximation methods worsens as the variance of the underlying shocks increases. The method applied here is an exact-solution procedure based on value-function and transition-probability iterations using discrete grids to approximate the state space. The drawback is that this method is memory intensive and allows only simple representations of shocks and a small number of state variables.

Shocks are assumed to follow two-point symmetric Markov chains according to the "simple persistence" rule, under the assumption that sectoral productivity shocks are perfectly correlated. This reduces the number of free parameters characterizing stochastic shocks to the following:

$$(21)\quad \sigma_{e^p} = e^p, \qquad \sigma_{e^i} = e^i, \qquad \rho_{e^i} = \rho_{e^p} = \theta \qquad \text{and} \qquad \rho_{e^i,e^p} = 4\Pi - 1 \quad \text{for } i = x, f, n.$$

Standard deviations, σ_{e^i} for $i = x, f, n$ and σ_{e^p}, are given by the size, in percent, of each shock as represented by the "high" states of the Markovian chains (e^i, for $i = x, f, n$, and e^p). ρ_{e^i}, $i = x, f, n$, and ρ_{e^p} are coefficients of first-order autocorrelation, which simple persistence forces to be equal to a common parameter θ, $-1 < \theta < 1$. Correlations between productivity shocks and terms-of-trade shocks, ρ_{e^i,e^p}, $i = x, f, n$, are determined by the long-run probability of the state of nature in which all shocks are "high" (Π).

The algorithm computes moments for variables in units of each variable or at import prices. Following Frenkel and Razin (1987), the algorithm is extended to compute also the consumer price index (CPI) that determines the equilibrium relative price of the CES composite. This CPI produces moments for consumption and real exchange rates comparable with standard definitions of real consumption and CPI-based real exchange rates—which involve weighted sums of prices of

[11] Δ in (20) is a nonbinding borrowing constraint that ensures intertemporal solvency as in Mendoza (1991a).

traded and nontraded goods. The model's CPI is derived by noting that, because the CES function is homogenous of degree one, there is an expenditure function with the following price index:

$$P_t = [(a^{-a}(1-a)^{-(1-a)}(e_t^p p^x)^a)^{\mu/(1+\mu)} + (\hat{p}_t^n)^{\mu/(1+\mu)}]^{(1+\mu)/\mu}. \tag{22}$$

Interest rate differentials can then be defined by noting that the domestic real rate of return of a risk-free asset in units of the CES composite is $(P_{t+1}/P_t)(1 + r^*)$. Similarly, it is of interest to construct a measure of GDP comparable to conventional real GDP, and consistent with the notion of an aggregate Cobb-Douglas technology. In this case, the aggregate Cobb-Douglas production function is represented as a geometric weighted average of sectoral Cobb-Douglas production functions.

4. BENCHMARK PARAMETERS

This section sets parameter values for industrial and developing benchmark economies. Parameterizing the model is difficult because the sectoral breakdown available in international databases is limited. The best approach to infer information on this breakdown is to refer to the detailed sectoral decompositions of production and expenditures contained in the work of Kravis, Heston, and Summers (1982) and (1983) (KHS). However, most KHS data are point observations for 1975, and hence the parameterizations proposed below are rough approximations.

Industrial Country Benchmark.

$$e^x = e^f = 1.9,\ e^n = 1.4,\ e^p = 4.7,\ \theta = 0.473,\ \rho_{e^x,e^p} = 0.165,\ r^* = 0.04, \tag{23}$$

$$\alpha x = 0.51,\ \alpha f = 0.73,\ \alpha n = 0.56,\ \delta = 0.1,\ \phi = 0.028,\ Q = 1.0,$$

$$\gamma = 1.5,\ \mu = 0.35,\ a = 0.3,\ \omega = 2.08\ \beta = 0.009.$$

Stochastic Shocks. The covariance structure of shocks is determined by combining terms-of-trade data with sectoral HP-filtered Solow residuals created by Stockman and Tesar (1990) for five G-7 countries using OECD data.[12] These residuals must be interpreted with caution because the model allows for trade in capital and thus critiques to Solow residuals as proxies for productivity shocks raised by Finn (1991) and McCallum (1989) apply. $e^p = 4.7$ and $\theta = 0.473$ are the G-7 averages of the standard deviation and first-order autocorrelation of the terms of trade from Table 1. $e^x = e^f = 1.9$ percent and $e^n = 1.4$ percent are Stockman-Tesar estimates of standard deviations of Solow residuals for traded and nontraded sectors respectively. They also estimated autocorrelations of Solow residuals at 0.154 and 0.632 for traded and nontraded sectors respectively, with negligible off-diagonal elements in the autocorrelation matrix. Thus, the "simple persistence" condition that the autocorrelation of all shocks is $\theta = 0.473$ is not a

[12] The sample excludes the U.K. and France, and consists of annual data for the period 1971–85.

bad first approximation. Country-specific Solow residuals and terms-of-trade shocks are weakly correlated; the average correlation of TOT with nontraded-sector residuals is 0.29, and that with traded-sector residuals is 0.04.[13] Using the mid-point of these averages, $\rho_{e^x e^p} = 0.165$ ($\Pi = 0.29$). From a global equilibrium perspective, if terms-of-trade shocks reflect productivity shocks abroad, the comovement pattern of shocks is consistent with findings of Stockman and Tesar showing that Solow residuals are weakly correlated across countries, while within-country sectoral correlations are near 0.5.

Utility. Preference parameters are set using KHS data, evidence from econometric studies, and the model's deterministic steady-state conditions. $\gamma = 1.5$ is in the range of existing estimates. Point estimates are controversial, but values between 1 and 2 are useful to mimic key stylized facts in RBC models. Using GMM and decomposing consumption into traded and nontraded goods, Barrionuevo (1992) could not reject the hypothesis that γ is slightly above 1. μ is estimated by running the regression of logged relative expenditures on logged relative prices and logged per capita GDP proposed by Stockman and Tesar (1990), using data from KHS (1982).[14] This yields $1/(1 + \mu) = 0.74$, with a standard error of 0.438, which is higher than the Stockman-Tesar estimate ($1/(1 + \mu) = 0.44$) because developing countries are excluded from the sample. Time allocations to labor and leisure, and the value of ω, are set following the standard RBC calibration strategy. Households are assumed to allocate 80 percent of their time to leisure ($l/T = 0.8$). Given that sectoral information on labor supply is not available, 10 percent of net-of-leisure time is allocated to the traded sector (5 percent to each industry) and 10 percent to the nontraded sector (i.e., $L^n/T = 0.1$, $L^x/T = L^f/T = 0.05$). ω, a and β are then defined by solving the deterministic steady-state system imposing the time allocations of labor and leisure, and the conditions that the model must mimic G-7 average ratios of total trade and net foreign factor payments to GDP, as explained below.[15]

