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International Business Cycles: Theory vs. Evidence*

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In modern developed economies, goods and assets are traded across national borders, so that events in one country generally have economic repercussions in others. International business cycle research focuses on the economic connections among countries and on how much of an impact these connections have on the transmission of aggregate fluctuations across various countries. In academic studies, this focus is expressed in terms of the volatility and comovements of international time series data. Examples include the volatility of fluctuations in a country's balance of trade, the correlation of the trade balance with the country's output, the correlation of output and consumption across countries, and the volatility of prices of goods produced in a country and elsewhere.

A large and growing number of studies consider international business cycles from the perspective of dynamic general equilibrium theory. In closed-economy studies, models based on this theory have been able to account for a large fraction of the variability of a country's aggregate output and for the relative variability of its investment and consumption; see, for example, Prescott's (1986) review. In public finance studies, similar models have assessed the impact of fiscal policy on a country's aggregate output, employment, and saving; the work of Auerbach and Kotlikoff (1987) is a prominent example. In international macroeconomic studies, this approach has been able to account for some of the notable features of international data: for example, the time series correlation of saving and investment rates (Finn 1990; Cardia 1991; and Baxter and Crucini, forthcoming), the countercyclical movements of the trade balance (Mendoza 1991; Glick and Rogoff 1992; and Backus, Kehoe, and Kydland, forthcoming), and the relation between the trade balance and the *terms of trade*, or the relative prices of goods across countries (Smith 1993; Backus, Kehoe, and Kydland, forthcoming; and Macklem, forthcoming).

These efforts illustrate the insights that dynamic general equilibrium theory has contributed so far and is likely to continue to contribute. However, the most important aspects of this line of work for future research are those for which the theory remains significantly different from the data. Here we describe in detail two such discrepancies.

One concerns the relations between aggregate quantities in various countries. We examine cross-country comovements of output, consumption, and other aggregates in the natural extension of Kydland and Prescott's (1982)

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closed-economy model to an international setting. In this extension, agents in the two countries produce and trade a single good. Fluctuations are driven by exogenous movements (or *shocks*) in productivity. Although the theory mimics some features of the data, it does poorly with the international comovements. Using parameters for the stochastic process for productivity shocks that we estimate from data for the United States and a European aggregate, we find that cross-country correlations of output are larger than such correlations of consumption and productivity shocks. In the model, however, the shocks produce output fluctuations that are less highly correlated than fluctuations in consumption and productivity shocks. The ranking of output, consumption, and productivity shock correlations in the model is extremely robust: it survives several large changes in several of the model's parameters. Since these differences between theory and data are relatively insensitive to the choice of parameter values and even the model's structure, we term them collectively the *consumption/output/productivity shock anomaly,* or simply the *quantity anomaly.*

The other discrepancy we describe here concerns the terms of trade. To examine fluctuations in this relative price of imports to exports, we extend the theoretical model to allow the outputs of the two countries to be imperfect substitutes. This extension, of course, allows the relative price of the two goods to differ from 1. In the data, fluctuations in the terms of trade in the industrialized world have been very persistent and highly variable. These properties, and similar properties of the real exchange rate, are perhaps the most widely studied issues in international macroeconomics. We find that the model generates fluctuations in the terms of trade as persistent as such fluctuations are in the data, but much less variable. If we lower the model's substitutability of foreign and domestic goods, we can increase the variability of the terms of trade, but this comes at the expense of reducing the variability of imported and exported goods far below that in the data. We call this second discrepancy the *price variability anomaly,* or more simply, the *price anomaly.*

The quantity and price anomalies pose a challenge for international business cycle research. With them in mind, we follow their description with a review of a rapidly expanding body of work aimed at these and other issues, and we speculate on directions future work might take. Notable extensions of the theory include adding nontraded goods, making markets incomplete, including money, and making firms imperfectly competitive. Unfortunately, none of these extensions has yet to provide a persuasive resolution of the quantity and price anomalies.

Quantities

Evidence . . .

We begin by reviewing some of the salient properties of business cycles in and across countries. These features of the data serve as a basis of comparison with theoretical economies. As described here, these properties refer to moments of Hodrick-Prescott filtered variables.[1] Our data are from three publications: *Quarterly National Accounts* and *Main Economic Indicators,* published by the Organisation for Economic Co-operation and Development (OECD), and *International Financial Statistics,* published by the International Monetary Fund (IMF).

□ *Within Countries*

Table 1 displays some properties of business cycle experience between 1970 and mid-1990 in 10 developed countries and a European aggregate constructed by the OECD. We focus on three features of a set of common macroeconomic time series: *volatility,* measured by standard deviations; *persistence,* measured by autocorrelations; and *comovement,* measured by correlations.

With respect to volatility, we can see both similarities and differences. Internationally, consumption has generally had about the same standard deviation, in percentage terms, as output; investment in fixed capital has been from two to three times more volatile than output; and employment has been somewhat less volatile than output. The magnitudes of these fluctuations, however, have differed across countries. The standard deviation of output fluctuations ranges from a low of 0.90 percent in France to a high of 1.92 percent in Switzerland and the United States. We also find some differences in consumption volatility. Similarly, the standard deviation of consumption, relative to that of output, ranges from 0.66 in Australia to 0.75 in the United States to 1.15 in the United Kingdom. The consumption numbers are larger than those generally reported in studies of the United States, partly because consumption in this data set includes expenditures on consumer durables. If we exclude durables, which the data let us do for only five countries, the volatility ratios fall from 0.75 to 0.52 for the United States, from 0.85 to 0.59 for Canada, from 0.99 to 0.77 for France, from 0.78 to 0.61

[1] For descriptions of the Hodrick-Prescott filter and its relation to others, see Prescott 1986 and King and Rebelo 1989.