Production. Technology parameters are set using sectoral decompositions by KHS (1982), (1983) and Stockman and Tesar (1990), and sectoral GDP information from STARS and the OECD *National Accounts* (OECD 1988).[16] Because industrial countries are net exporters of manufactures, their average labor income share in manufacturing determines $\alpha x = 0.51$. αf is then determined by considering that the average G-7 labor income share in the traded sector is 0.61 and traded sector output is about 1/2 of total GDP (both from Stockman and Tesar 1990), together with the

[13] Correlations between traded (nontraded) sector Solow residuals and terms of trade are U.S. −0.08 (0.54), Germany 0.13 (0.53), Japan 0.26 (0.38), Italy 0.11 (0.25), and Canada −0.20 (−0.25).

[14] The data are reproduced in the Statistical Supplement available from the author.

[15] Alternatively, the observed share of consumer good imports in tradables expenditures would imply $a = 0.72$. However, this estimate excludes consumption of importables produced in the domestic economy and results in total trade-GDP ratios significantly below those observed in the data (see Mendoza 1992a for details).

[16] The Statistical Supplement reports GDP shares of agriculture, industry (manufacturing and nonmanufacturing), and services, and labor income shares in manufacturing, nonmanufacturing, and total.

fact that manufactures are 27 percent of GDP (STARS). The last two GDP shares imply that manufactures are 55 percent of traded-sector GDP, and hence $\alpha f = (0.61 - 0.55\alpha x)/(1 - 0.55)$. The rest of the technology parameters ($Q = 1$, $\delta = 0.1$, $r^* = 0.04$, and $\phi = 0.028$) are from the study of the Canadian economy by Mendoza (1991a).

Deterministic Steady State. Given αx, αf, l, L^x, L^f, L^n, δ, ϕ, Q, r^*, γ, and μ, a steady-state system of nine equations determines a, ω, β, K^n, p^n, K, K^f, K^h and A. The equations are (1) the stationarity condition equating the rate of time preference with r^*, (2) the marginal rate of substitution between n and f, (3) the marginal rate of substitution between l and n, (4) the ratio of net foreign interest payments to GDP, r^*A/Y, (5) the ratio of expenditure on nontradables to expenditure on tradables, Ω, (6) the ratio of total trade to GDP, TT/Y, (7) the equilibrium condition equating the net marginal productivity of K^f with r^*, (8) a condition equating net marginal products of K^h and K^f, and (9) the definition of aggregate capital in tradables $K = K^f + K^h$. The solution also assumes $p^x = 1$ in the steady state, and the values for r^*A/Y, Ω, and TT/Y are taken from averages of actual data. Data from IMF (1993) show that the G-7 mean of r^*A/Y is near zero, the mean of Ω in KHS (1982) is 0.87, and the mean TT/Y in UNCTAD (1989) is 0.62.

Developing Country Benchmark.

$$\text{(24)} \quad e^x = e^f = 4.0,\ e^n = 3.8,\ e^p = 11.77,\ \theta = 0.414,\ \rho_{e^x,e^p} = -0.46,\ r^* = 0.04,$$

$$\alpha x = 0.429,\ \alpha f = 0.302,\ \alpha n = 0.34,\ \delta = 0.1,\ \phi = 0.028,\ Q = 0.3,$$

$$\gamma = 2.61,\ \mu = -0.218,\ a = 0.15,\ \omega = 0.786,\ \beta = 0.009.$$

Despite serious sectoral data limitations for DCs, important differences in key parameters have been identified in empirical studies, or result from examining long-run averages, and hence are important to consider.

Stochastic Shocks. $e^p = 11.77$ and $\theta = 0.414$ are DC means of the standard deviation and first-order autocorrelation of TOT in Table 1. Traded-sector shocks are larger than nontraded-sector shocks by the same factor found in G-7 data ($e^i/e^n = 1.9/1.4$ for $i = x, f$ with $e^x = e^f$), and e^x and $\rho_{e^x e^p}$ are set to match DC averages of the percentage standard deviation of GDP at domestic prices and its correlation with TOT (4.5 and 0.09 respectively).

Utility. $\gamma = 2.6$ and $1/(1 + \mu) = 1.279$ are GMM estimates from the panel study of 13 DCs by Ostry and Reinhart (1992). They found significant regional differences in the value of μ, with more industrialized DCs displaying lower elasticity of substitution between traded and nontraded goods.[17] Time allocations of leisure and

[17] Running the regression suggested by Stockman and Tesar (1990) using KHS data for DCs yields $1/(1 + \mu) = 0.43$. This estimate is incompatible with estimates of Ostry and Reinhart, and the use of GDP per capita as an explanatory variable violates the homotheticity assumption implicit in (2). The estimate

labor were altered to reflect the lower level of wealth in DCs. Lacking specific evidence on labor supply behavior in these economies, leisure is reduced only by 5 percentage points of total time, with the additional labor allocated to the nontraded sector (i.e., $l/T = 0.75$, $L^n/T = 0.15$, $L^x/T = L^f/T = 0.05$). ω, a, and β are solved for as before.

Production. Most DCs are net importers of manufactures, hence $\alpha f = 0.302$ is the DC average labor income share in manufacturing.[18] $\alpha x = 0.429$ and $\alpha n = 0.34$ are then derived by assuming that some features of the technology are similar across industrial and developing countries; in particular, the ratio of nonmanufacturing to manufacturing labor income shares is the same (1.42), the exportables industry accounts for the same fraction of traded-sector GDP (55 percent), and the ratio of nontraded to traded sector labor income shares ($\alpha n/\alpha t$) is the same (0.918). Thus, $\alpha x = 1.42\alpha f$, $\alpha t = 0.55\alpha x + (1 - 0.55)\alpha f$, and $\alpha n = 0.918\alpha t$.[19] Given that, for a common r^*, Cobb-Douglas technologies and the lower α parameters set for DCs would result in larger GDP than in the G-7 benchmark, it is necessary to adjust total factor productivity. $Q = 0.3$ is set to make the DC benchmark GDP 20 percent of the G-7 benchmark GDP in the deterministic steady state.[20] δ, r^*, and ϕ are unchanged.