Table 1

Business Cycles in 10 Developed Countries*

1970–mid-1990

	Volatility							Persistence:	Comovement: Correlation With Output					
	Standard Deviation		Ratio of Standard Deviation to That of Output											
Country	Output	Net Exports	Consumption	Investment	Government Purchases	Employment	Productivity Shock	Autocorrelation of Output	Consumption	Investment	Government Purchases	Net Exports	Employment	Productivity Shock
Australia	1.45%	1.23%	.66	2.78	1.28	.34	1.00	.60	.46	.68	.15	–.01	.12	.98
Austria	1.28	1.15	1.14	2.92	.36	1.23	.84	.57	.65	.75	–.24	–.46	.58	.65
Canada	1.50	.78	.85	2.80	.77	.86	.74	.79	.83	.52	–.23	–.26	.69	.84
France	.90	.82	.99	2.96	.71	.55	.76	.78	.61	.79	.25	–.30	.77	.96
Germany	1.51	.79	.90	2.93	.81	.61	.83	.65	.66	.84	.26	–.11	.59	.93
Italy	1.69	1.33	.78	1.95	.42	.44	.92	.85	.82	.86	.01	–.68	.42	.96
Japan	1.35	.93	1.09	2.41	.79	.36	.88	.80	.80	.90	–.02	–.22	.60	.98
Switzerland	1.92	1.32	.74	2.30	.53	.71	.67	.90	.81	.82	.27	–.68	.84	.93
United Kingdom	1.61	1.19	1.15	2.29	.69	.68	.88	.63	.74	.59	.05	–.19	.47	.90
United States	1.92	.52	.75	3.27	.75	.61	.68	.86	.82	.94	.12	–.37	.88	.96
Europe	1.01%	.50%	.83	2.09	.47	.85	.98	.75	.81	.89	.10	–.25	.32	.85

*All data are quarterly and have been detrended with the Hodrick-Prescott filter. All but net exports have also been logged. The specific variables included are real output; real consumption; real fixed investment; real government purchases; the ratio of net exports to output, both measured in current prices; civilian employment; and a productivity shock, which is the Solow residual, as defined in equations (1) and (2).

Sources of basic data: OECD and IMF

for Italy, and from 1.15 to 0.96 for the United Kingdom. Some of these differences almost certainly reflect differences in the procedures used to construct aggregate data, but more work is needed before we can quantify the impact of disparities of measurement. In terms of persistence, we see that in all countries the autocorrelation of output has been fairly high (close to 1). It ranges from 0.57 for Austria to 0.90 for Switzerland.

The volatility of employment has varied even more: the ratio of the standard deviation of employment to that of output ranges from 0.34 in Australia to 0.86 in Canada to 1.23 in Austria. At least some of this disparity appears to reflect international differences in labor market experience. Burdett and Wright (1989) and Blackburn and Ravn (1992) note that in the United States fluctuations in total hours worked are largely the result of movements in employment, while in the United Kingdom the total hours fluctuations are primarily due to changes in hours per worker. Note that employment has been positively correlated with output—or *procyclical*—in all 10 countries, but the magnitude of the correlation varies substantially across countries.

The last variable in Table 1 is what we call the *productivity shock*. It is the Solow residual, z, as defined implicitly in the Cobb-Douglas production function:

$$(1) \qquad y = zk^{\theta}n^{1-\theta}$$

where y is output, k is the stock of physical capital, and n is employment. This allows us to compute the Solow residual, in logarithms, by

$$(2) \qquad \log(z) = \log(y) - [\theta\log(k) + (1-\theta)\log(n)].$$

We set the parameter θ equal to 0.36, as explained below. Since comparable capital stock data are not available quarterly, we omit the capital part of the expression. This omission is probably not a problem, since the capital stock contributes very little to the cyclical fluctuations of output; see, for example, Kydland and Prescott 1982, Table 4. Productivity shocks, by this measure, are strongly procyclical, but their volatility is generally less than that of output.

Two exceptions to this tendency for aggregate variables to move procyclically are government purchases and our measure of the trade balance, the ratio of net exports to output (which we will hereafter call simply *net exports*). Government purchases are procyclical in seven countries and countercyclical in three, but the correlations are small everywhere. Net exports, however, is countercyclical in all ten countries, although both its standard deviation and its correlation with output vary substantially across countries.

□ *Across Countries*

Table 2 displays statistics with more of an international flavor: It shows the correlations of each economic variable across countries.

In the first column, we list the correlation of output fluctuations between each country and the United States. These vary in magnitude but are all positive. The largest is 0.76 for Canada. The correlations for Japan and the major European countries lie between 0.40 and 0.70.

Table 2 also includes correlations of consumption, investment, government purchases, employment, and productivity shocks across countries. With respect to consumption, the correlations are smaller than those of output for every country, but the difference is large only for Australia. The consumption correlation between the United States and the European aggregate, for example, is 0.51, while the output correlation is 0.66. Most of the correlations of investment, employment, and productivity shocks

Table 2

International Comovements*

1970–mid-1990

	Correlation of Each County's Variable With the Same U.S. Variable					
Country	Output	Consumption	Investment	Government Purchases	Employment	Productivity Shock
Australia	.51	−.19	.16	.23	−.18	.52
Austria	.38	.23	.46	.29	.47	.17
Canada	.76	.49	−.01	−.01	.53	.75
France	.41	.39	.22	−.20	.26	.39
Germany	.69	.49	.55	.28	.52	.65
Italy	.41	.02	.31	.09	−.01	.35
Japan	.60	.44	.56	.11	.32	.58
Switzerland	.42	.40	.38	.01	.36	.43
United Kingdom	.55	.42	.40	−.04	.69	.35
Europe	.66	.51	.53	.18	.33	.56

*All data are quarterly and have been detrended with the Hodrick-Prescott filter. For definitions of the variables, see the note on Table 1.