Deterministic Steady State. The steady-state system solves for the same variables as before. The only changes are that in DCs the average of r^*A/Y is -3 percent (using data from IMF 1993), TT/Y is less than 1/2 on average (UNCTAD 1989), and the mean of Ω is 0.86 (KHS 1982).

5. BENCHMARK SIMULATIONS

Tables 7 and 8 compare business cycles in benchmark economies with those observed in the G-7 and the DCs. Moments for sectoral variables which do not have empirical counterparts, but that are helpful in understanding aggregate dynamics are also listed. In general, the model explains several *qualitative* features of the business cycle, but from a *quantitative* perspective it fails to mimic various stylized facts.

Consider first the model's implications for the Harberger-Laursen-Metzler effect. The model is consistent with the data in showing that TB and TOT display low positive correlation—although correlations in the data are somewhat higher than in the model. Given differences in parameters, the economy with more persistent terms-of-trade shocks (the G-7 benchmark) exhibits a marginally stronger TB-TOT correlation, thus providing evidence indicating that structural differences may account for the lack of co-movement between TB-TOT correlations and TOT autocorrelations. To substantiate this argument, G-7 and DC benchmarks were

for G-7 countries also violates homotheticity, but is in line with the view that these countries exhibit lower elasticity of substitution.

[18] Details are provided in the Statistical Supplement.

[19] $\alpha n = 0.34$ is also the DC average labor income share in nonmanufacturing activities.

[20] This estimate is based on GDP per capita adjusted for purchasing power reported in KHS (1982).

TABLE 7

BUSINESS CYCLE PROPERTIES OF MACROECONOMIC AGGREGATES IN THE DATA AND IN THE INDUSTRIAL COUNTRY BENCHMARK*

(*Variables measured at constant import prices*)**

Variable (x =)	G-7 Average σ_x/σ_{tot}	$\rho_{xt,xt-1}$	$\rho_{xt,GDPt}$	$\rho_{xt,TOTt}$	Industrial Country Benchmark σ_x/σ_{tot}	$\rho_{xt,xt-1}$	$\rho_{xt,GDPt}$	$\rho_{xt,TOTt}$
Aggregates Measured in the Data								
GDP	1.69	0.494	1.000	0.785	0.86	0.679	1.000	0.777
Consumption	1.59	0.447	0.959	0.743	1.01	0.854	0.806	0.385
Investment	1.90	0.514	0.843	0.666	2.00	0.144	0.667	0.695
Trade balance	1.62	0.328	0.182	0.241	3.51	0.370	−0.111	0.185
Terms of trade	1.00	0.473	0.785	1.000	1.00	0.473	0.777	1.000
Real exchange rate	1.44	0.379	0.581	0.705	0.57	0.787	0.800	0.566
Cobb-Douglas aggregate GDP***	0.42	0.531	1.000	0.087	0.39	0.563	1.000	0.060
CES aggregate consumption***	0.60	0.559	0.593	0.226	0.51	0.828	0.526	0.133
Sectoral Aggregates not Measured in the Data								
Relative price of nontradables	—	—	—	—	1.06	0.860	0.665	0.323
Weighted relative price of nontradables	—	—	—	—	0.50	0.861	0.663	0.321
Labor supply	—	—	—	—	0.12	0.879	0.469	0.042
GDP								
Tradables	—	—	—	—	0.95	0.577	0.889	0.875
Nontradables	—	—	—	—	1.13	0.865	0.774	0.348
Consumption								
Tradables	—	—	—	—	0.90	0.838	0.838	0.425
Nontradables	—	—	—	—	1.13	0.865	0.774	0.348
Marshallian Demands								
Households								
Importables	—	—	—	—	0.90	0.838	0.838	0.425
Exportables	—	—	—	—	1.02	0.689	−0.022	−0.603
Nontradables	—	—	—	—	0.29	0.505	0.594	0.176
Firms								
Capital in exportables	—	—	—	—	0.62	0.896	0.707	0.612
Capital in importables	—	—	—	—	1.16	0.390	−0.654	−0.954
Labor in nontradables	—	—	—	—	0.12	0.879	0.469	0.042
Memorandum Items								
Real interest rate differential	—	—	—	—	0.38	−0.324	—	0.458
Saving-investment correlation		0.872				0.469		
Real exchange rate-real interest differential correlation		—				0.326		

*The statistical moments reported are the percentage standard deviation relative to the percentage standard deviation of the terms of trade, σ_x/σ_{tot}, the first order serial auto correlation, $\rho_{xt,xt-1}$, the correlation with GDP $\rho_{xt,GDPt}$, and the correlation with the terms of trade $\rho_{xt,TOTt}$.

**Except Marshallian demands, which are in units of the corresponding good, CES aggregate consumption, which is deflated by the CPI, and Cobb-Douglas aggregate GDP, which is in units of domestic output.

***G-7 average moments correspond to data from national accounts at constant prices. Tables A1–A2 in the statistical supplement available from author provide country-by-country details.