Sources of basic data: OECD and IMF

are also positive. Productivity shocks are generally less highly correlated across countries than output is, though in our data, the differences are generally small. Finally, the cross-country correlations of government purchases vary in sign but, again, are generally small.

We summarize briefly. Despite some heterogeneity in international business cycle experience across the major industrialized countries over the last 20 years, most of the regularities emphasized in Kydland and Prescott's (1982) closed-economy study stand up. Among the statistics that capture comovements across countries, remember this relationship: The cross-country correlations of output are larger than those of consumption and productivity shocks.

. . . vs. Theory

□ A Model

Now let's compare these properties of international business cycles to those of a theoretical world economy.

We start with an economy in which agents in two countries produce a single homogeneous good. The structure is a streamlined version of that in Backus, Kehoe, and Kydland 1992; here we have eliminated inventory accumulation and leisure durability. This is a two-country extension of Kydland and Prescott's (1982) closed-economy real business cycle model.

In the model here, each country is represented by a single agent. The preferences of the representative consumer in country i, for $i = 1, 2$, are characterized by an expected utility function of the form

$$(3) \qquad u_i = E_0 \sum_{t=0}^{\infty} \beta^t U(c_{it}, 1-n_{it})$$

where c_{it} and n_{it} are consumption and employment in country i and $U(c,1-n) = [c^{\mu}(1-n)^{1-\mu}]^{1-\gamma}/(1-\gamma)$.

The single good is produced in each country with inputs of capital, k, and domestic labor (employment), n, and influenced by the productivity shocks, z. Output in country i is

$$(4) \qquad y_{it} = z_{it} F(k_{it}, n_{it})$$

where $F(k,n) = k^{\theta} n^{1-\theta}$, so that (4) is the same relation as (1), which we used to construct Solow residuals. Since the two countries produce the same good, the world resource constraint for the good is

$$(5) \qquad \sum_i (c_{it}+x_{it}+g_{it}) = \sum_i z_{it} F(k_{it}, n_{it})$$

where x_{it} is the amount of the good allocated to fixed capital formation (or investment) and g_{it} is government purchases, both for country i. Net exports in country i is, then,

$$(6) \qquad nx_{it} = y_{it} - (c_{it}+x_{it}+g_{it})$$

which is the difference between the goods produced and the goods used.

Capital formation incorporates the time-to-build structure emphasized by Kydland and Prescott (1982). Additions to the stock of fixed capital require inputs of the produced good for J periods, or

$$(7) \qquad k_{it+1} = (1-\delta) k_{it} + s_{it}^1$$

$$(8) \qquad s_{it+1}^j = s_{it}^{j+1}$$

for $j = 1, ..., J-1$, where δ is the depreciation rate and s_{it}^j is the number of investment projects in country i at date t that are j periods from completion. We denote by ϕ_j, for $j = 1, ..., J$, the fraction of value added to an investment project in the jth period before completion. We set $\phi_j = 1/J$, so that an investment project adding one unit to the capital stock at date $t+1$ requires expenditures of $1/J$ for the J periods before $t+1$. Fixed investment at date t is

$$(9) \qquad x_{it} = \sum_{j=1}^{J} \phi_j s_{it}^j$$

which is the sum of investment expenditures on all existing projects.

The vectors $z_t = (z_{1t}, z_{2t})$ and $g_t = (g_{1t}, g_{2t})$ are stochastic shocks to productivity and government purchases, respectively, that we model as independent bivariate autoregressions. The productivity shocks follow

$$(10) \qquad z_{t+1} = A z_t + \varepsilon_{t+1}^z$$

where the innovations $\varepsilon^z = (\varepsilon_1^z, \varepsilon_2^z)$ are distributed normally and independently over time with variance V_z. The correlation between the productivity shocks, z_1 and z_2, is determined by the off-diagonal elements of A and V_z. Similarly, shocks to government purchases follow

$$(11) \qquad g_{t+1} = B g_t + \varepsilon_{t+1}^g$$

where $\varepsilon^g = (\varepsilon_1^g, \varepsilon_2^g)$ is distributed normally with variance V_g. The productivity shocks, z, and the government spending shocks, g, are independent.

Defining a competitive equilibrium for this economy with complete contingent claims markets is straightforward, but notationally burdensome. In the equilibrium, consumers use contingent claims markets to diversify country-specific risk across states of nature. By so doing, consumers end up equating the marginal utility of consumption across countries. Such an equilibrium is, of course, Pareto optimal, and we can characterize the equilibrium allocations by exploiting this feature. We compute, in particular, the equilibrium associated with the optimum problem: maximize $u_1 + u_2$ subject to the technology and the resource constraint. In this optimum problem, the marginal utility of consumption is also equated across countries for each state of nature; thus, country-specific risk is optimally diversified. We approximate this problem with one that has a quadratic objective function and linear constraints. Details of this procedure are described in Backus, Kehoe, and Kydland 1992, sec. 2.

□ *The Benchmark Experiment*

Quantitative properties of this theoretical economy depend, to a large extent, on the values of the model's parameters. The parameter values we use in our first experiment are listed in Table 3. With the exception of the parameters of the shocks to productivity and government purchases, these benchmark values are taken from Kydland and Prescott's (1982) closed-economy study. The parameters of the technology process are based on productivity shocks (Solow residuals) for the United States and an aggregate of European countries, as described in our earlier paper (Backus, Kehoe, and Kydland 1992, sec. 3). The parameters imply that the productivity shocks are persistent and positively correlated across countries. For the time being, we set $g_t = 0$, thereby eliminating government purchases from the model.

Properties of this benchmark world economy are reported and compared to those of the U.S. and European economies in Table 4. The entries in the table are means of various statistics across 20 stochastic simulations of the benchmark economy, each for 100 periods. As with the data, the statistics refer to Hodrick-Prescott filtered variables.

We find, first, that the volatility of output in this benchmark economy is somewhat less than that in the U.S. data, but larger than that of the European aggregate, as well as some of the individual European countries. The differences between theory and data, in this respect, are not large compared to the differences among countries. The

Table 3

The Model's Benchmark Parameter Values

Type	Name	Symbol and Value
Preferences	Discount Factor	$\beta = 0.99$
	Consumption Share	$\mu = 0.34$
	Curvature Parameter	$\gamma = 2.0$
Technology	Capital Share	$\theta = 0.36$
	Depreciation Rate	$\delta = 0.025$
	Time-to-Build	$J = 4$
Forcing Processes	Productivity Shocks	$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{12} & a_{11} \end{bmatrix} = \begin{bmatrix} 0.906 & 0.088 \\ 0.088 & 0.906 \end{bmatrix}$
		$\text{var}\ \varepsilon_1^z = \text{var}\ \varepsilon_2^z = 0.00852^2$
		$\text{corr}\left(\varepsilon_1^z, \varepsilon_2^z\right) = 0.258$
	Government Purchases	$g_t = 0$

behavior of some of the output components, however, differs substantially from the data. The variability of consumption relative to output is smaller in the model than it is in the U.S. data when durables are included (0.42 vs. 0.75). Since the model disregards durability, a comparison with the volatility of U.S. nondurables consumption may be more appropriate; with nondurables, most of the discrepancy disappears. (The volatility of U.S. nondurables consumption is 0.52.) Investment, however, is more than three times more variable relative to output in the model than in the U.S. data (10.99 vs. 3.27). The standard deviation of net exports is about seven times larger in the model than in the U.S. data and much larger than for any country in Table 1. Net exports in the model is essentially uncorrelated with output (with a contemporaneous correlation of 0.01) and is not countercyclical as net exports is in all the countries of Table 1.

We can get some intuition for these properties of the model by examining the dynamic responses pictured in Charts 1 and 2. These charts illustrate the responses in the benchmark economy to a one-time, one-standard-deviation increase in the home country's technology innovation ε_1, starting from the steady state. In the charts, the productivity shock is measured as a percentage of its steady-state

Tables 4–6

The Model vs. The Data*

1970–mid-1990

Table 4 National Business Cycles

Economy	Volatility: Standard Deviation: Output	Volatility: Standard Deviation: Net Exports	Volatility: Ratio of Standard Deviation to That of Output: Consumption	Investment	Employment	Productivity Shock	Persistence: Autocorrelation of Output	Comovement: Correlation With Output: Consumption	Investment	Net Exports	Employment	Productivity Shock
Data:												
United States	1.92%	.52%	.75	3.27	.61	.68	.86	.82	.94	−.37	.88	.96
Europe	1.01	.50	.83	2.09	.85	.98	.75	.81	.89	−.25	.32	.85
Experiments:												
Benchmark	1.50%	3.77%	.42	10.99	.50	.67	.62	.77	.27	.01	.93	.89
Transport Cost	1.35	.37	.47	2.91	.47	.75	.61	.81	.92	.23	.92	.98
Autarky	1.26	—	.54	2.65	.91	.99	.62	.90	.96	—	.91	.99

Table 5 International Comovements

Economy	Correlation of Foreign and Domestic Variables: Output	Consumption	Investment	Employment	Productivity Shock
Data:					
United States vs. Europe	.66	.51	.53	.33	.56
Experiments:					
Benchmark	−.21	.88	−.94	−.78	.25
Transport Cost	−.05	.89	−.48	−.70	.25
Autarky	.08	.56	−.31	−.51	.25

Table 6 The Terms of Trade

Economy	Volatility: Standard Deviation	Persistence: Autocorrelation	Comovement: Correlation With Net Exports	Comovement: Correlation With Output
Country:				
Australia	5.78%	.82	−.10	−.27
Austria	1.73	.46	−.24	.04
Canada	2.99	.85	.05	−.05
France	3.52	.75	−.50	−.13
Germany	2.66	.85	−.08	−.11
Italy	3.50	.78	−.66	.38
Japan	7.24	.86	−.56	−.22
Switzerland	2.85	.88	−.61	.41
United Kingdom	3.14	.80	−.58	.09
United States	3.68	.83	.30	−.20
Experiments:				
Benchmark	.48%	.83	−.41	.49
Two Shocks	.57	.67	−.05	.39
Large Import Share	.66	.83	−.41	.55
Small Elasticity	.76	.77	−.80	.51

*All statistics are based on Hodrick-Prescott filtered data. The entries for the model economies are averages over 20 simulations, each 100 periods long. The terms of trade is the relative price of imports to exports. Other variables are defined in a note on Table 1.

Sources of basic data: OECD and IMF

value; the remaining variables are measured as percentages of steady-state output.

Chart 1 shows what happens in the home country. There, the technology innovation is followed by an immediate jump in the productivity shock that slowly decays. This increase is accompanied by increases in domestic investment, consumption, and output. The movement in investment is by far the largest, and it leads to a deficit in net exports (not shown on the chart).

In Chart 2, we see that the innovation to the domestic productivity shock leads eventually, through the technology spillover, to a rise in foreign productivity. Despite this, foreign output and investment both fall initially. Roughly speaking, resources are shifted to the more productive location, the home country. This happens both with capital, as investment rises in the home country and falls abroad, and with labor, which follows a similar pattern. This tendency to make hay where the sun shines means that with uncorrelated productivity shocks, consumption will be positively correlated across countries while investment, employment, and output will be negatively correlated. With productivity shocks that are positively correlated, as they are in the benchmark model, all of these correlations rise, but with the benchmark parameter values, none change sign. This helps explain why (in Table 5) the correlations of foreign and domestic output, investment, and employment are negative and why the output correlation is smaller than the productivity shock correlation.