TABLE 8

BUSINESS CYCLE PROPERTIES OF MACROECONOMIC AGGREGATES IN THE DATA AND IN THE DEVELOPING COUNTRY BENCHMARK*

*(Variables measured at constant import prices)***

	DC Group Average				Developing Country Benchmark			
Variable (x =)	σ_x/σ_{tot}	$\rho_{xt,xt-1}$	$\rho_{xt,GDPt}$	$\rho_{xt,TOTt}$	σ_x/σ_{tot}	$\rho_{xt,xt-1}$	$\rho_{xt,GDPt}$	$\rho_{xt,TOTt}$
Aggregates Measured in the Data								
GDP	1.30	0.490	1.000	0.255	0.47	0.815	1.000	0.321
Consumption	1.27	0.421	0.894	0.178	1.32	0.995	0.749	0.029
Investment	1.62	0.488	0.723	0.264	0.94	0.111	0.393	0.277
Trade balance	1.60	0.378	−0.168	0.317	0.86	0.692	−0.448	0.076
Terms of trade	1.00	0.414	0.255	1.000	1.00	0.414	0.321	1.000
Real exchange rate	1.23	0.437	0.521	−0.005	0.60	0.949	0.705	0.253
Cobb-Douglas aggregate GDP***	0.40	0.470	1.000	0.087	0.31	0.555	1.000	0.103
CES aggregate consumption***	0.56	0.404	0.450	0.161	0.79	0.970	0.130	−0.148
Sectoral Aggregates not Measured in the Data								
Relative price of nontradables	—	—	—	—	1.22	0.974	0.679	0.123
Weighted relative price of nontradables	—	—	—	—	0.51	0.973	0.684	0.139
Labor supply	—	—	—	—	0.15	0.978	−0.646	−0.001
GDP								
Tradables	—	—	—	—	0.42	0.612	0.737	0.462
Nontradables	—	—	—	—	1.15	0.994	0.764	0.030
Consumption								
Tradables	—	—	—	—	1.47	0.995	0.739	0.023
Nontradables	—	—	—	—	1.15	0.994	0.764	0.030
Marshallian Demands								
Households								
Importables	—	—	—	—	1.47	0.995	0.739	0.023
Exportables	—	—	—	—	1.77	0.810	0.433	−0.545
Nontradables	—	—	—	—	0.26	0.432	0.196	−0.442
Firms								
Capital in exportables	—	—	—	—	1.81	0.437	0.373	0.992
Capital in importables	—	—	—	—	0.80	0.451	−0.124	−0.920
Labor in nontradables	—	—	—	—	0.15	0.978	−0.646	−0.001
Memorandum Items								
Real interest rate differential	—	—	—	—	0.20	−0.302	—	0.464
Saving-investment correlation		0.637				0.266		
Real exchange rate-real interest differential correlation		—				0.156		

*The statistical moments reported are the percentage standard deviation relative to the percentage standard deviation of the terms of trade, σ_x/σ_{tot}, the first order serial auto correlation, $\rho_{xt,xt-1}$, the correlation with GDP $\rho_{xt,GDPt}$, and the correlation with the terms of trade $\rho_{xt,TOTt}$.

**Except Marshallian demands, which are in units of the corresponding good, CES aggregate consumption, which is deflated by the CPI, and Cobb-Douglas aggregate GDP, which is in units of domestic output.

***DC group average moments correspond to data from national accounts at constant prices. Tables A1–A2 in the statistical supplement available from the author provide country-by-country details.

TABLE 9

VARIABILITY RATIOS AND CORRELATION COEFFICIENTS OF MACROECONOMIC VARIABLES FOR ALTERNATIVE MODEL ECONOMIES*

Model Economy	Variability Ratios**						Correlation Coefficients				
	Y	C	I	L	TB	RER	$\rho_{C,Y}$	$\rho_{TB,Y}$	$\rho_{S,I}$	$\rho_{RER,TOT}$	$\rho_{TB,TOT}$
Low intertemporal elasticity of substitution ($\gamma = 2.61$)	0.85	0.95	2.10	0.12	3.32	0.56	0.814	−0.055	0.510	0.621	0.180
High atemporal elasticity of substitution ($\mu = -0.218$)	0.79	0.91	2.00	0.10	3.88	0.47	0.727	−0.008	0.425	0.651	0.189
Low elasticity of labor supply ($\omega = 0.786$)	0.82	0.79	2.01	0.08	3.10	0.47	0.820	0.051	0.517	0.666	0.213
Negatively correlated shocks ($\rho e^x, e^p = -0.46$)	0.66	0.80	1.47	0.10	2.49	0.52	0.822	−0.179	0.522	0.700	0.111
Transitory shocks											
($\theta = 0.0$)	0.61	0.74	1.17	0.11	5.55	0.45	0.497	0.506	−0.607	0.328	0.677
($\theta = 0.414$)	0.83	0.95	1.97	0.12	3.55	0.53	0.804	−0.090	0.484	0.588	0.186
Larger terms-of-trade shocks ($e^p = 11.77$)	1.52	1.60	2.68	0.21	8.50	0.99	0.693	0.372	0.151	0.601	0.626
Larger productivity shocks ($e^x = e^f = 4$, $e^n = 3.8$)	1.02	1.20	2.40	0.16	5.47	0.65	0.723	0.089	0.300	0.328	0.359
Memorandum item											
Industrial country benchmark	0.86	1.01	2.00	0.12	3.51	0.57	0.806	−0.111	0.469	0.566	0.185

*The variables listed are output (Y), consumption (C), investment (I), labor supply (L), the trade balance (TB), and the real exchange rate (RER). All variables, except L, are measured at import prices.

**Standard deviation relative to the standard deviation of the terms of trade in the G-7 benchmark ($\sigma_{tot} = 0.0473$).

simulated using each of the 30 TOT autocorrelations estimated from the data. The 30 simulated TB-TOT correlations were regressed on actual TOT autocorrelations to produce a simulated linear relationship between the two moments. This simulated regression line is plotted in Figure 2 to compare it to the one fitted using actual data. The slope of the two lines is very similar, although the simulated line is below the actual line. Thus, low positive TB-TOT correlations that are independent of TOT autocorrelations are consistent with the intertemporal equilibrium framework and cannot be interpreted as evidence of limited capital mobility, borrowing constraints, or noncompetitive capital markets.

The G-7 benchmark is also consistent with the Obstfeld-Svensson-Razin framework in that, ceteris paribus, the lower the persistence of TOT the stronger the TB-TOT correlation—if $\theta = 0$, the correlation increases from 0.185 to 0.677 (see Table 9). However, in the DC benchmark the opposite is true (the TB-TOT correlation rises as the persistence of the shocks rises) because of the negative correlation between productivity and terms-of-trade shocks. Positive TOT shocks, pushing for an increase in net exports, are expected to coincide with adverse productivity shocks, which push for a worsening trade balance. Thus, the direction of the equilibrium co-movement between terms-of-trade shocks and net exports depends on the co-variance structure relating terms-of-trade and productivity disturbances, and not only on the serial autocorrelations.

Benchmark simulations replicate some of the uniformity features found in international business cycles. However, some ratios of standard deviations differ significantly in the two simulations, contrary to what is observed in the data. In particular, the variability ratio of net exports in the G-7 benchmark is about 3.5, compared with 0.9 in the DC benchmark, and actual ratios between 1 and 2 for the G-7 and regional DC averages. Thus, the model overestimates significantly trade-balance fluctuations in industrial countries—an anomaly that seems related to the specification of sectoral productivity disturbances, as impulse response analysis shows below.