The benchmark economy, then, differs from postwar international data in several respects. In the model, investment and net exports are more variable than in the data, whereas consumption is more highly correlated across countries and output is less highly correlated. Our intuition is that the volatility of investment and net exports reflects the ability of agents in the model to shift perfectly substitutable goods costlessly between countries and to trade in complete markets for state-contingent claims. The ability to shift resources allows agents to shift capital and production effort to the country with the higher current productivity shock; that movement shows up in the model as excessive variability of investment and negative correlation of output across countries. Consumers' ability to insure themselves against adverse movements in their own productivity shocks suggests that the shifting of production will not be reflected in consumption plans.

□ *Other Experiments*

We therefore investigate frictions in the physical trading process and the market structure.

Charts 1 and 2

The Effects of a Productivity Shock in the Benchmark Model

Percentage Changes of Various Variables From Steady State*
After a One-Standard-Deviation Innovation
in the Productivity Shock in the Home Country

Chart 1 **Effects in the Home Country**

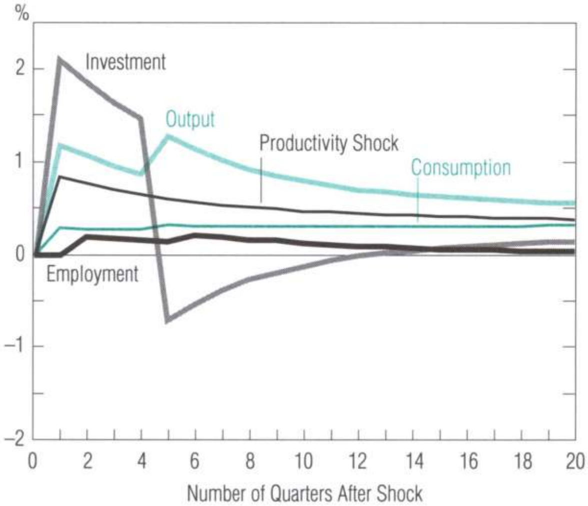
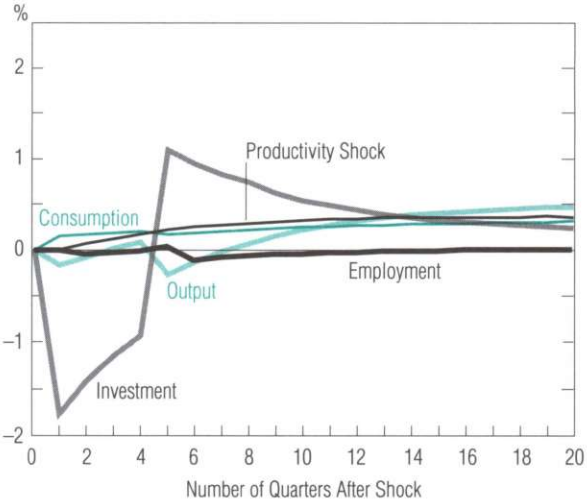


Chart 2 **Effects in the Foreign Country**



*The change in the productivity shock is measured as a percentage of its steady-state value. Changes in other variables are measured as percentages of the steady-state value of output.

In an experiment we call *transport cost,* we impose a quadratic cost on goods shipped between countries. The average cost, in equilibrium, is less than 1 percent, so that if 1 unit of the good is exported from one country, more than 0.99 unit arrives in another country.

As we see in Table 5, adding a transport cost reduces the variability of net exports substantially: the standard deviation of net exports falls from 3.77 percent in the benchmark economy to 0.37 percent in the one with a transport cost. This cost also lowers the standard deviation of investment relative to output by a factor of almost four, from 10.99 to 2.91. Across countries, output's correlation rises a bit, from –0.21 to –0.05, and so does consumption's, from 0.88 to 0.89. In short, this type of friction greatly reduces the variability of net exports and investment but has little effect on the difference between the cross-country correlations of output and consumption.

Now we consider limitations on agents' ability to share risk across countries. With complete markets, we know that if preferences are additively separable between consumption and leisure, as they would be if we set $\gamma = 1$, then the ability of agents to trade in markets for contingent claims leads to a perfect correlation of consumption across countries. The nonseparability lowers this correlation, in our benchmark economy, to 0.88, which is far larger than we saw in the data (Table 2). Here, we consider an extreme experiment, labeled *autarky,* in which we eliminate from the model all trade in goods and assets. The only connection between countries in this case is the correlation between productivity shocks.

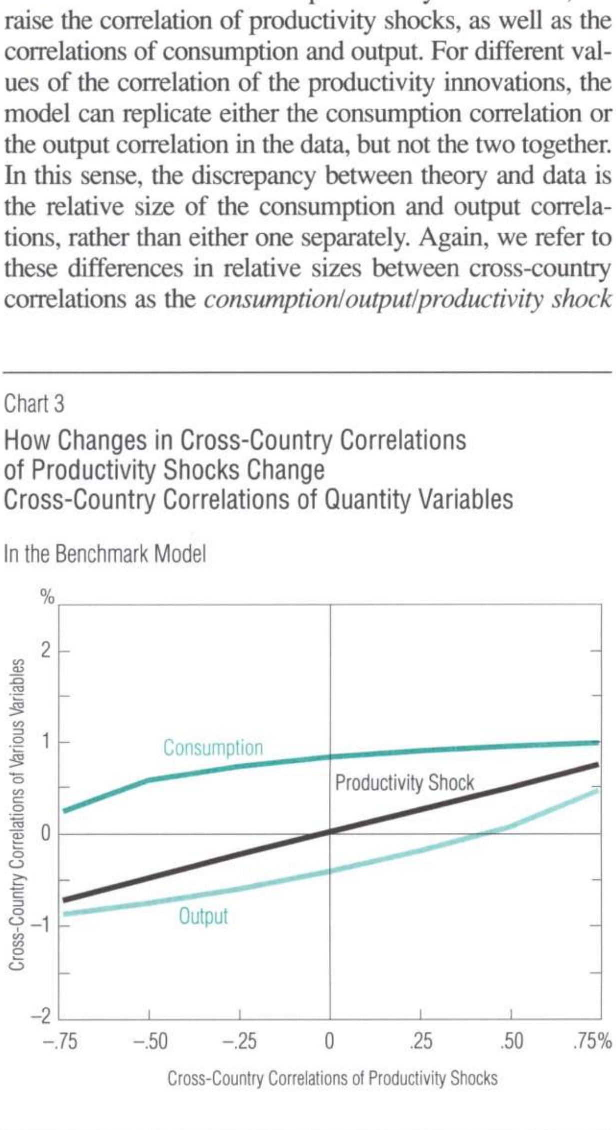
We see in Table 5 that eliminating trade reduces the consumption correlation across countries to 0.56, which makes it only slightly larger than the correlation of 0.51 between the United States and Europe. Output, however, remains much less highly correlated in the model than in the data. Even in this extreme experiment, the difference between theory and data is considerable. Recall that our intuition for the large consumption correlation in the benchmark economy was that it reflected agents' ability to share risk internationally. Under autarky, risk-sharing is prohibited, yet we still see a positive correlation. This correlation seems to reflect, instead, the operation of the permanent income hypothesis. The foreign agent knows that a rise in productivity in the home country will spill over to the foreign country and raise the agent's own future productivity and income. In anticipation of this, the foreign agent chooses to increase consumption immediately and postpone some investment.

One way to raise the correlation between foreign and domestic output is to make the productivity shocks more highly correlated. In the benchmark economy, the correlation of productivity shocks (z) is 0.25. If we vary the correlation of innovations, we can make this correlation as large or as small as we like. In Chart 3, we graph the cross-country correlations of consumption, output, and productivity shocks against the cross-correlation of productivity shocks for different values of the correlation of productivity innovations, $\mathrm{corr}(\varepsilon_1^z,\varepsilon_2^z)$. Clearly, as we increase the correlation of the productivity innovations, we raise the correlation of productivity shocks, as well as the correlations of consumption and output. For different values of the correlation of the productivity innovations, the model can replicate either the consumption correlation or the output correlation in the data, but not the two together. In this sense, the discrepancy between theory and data is the relative size of the consumption and output correlations, rather than either one separately. Again, we refer to these differences in relative sizes between cross-country correlations as the *consumption/output/productivity shock*

Chart 3

How Changes in Cross-Country Correlations of Productivity Shocks Change Cross-Country Correlations of Quantity Variables

In the Benchmark Model



anomaly, or more simply, as the *quantity anomaly.*[2]

In short, the theoretical economy generates fluctuations that differ sharply in some respects from the fluctuations we see in the data. The most interesting differences, we think, concern correlations across countries. In contrast to the data, the model generally produces output fluctuations that are less highly correlated across countries than those of consumption and the productivity shock. We will return to this issue later in the context of a theoretical economy in which foreign and domestic output are imperfect substitutes. For now, though, we note that these properties are not unique to international economies: similar features should hold in multisector models of closed economies. The tendency for output fluctuations to be less highly correlated than productivity shock fluctuations, for example, should be more pronounced in a closed economy where labor is mobile across sectors, yet we know that sectoral outputs are strongly correlated in the data. Similarly, consumption fluctuations should be strongly correlated across regions or individuals. Atkeson and Bayoumi (1991), Crucini (1992), and Van Wincoop (1992) are among those who compare related theories to data for regions within countries. Their work suggests that the one-sector methodology has also masked some interesting features of closed-economy business cycle behavior.

Prices

We turn now to the behavior of international relative prices, which has been one of the leading issues in international macroeconomics since the collapse of the Bretton Woods system of fixed exchange rates in 1971. The terms of trade, which we label p, is the ratio of the implicit price deflators for imports and exports—the relative price of imported goods. This definition is the inverse of the definition used by trade theorists, but corresponds to the convention applied in international macroeconomics to the real exchange rate. The deflators are from the OECD's *Quarterly National Accounts*. Here, as we did earlier, we measure the trade balance, labeled nx, as the ratio of net exports to output (which we call just *net exports*), with both of these measured in current prices as reported in the national income and product accounts. Output, as before, is labeled y. Statistics for p and y refer to logarithms.

Evidence . . .

We note in Table 6 several regularities among countries in the behavior of the terms of trade.

First, it has been highly variable. The standard deviation of the terms of trade varies somewhat across countries, but within a country, it is always greater than that of output (Table 1), sometimes by a factor of two or three. (For the United States, for example, the ratio of these standard deviations is 3.68/1.92 = 1.92.)

A second regularity is the persistence of relative price movements: the terms of trade is highly persistent, with an autocorrelation in the neighborhood of 0.8 for most countries.

Finally, the contemporaneous correlation between the terms of trade and net exports is negative in most countries. In France, Italy, Japan, Switzerland, and the United Kingdom, the correlations are less than –0.4. The United States is the only country in our table for which these two variables have a sizable positive contemporaneous correlation.

In short, among these countries, the behavior of net exports and the terms of trade has several regularities. Prominent among them are the large standard deviations of international relative prices and the high degree of persistence of these variables.

. . . vs. Theory

□ *A Modified Model*

A theory of relative price movements of foreign and domestic goods requires, obviously, that these two goods be different. Accordingly, we modify the model used above so that the two countries produce different, imperfectly substitutable goods.

Here, as before, the preferences of the representative agent in each country i are characterized by an expected utility function of the form

$$(12) \qquad u_i = E_0 \sum_{t=0}^{\infty} \beta^t U(c_{it}, 1-n_{it})$$

where c_{it} and n_{it} are consumption and employment in country i and $U(c,1-n) = [c^{\mu}(1-n)^{1-\mu}]^{1-\gamma}/(1-\gamma)$.