The model accounts for large deviations from PPP driven by real shocks, although a fraction of real-exchange-rate fluctuations is still left unexplained. The real exchange rate has different interpretations in equilibrium models. Some models treat p^n, or p^n weighted by the share of nontradables in total expenditure, as equivalent to the real exchange rate (Ostry 1988); however, in three-good models that examine explicitly terms-of-trade effects (see Greenwood 1984), the real exchange rate is better measured using the domestic relative price of aggregate consumption—which is a function of both p^n and p^x. This CPI measure is the one referred to as the real exchange rate in Tables 7 and 8. According to the three measures, the ratio of RER to TOT variability is between 0.5 and 1.2 in both G-7 and DC benchmarks, compared to 1.4 and 1.3 for the respective actual averages. Using the CPI-based RER, the model explains 40 and 49 percent of real exchange rate variability observed in G-7 and DCs respectively, mimics the procyclical behavior of RER, and produces stronger TOT-RER correlations in G-7 countries than in DCs, although these correlations are slightly overestimated. Impulse response analysis will show that the separation of productivity and terms-of-trade shocks is critical for these results.

The three-good structure of the model allows the domestic intertemporal relative price of consumption to differ from the world real interest rate. In turn, the breakdown of the real interest parity condition, a well-documented stylized fact (see Baxter 1994), is key for explaining some observed features of consumption behavior. In particular, and in contrast with one-good models of the small open economy, the correlation between C and GDP is positive but not perfect. This is because wealth effects induced by the shocks, which affect demand for x, f, and n positively, are weakened by substitution effects between the three goods induced by changes in current and expected relative prices. Moreover, the model accounts for real interest differentials as large as 3.6 percent for G-7 countries and 4.6 percent for DCs,[21] and produces low positive correlations between these differentials and RER. The issue of whether neoclassical models, featuring flexible prices and perfect capital mobility, can explain the positive link between deviations from PPP and RIRP at business cycle and lower frequencies has been the subject of recent debate (see Baxter 1994 and Obstfeld 1993). In Baxter (1994), business cycle correlations between RER and short term, ex ante real interest differentials for the United States and five other industrial countries produce an average of 0.14, compared to 0.33 and 0.16 in the two benchmark economies.

One key motivation of this paper is to measure the contribution of terms-of-trade shocks as a driving force of business cycles separate from domestic productivity shocks, given the evidence on large TOT disturbances and the controversy surrounding Solow residuals. If the G-7 model is simulated setting $\sigma_{e^i} = 0$ for $i = x, f, n$, the standard deviation of GDP at import prices (σ_{GDP}) falls to 3.6 percent. Thus, since σ_{GDP} in the benchmark is 4.1 percent, 88 percent of the G-7 model's GDP variability is due to TOT shocks. Moreover, the ratio $\sigma_{\text{GDP}}/\sigma_{\text{TOT}}$ in the G-7 benchmark is about 1/2 of the actual G-7 average, so about 45 percent of actual G-7 business cycles can be attributed to terms-of-trade shocks. The same type of comparison for real GDP at domestic prices shows that TOT shocks account for 1/3 of observed GDP variability. In the DC benchmark, σ_{GDP} in fact rises marginally in the absence of domestic productivity shocks because these shocks and terms-of-trade disturbances are negatively correlated, and hence agents do not expect adverse changes in domestic productivity to offset terms-of-trade gains. TOT shocks in the DC model explain 37 percent and 56 percent of the actual variability of GDP at import prices and domestic prices respectively. While these results are notable, they still imply that domestic shocks play an important role in explaining business cycles. Moreover, from a perspective of world equilibrium, terms-of-trade shocks must originate in other exogenous shocks, which may correspond to standard productivity or demand shocks at the global level or in large economies, but may also reflect rare events like the OPEC oil embargo, the collapse of planned economies, or natural disasters. Note, however, that although the model does not identify underlying external real shocks driving the terms of trade, comovement between domestic and global shocks is captured by allowing domestic productivity and terms-of-trade shocks to be correlated.

[21] Based on standard deviations from Tables 7 and 8 and viewing the interest differential as a two-sigma event.

The results of the simulations are also indicative of the importance of modelling investment and production decisions in open-economy intertemporal equilibrium models. This is illustrated by comparing the comovement between GDP and TB and the variability of RER in the G-7 benchmark with a G-7 endowment economy. The latter, as noted in Mendoza (1992a), produces a procyclical trade balance and small deviations from PPP. In contrast, in the model examined here investment goods are importable commodities. Thus, investment dynamics reflect optimal portfolio allocation of savings across K and A, and intertemporal and atemporal substitution effects unchained by the effect of persistent terms-of-trade and productivity shocks on the relative returns on capital in traded-sector industries and on foreign bonds. Depending on the comovement structure of the shocks, pro-borrowing and investment-augmenting effects induced by a positive, persistent domestic productivity shock, as agents increase investment to take advantage of higher expected returns on domestic capital, may be offset or amplified by expectations of the future path of terms of trade. In the G-7 benchmark, the covariance structure of the shocks is such that the investment-augmenting effect weakens the TB-GDP correlation markedly, relative to the endowment economy—the TB-GDP correlation in the latter is 0.48, compared with −0.11 in Table 7. The addition of investment and production decisions also results in an increase of the variability ratio of RER relative to TOT from 0.5 to 1.44.

J-curve dynamics of cross-correlations between net exports and terms of trade, identified using G-7 data in the two-country, complete-markets analysis of Backus et al. (1992b), are partially explained by the model. The shocks driving the model are by definition stationary AR(1) processes, and the numerical solutions of the unique, invariant joint limiting distribution of the state variables show that endogenous stochastic processes are also stationary AR(1). Thus, the correlation between TB at t and TOT at lag k is simply $\theta^k \rho_{\mathrm{TOT,TB}}$. The evidence documented by Backus et al. shows that this is a good proxy for some G-7 countries, except Canada and the United States.[22] It is still interesting to note that the small open economy model can approximate some TB-TOT cross-correlations without the transmission mechanisms present in the two-country, complete-markets framework.