The technology in the model must change. Each country now specializes in the production of a single good, labeled a for country 1 and b for country 2. Each good is produced using capital, k, and labor, n, with linear homogeneous production functions of the same form. This

[2]Reynolds (1992) argues that our assessment of the theory is unduly pessimistic, in part because uncertainty about the parameter values makes the theory's predictions less precise. In her view, a model with multiple traded goods "is capable of replicating and explaining both the output and consumption correlations" (Reynolds 1992, abstract). Most of her point estimates, however, imply that the output correlations in her theory are smaller than the consumption correlations, and in one case, the difference is significant in a statistical sense.

gives us these resource constraints:

$$(13)\quad a_{1t} + a_{2t} = y_{1t} = z_{1t}F(k_{1t},n_{1t})$$

$$(14)\quad b_{1t} + b_{2t} = y_{2t} = z_{2t}F(k_{2t},n_{2t})$$

in countries 1 and 2, respectively, where $F(k,n) = k^{\theta}n^{1-\theta}$. The quantity y_{it} denotes total output in country i, measured in units of the local good, and a_{it} and b_{it} denote uses of the two goods in country i.

Consumption, investment, and government purchases in each country are composites of the foreign and domestic goods, with

$$(15)\quad c_{1t} + x_{1t} + g_{1t} = G(a_{1t},b_{1t})$$

$$(16)\quad c_{2t} + x_{2t} + g_{2t} = G(b_{2t},a_{2t})$$

where $G(a,b) = [\omega a^{1-\alpha}+b^{1-\alpha}]^{1/(1-\alpha)}$. The parameters α and ω are both positive, and the elasticity of substitution between foreign and domestic goods is $\sigma = 1/\alpha$. This method of treating foreign and domestic goods, widely used in computable static general equilibrium trade models, is due to Armington (1969), and the resulting function G is called the *Armington aggregator.*

We simplify the capital formation process by setting the time-to-build parameter J equal to 1. The capital stocks then evolve according to

$$(17)\quad k_{it+1} = (1-\delta)k_{it} + x_{it}$$

where δ, again, is the depreciation rate.

To develop some intuition for this economy, think of good a as aluminum and good b as bricks. Thus, both countries use capital and domestic labor in their production process, but country 1 specializes in making aluminum while country 2 specializes in making bricks. Country 1 keeps a_1 units of aluminum for domestic use and exports the rest, a_2. It then imports b_1 units of bricks from country 2 and combines the bricks and aluminum to make $G(a_1,b_1)$ units of country 1 goods. One can think of G as a function that simply transforms the aluminum and bricks into a country 1–specific good which is then used for consumption, investment, and government spending in country 1. Likewise, country 2 imports a_2 units of aluminum from country 1 and combines them with b_2 units of bricks that it produces to make $G(b_2,a_2)$ units of country 2–specific goods. These goods are used for consumption, investment, and government spending in country 2.

Here, as before, we compute equilibrium quantities by finding an optimal allocation. If q_{1t} and q_{2t} are the prices of the domestic and foreign goods, respectively, then the terms of trade is $p_t = q_{2t}/q_{1t}$. In equilibrium, this relative price can be computed from the marginal rate of substitution in the Armington aggregator,

$$(18)\quad p_t = q_{2t}/q_{1t} = \{\partial G(a_{1t},b_{1t})/\partial b_{1t}\}/\{\partial G(a_{1t},b_{1t})/\partial a_{1t}\} = \omega^{-1}(a_{1t}/b_{1t})^{1/\sigma}$$

evaluated at equilibrium quantities. The trade balance of country 1, expressed in units of the domestic good, is $a_{2t} - p_t b_{1t}$. Properties of this variable in the tables refer to the ratio of net exports to domestic output, y_{1t}, denoted

$$(19)\quad nx_{1t} = (a_{2t} - p_t b_{1t})/y_{1t}.$$

□ *The Benchmark Experiment*

With these elements and some parameter values, we can approach the behavior of the terms of trade. Relative to Table 3, the parameter set for this benchmark experiment includes $J = 1$ and the parameters of the Armington aggregator: the elasticity of substitution, σ, we set equal to 1.5, and the steady-state ratio of imports to output we set equal to 0.15 by choosing ω appropriately. In this benchmark version of the economy, foreign and domestic goods are better substitutes than they would be with Cobb-Douglas preferences. Our choice of σ is consistent with many studies, as documented by Whalley (1985, chap. 4). The import share is slightly larger than those in the United States, Japan, or an aggregate of European countries (with intra-European trade netted out).

Several properties of the theoretical economy with alternative parameter settings are reported at the bottom of Table 6. Consider, first, the persistence of the terms of trade. The autocorrelation for our benchmark parameter values is identical to that in the U.S. data: 0.83. This property is not especially surprising; the variables of the model, including the terms of trade, inherit the high degree of persistence observed in technology shocks in the data and incorporated into our productivity shock process.

A second property of this benchmark model is the comovement, or contemporaneous correlation, of net exports and the terms of trade. Recall that in the data this correlation is generally negative—everywhere but in Canada and the United States, in fact. In the theoretical economy, with the benchmark parameter values, the correlation is –0.41.

This number is in the middle of the range observed across the countries in our sample.

Finally, consider the volatility of the terms of trade. With our benchmark parameter values, the standard deviation is 0.48 percent, which is a factor of more than seven times smaller than that for the United States (3.68). This large difference between the standard deviation in the model and the data is our second anomaly: the *price variability anomaly,* or just the *price anomaly.*

□ *Other Experiments*

Like the quantity anomaly, the price anomaly is robust to reasonable changes in parameter values.

We add government spending shocks in the experiment labeled *two shocks.* In this experiment, we calibrate the government spending process to U.S. data: the mean value of g in each country is 20 percent of steady-state output, $B = \text{diag}(0.95, 0.95)$, and the innovations are assigned standard deviations equal to 2 percent of mean government purchases, or 0.004. The resulting shocks are independent across countries and of the productivity shocks, as they tend to be in international data (Table 2). With these shocks added to the benchmark model, the terms of trade standard deviation rises, but only to 0.57, which is still far below that in the data.