Consider finally the issue of the welfare costs of consumption instability, or the welfare gains of international asset trading. The analysis of Lucas (1987), based on compensating variations of stationary consumption streams, produced the puzzling result that welfare costs of economic fluctuations are trivial at less than 1/10 of a percent. Open-economy RBC analysis showed in addition that costs of restricting international capital mobility (Mendoza 1991b) or forcing an autarky equilibrium (Backus et al. 1992a) in one-good models, in which gains from trade originate only in consumption-smoothing and risk-sharing possibilities, are also trivial. In principle, because the three-sector setting examined here introduces intertemporal and atemporal trade in differentiated commodities and limits risk-sharing and consumption-smoothing in nontraded goods, welfare costs of business cycle and trade

[22] TB-TOT cross-correlations for G-7 countries computed with the data used in Table 1 also support this view.

barriers could be larger. Larger welfare costs could also result from the large magnitude of terms-of-trade shocks relative to available measures of productivity disturbances. However, the simulations show that costs of fluctuations are still negligible, although business cycles in the DC benchmark are more costly than in the G-7 benchmark (since shocks are larger and the degree of risk aversion is higher). The compensating variation in a stationary consumption stream that equates expected lifetime utility in the G-7 benchmark with that generated by the corresponding deterministic stationary equilibrium is 0.011 percent, and the comparable figure for DCs is 0.016 percent. Moreover, the extra cost resulting from imposing capital controls in the G-7 benchmark, forcing households to match changes in saving with changes in domestic investment, is also small (0.03 percent). Thus, terms-of-trade uncertainty and the existence of nontraded goods do not resolve the puzzle of negligible welfare gains of international asset trading. This result is in line with recent findings by Tesar (1994) in a two-country, complete-markets framework.

6. IMPULSE RESPONSES AND SENSITIVITY ANALYSIS

This section examines the role that structural parameters play in explaining the properties of business cycles in the model, and studies impulse responses of macroeconomic aggregates induced by terms-of-trade and productivity shocks. These exercises are useful because the multi-sector nature of the model makes it difficult to derive theoretical predictions regarding determinants of macroeconomic comovements. In particular, mathematical analysis of multi-sector deterministic models produces ambiguous results that depend on the relative size of several parameters (see Greenwood 1984 and Frenkel and Razin 1987). Key parameters determining equilibrium comovements are: the intertemporal elasticity of substitution in aggregate consumption ($1/\gamma$), the elasticity of substitution between tradable and nontradable goods ($1/1 + \mu$), and the persistence of terms-of-trade shocks (θ).[23] The sensitivity analysis undertaken here also explores the role of the elasticity of labor supply (ω), and the correlation and relative size of terms-of-trade and productivity shocks ($\rho_{e^x e^p}$ and e^i/e^p for $i = x, f, n$).

Impulse Response Analysis. Figures 3 to 4 plot impulse responses to 1-percent positive terms-of-trade and productivity shocks in the G-7 benchmark. According to Figure 3, the terms-of-trade gain induces on impact an investment boom of nearly 1.5 percent. Part of the additional capital allocated to the exportables industry—where marginal profitability increases as the terms of trade improve—comes from a sectoral reallocation of capital between exportables and importables industries, as illustrated by the large positive K^x-TOT and large negative K^f-TOT correlations in Table 7. GDP at import prices also booms, reflecting mainly the direct positive impact of TOT on the purchasing power of exports, since initial

[23] Relative expenditure shares of the three goods in aggregate consumption and sectoral ratios of consumption to production also appear in the expressions of comparative statics derivatives (see Ostry 1988).

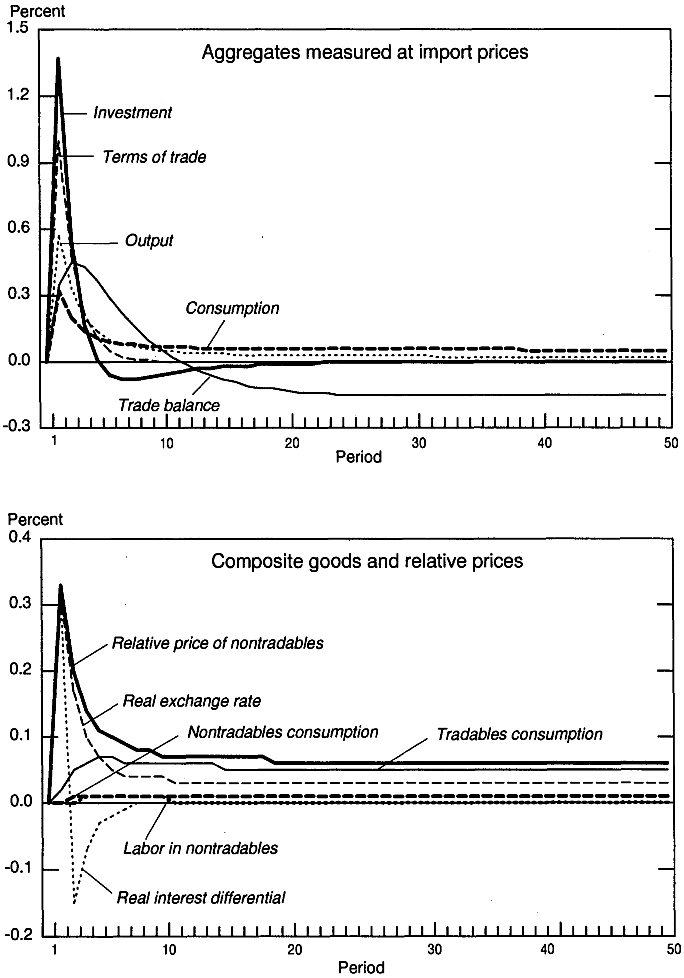

FIGURE 3

aggregate capital is fixed, labor is inelastically supplied in traded-sector industries, and the labor supply response in the nontraded sector is negligible. Households wish to smooth consumption, given the shock's impact on permanent income, and face relative price increases in exportables and nontradables; as a result, the consumption boom induced by the shock is weaker than GDP and investment booms. Net exports improve about as much as consumption when the shock hits, as the permanent income gain requires additional savings in excess of what additional investment can optimally absorb, thus inducing agents to accumulate foreign assets. Alternatively, the trade balance improvement shows that the increase in the purchasing power of exports, and the reduced domestic demand for exportables, more than offset the increased demand for importables.

Figure 3 also shows that both p^n and RER appreciate on impact in response to a TOT shock, reflecting the fact that increased demand for nontradables faces a virtually unchanged supply. The increase in p^n is 1/3 of the increase in TOT, and, given the structure of the CPI, it results in a real appreciation near 0.3 percent. Note that ω and μ play a key role in this result; a high labor elasticity combined with a low elasticity of substitution between traded and nontraded goods would strengthen the labor supply response in the nontraded sector and weaken the real appreciation (see equation (14)). A positive real interest differential surges in tandem with the real appreciation, and subsequently the expected realignment of the real exchange rate induces a negative interest differential. This explains why RER and the real interest differential are positively but weakly correlated in Table 7.

As the TOT shock dissipates, the relative profitability of domestic versus foreign capital realigns, and hence investment shows a small recession before returning to its initial state. The GDP boom weakens reflecting the declining purchasing power of exports and the adjustment of K back to the initial level, but it converges monotonically without negative deviations from mean. C also converges monotonically, but at a slower rate as trade surpluses of early periods finance future deficits that slowdown the adjustment of consumption. TB takes time in fully adjusting back to the initial equilibrium because net exports must balance in net present value, and hence surpluses of early periods are offset by deficits over several periods in the future.

Impulse responses to a 1-percent positive productivity shock uniform across sectors are plotted in Figure 4. Impulse response dynamics differ from those induced by a TOT shock in several important respects. First, on impact the productivity shock induces a stronger boom in net exports and a weaker investment boom. This reflects the fact that the expansion in GDP, as the shock rises productivity in traded and nontraded sectors uniformly, causes a strong wealth effect inducing households to increase savings. The increase in savings is largely allocated to foreign assets because capital is in fixed supply in the nontraded sector, and because the variance-covariance and autocorrelation structures of the shocks are such that deviations in expected, risk-adjusted differentials between domestic marginal products of capital in the traded sector and r^* are not very large or persistent. Thus, the large variance of TB in the G-7 benchmark can be attributed to the estimated size of productivity shocks and their positive correlation with TOT shocks. The responses of the real exchange rate, the relative price of nontradables, and the real interest rate differential are also different. With the productivity shock there is a strong supply response in tradables and nontradables, even tough L^n falls slightly due to a wealth effect on leisure, and hence p^n falls to clear the market and RER depreciates. Because the terms of trade do not move, the real depreciation is smaller than the fall in the price of nontradables. The real interest differential is negative when RER depreciates, and afterwards an expected appreciation changes the sign of the interest differential.

Impulse response charts for the DC benchmark are omitted to save space. In this economy, labor income shares are smaller, labor supply is less elastic, the degree of risk aversion is higher, the elasticity of substitution between traded and nontraded goods is higher, and shocks are drawn from a distribution such that a terms-of-trade gain is likely to coincide with a decline in domestic productivity. As a result, the shocks induce weaker percent mean deviations in macroeconomic

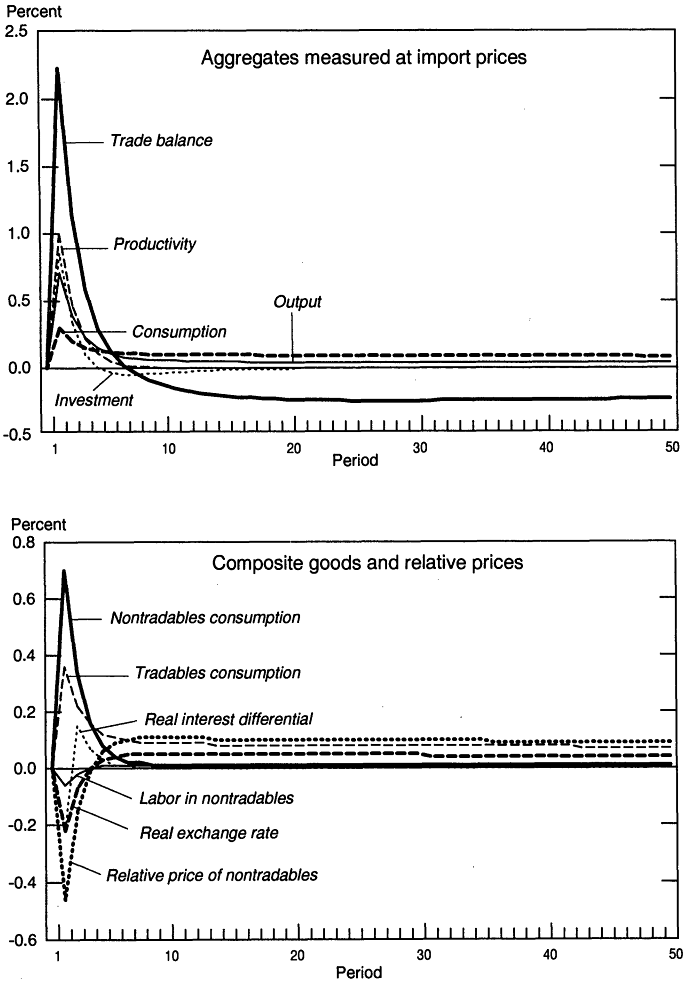

FIGURE 4

aggregates, although the directions are in most instances the same as those in the G-7 benchmark.[24] The supply response in nontradables remains negligible, indicating that within a range of reasonable parameters for ω and μ, wealth effects on labor supply are weak. The main difference between G-7 and DC impulse responses to TOT shocks is in consumption dynamics. In DCs, consumption at import prices displays a small, but highly persistent, increase, and tradables consumption and the CES composite actually fall on impact as TOT rises. This is because, in addition to the inelastic supply response of nontradables, importables demand is highly inelastic in response to terms-of-trade shocks (as illustrated by the near-zero correlation between importables and TOT in Table 8), and the correlation between

[24] This is not an indicator of relative magnitude of business cycles in the two benchmarks. Responses to a 1-percent shock are weaker in DCs, but TOT shocks up to 23 percent are within the 98 percent confidence interval, whereas in the G-7 benchmark the two-sigma limit for TOT shocks is 9 percent.

exportables and TOT is -0.55. Thus, wealth effects on f are weak when TOT shocks are expected to be offset by productivity losses and the substitution effect on x dominates the wealth effect. These features of the dynamics of traded and nontraded consumption play a key role in allowing the model to mimic the observed low correlation between C at domestic prices and the terms of trade.

Sensitivity Analysis. Table 9 documents the effects on some business cycle co-movements of the G-7 benchmark resulting from resetting the values of γ, μ, ω, $\rho_{e^x e^p}$, θ, e^p, and e^i for $i = x, f, n$, one at a time, to the values used in the DC benchmark. Results of a simulation for white-noise shocks ($\theta = 0$) are also included. The table shows that, within the range of G-7 and DC benchmark parameters, the elasticity of substitution between tradables and nontradables, and the size and correlation of terms-of-trade and productivity shocks, are the key determinants of the model's behavior. In contrast, the model's solution is not seriously affected by changes in ω, γ, or θ. However, for large changes in θ, for instance in the case that $\theta = 0$, equilibrium comovements do change significantly.

The variance-covariance and autocorrelation structures of the disturbances are important because they determine the magnitude and direction of wealth effects that affect consumption and asset accumulation under the limited risk-sharing possibilities allowed by incomplete markets. Capital accumulation is also affected by the duration and relative size of shocks because investment is set to equalize expected returns on K^x, K^f, and A weighted by the marginal utility of importables. Variability ratios of GDP, C, I and RER decline when the shocks are white noise, while that of TB increases and the one for L remains unchanged. Transitory shocks also induce a procyclical trade balance, a negative S-I correlation, and a significantly positive TB-TOT correlation. When shocks are white noise, there is little incentive to expand K in response to contemporaneous shocks to productivity or terms of trade because they are not expected to affect the marginal productivity of future capital. Thus, the gain in income is reflected mostly in accumulation of foreign assets, and hence the larger variability ratio and GDP and TOT correlations of net exports. A similar intuition explains changes in equilibrium comovements resulting from changes in the magnitude of the two shocks and in their contemporaneous correlation. In general, the results show that while the autocorrelation of TOT shocks is key in determining the TB-TOT correlation, as predicted by Obstfeld-Svensson-Razin models, the variance-covariance matrix of the shocks is also critical. Larger shocks strengthen the TB-TOT correlation, while low or negative correlations between shocks weaken it.

The elasticity of substitution between tradables and nontradables is important because goods are gross complements in the G-7 benchmark and gross substitutes in the DC benchmark. If the G-7 benchmark is simulated setting $\mu = -0.218$, so that goods are gross substitutes, variability ratios of GDP, C, L, and RER fall, albeit the one for L only marginally, while the variability of TB rises. The correlations of TB with GDP and TOT increase slightly. These results suggest that, everything else constant, pro-saving effects are stronger the higher the elasticity of substitution between tradables and nontradables—a well-established result from deterministic two-period models (see Greenwood 1984 and Ostry 1988). Moreover, μ also plays a key role in determining the response of labor supply, and hence of output and the relative price of nontradables, to exogenous shocks. From (14) is clear that, if traded and nontraded goods are perfect substitutes, the wealth effect on labor supply is eliminated and L^n responds only to the effect of contemporaneous productivity shocks on the nontraded sector's labor demand. Thus, business cycle properties of labor in this model depend as much on μ as they do on the leisure exponent ω.

The parameters γ and ω play a small role in the model's business cycle. The intertemporal elasticity of substitution is not critical, except for its impact on the variability of net exports, as long as it represents a small degree of relative risk aversion, a finding consistent with previous real-business-cycle studies for one-good small open economies (see Mendoza 1991a and 1992a). The leisure exponent ω has some noticeable effects in that as ω falls variability ratios fall moderately, although the effect on labor supply variability is very small. The smaller fluctuations in C and TB reflect the unitary elasticity of substitution between leisure and the CES composite.

7. CONCLUDING REMARKS

This paper conducts a quantitative examination of the link between terms-of-trade shocks and business cycles by comparing numerical solutions of the competitive equilibrium of a dynamic stochastic model of a small open economy with actual business cycles. In the model, households consume importable, exportable, and nontradable goods and leisure, and firms produce the three goods using capital, which is an importable good, and labor services. World markets of goods and financial assets are competitive and there are no controls on capital- or current-account flows. Asset trading is limited to one-period, risk-free bonds denominated in units of importables and random shocks affect productivity and the terms of trade separately. The model captures transmission mechanisms of terms-of-trade shocks via international capital mobility, the cost of imported inputs, and the overall purchasing power of exports, and allows for competitive deviations from PPP and real interest parity by incorporating nontraded goods.

Empirical regularities of business cycles in the G-7 and 23 developing countries are documented in detail. Cyclical components obtained from Hodrick-Prescott filtered data illustrate four key facts:

1) Terms-of-trade shocks are large, persistent, and weakly procyclical.
2) Net exports-terms of trade correlations are low and positive (i.e., there is a Harberger-Laursen-Metzler effect), and they are not systematically related to cross-country differences in terms-of-trade autocorrelations.
3) Developing economies exhibit larger variability in macroeconomic aggregates, but business cycles across industrial and developing countries exhibit similar characteristics in terms of variability ratios and measures of co-movement and persistence in output, consumption, investment, real exchange rates, and net exports.
4) There are large and procyclical fluctuations in real exchange rates.

The model is roughly consistent with these observations, although they contradict some theoretical predictions derived from deterministic intertemporal equilibrium models of endowment economies. Thus, the analysis shows that observed co-movements are features of these models once uncertainty, capital accumulation, and structural differences in tastes and technology are considered, without abandoning the assumptions of perfect capital mobility, price flexibility, and competitive capital markets. Simulations also show that terms-of-trade disturbances account for around 1/2 of the observed variability of GDP and real exchange rates, and that the model explains observed low positive correlations between deviations from PPP and deviations from real interest rate parity at business cycle frequencies. Moreover, impulse response analysis shows that macroeconomic dynamics in response to terms-of-trade shocks differ markedly from those induced by productivity shocks; in particular, the former induce real appreciations and positive real interest differentials, while the latter have opposite effects. Despite these favorable results, welfare costs of consumption instability and capital controls are small. Thus, the multi-sector framework cannot resolve the puzzle that welfare gains of international asset trading are negligible in business cycle models.

Sensitivity analysis shows that the persistence, magnitude, and contemporaneous correlation of terms-of-trade and productivity shocks, and the elasticity of substitution in consumption of tradable and nontradable goods, play a key role in the model's dynamics. The covariance and autocorrelation structures of shocks are important because, under incomplete markets, wealth effects resulting from country-specific shocks affect optimal saving behavior. The traded-nontraded elasticity of substitution has significant implications because benchmark parameters suggested by the data indicate that goods are gross complements in industrial countries and gross substitutes in developing countries. This implies differences for cross-price and cross-expenditure effects operating in model economies. In contrast, labor supply effects and moderate changes in the degree of risk aversion are of second order importance.

Given that the model is consistent with some basic features of the business cycle, additional work to examine policy implications would be worth pursuing. The credibility effects widely discussed in the literature on stabilization and commercial policies are a prime candidate.

Board of Governors of the Federal Reserve System, U.S.A.

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