In another experiment, labeled *large import share,* we raise the average share of imported goods to output from 0.15 to 0.25. Now the standard deviation of the terms of trade rises a bit more, to 0.66. Nevertheless, the variability of the terms of trade in the model remains well below that in the data.

The volatility of the terms of trade is also influenced by the elasticity of substitution between foreign and domestic goods, $\sigma = 1/\alpha$ in the Armington aggregator. In the *small elasticity* experiment, we lower σ from 1.5 to 0.5; the standard deviation of the terms of trade then rises from 0.48 percent in the benchmark economy to 0.76, which, again, however, is far below the data.

In the theory, prices are related to quantities by the first-order condition,

$$\text{(20)} \quad \log(p_t) = -\log(\omega) - \sigma^{-1}\log(b_{1t}/a_{1t})$$

where b_1 is imports and a_1 is output minus exports in country 1. Given a fixed amount of variability in the import ratio b_1/a_1, we can increase the variability of p without bound by lowering the value of σ. In Chart 4 we see that as σ approaches zero, the standard deviation of

Charts 4 and 5

The Effects of Varying the Elasticity of Substitution Between Foreign and Domestic Goods

Chart 4 Effects on the Volatility of the Terms of Trade and the Import Ratio

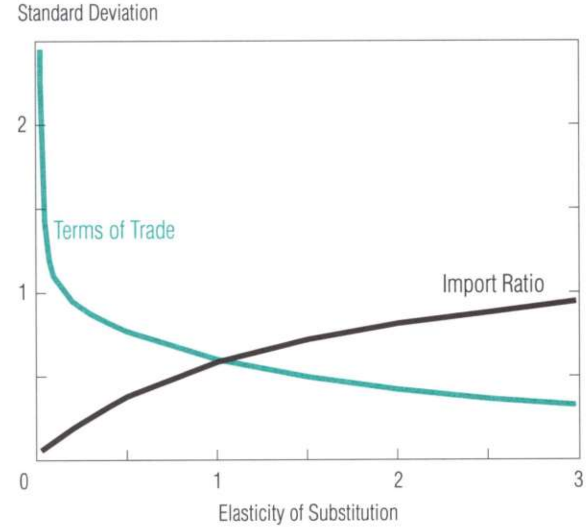
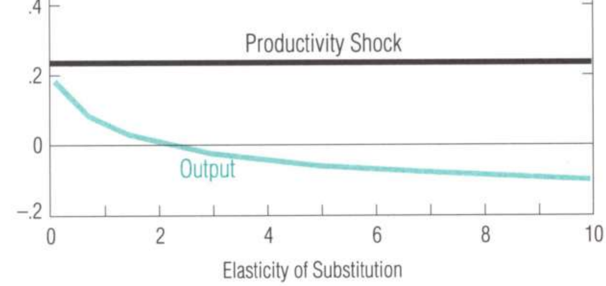


Chart 5 Effects on the Cross-Country Correlations of Selected Quantity Variables



the terms of trade rises and approaches values similar to those in the data. Closer inspection suggests, however, that raising the complementarity between foreign and domestic goods does not resolve the anomaly. The problem is that the variability of the import ratio in the data is not much different from that of the terms of trade. (See Table 7.) Thus, choosing a small value of σ only resolves the price anomaly by making the variability of b_1/a_1 much smaller in the model than it is in the data. Given the first-order condition, the problem of insufficient variability of the price, p, cannot be separated from that of insufficient variability of the quantity ratio, b_1/a_1.

Mussa (1986, 1990) adds another complication to this puzzle. He argues persuasively that an important ingredient in the price variability puzzle is the sharp difference in price behavior between fixed and floating exchange rate regimes. As he shows, and we report in Table 7, the variability of the terms of trade has been much higher since the Bretton Woods fixed exchange rate system was abandoned in 1971 than before that. By our estimates, the difference is a factor of about three in the major countries for which we have long data series available. Mussa (1986) also notes greater price variability in other periods of floating exchange rates (like in Canada between 1952 and 1962), so the distinction between fixed and floating rate regimes is not simply one of time period.

In our theory, and in others which have a similar first-order condition relating prices and quantities, the standard deviation of the terms of trade is directly related to quantity variability: if the standard deviation of the import ratio doubles, then so does the standard deviation of the terms of trade. With this in mind, we note that while in most countries (except Japan) the volatility of quantities has been greater in the post–Bretton Woods period, the increase has been much smaller than that for the terms of trade. The issue, then, is how to account for the sharp increase in price volatility without generating a similar increase in quantity volatility. At the very least, the tight connection between prices and quantities implied by first-order conditions like (20) must be abandoned.

Finally, we return briefly to our quantity anomaly. We have noted that complementarity between foreign and domestic goods influences the volatility of the terms of trade. It also influences the model's business cycle properties. As we see in Chart 5, the correlation between consumption in the two countries of our theoretical economy falls as we reduce the elasticity of substitution between foreign and domestic goods. At the same time, the correlation between foreign and domestic output rises. Nevertheless, for all values of σ above 0.025 (the smallest value we've been able to use), the consumption correlation exceeds the output correlation. The productivity shock correlation, of course, is not affected by the choice of σ: it equals 0.23 throughout. Thus, for reasonable values of σ, the theory and the data are substantially different in their values of the cross-country correlations of output, consumption, and productivity shocks. Imperfect substitutability between goods, that is, does not appear to resolve the quantity anomaly.

In sum, we must add relative price variability to our list of anomalies. An interesting wrinkle to this finding is that the anomalous behavior of prices is closely connected, in our theory, to the anomalous behavior of quantities.

Other Efforts

We have documented two striking differences between theory and data, the quantity and price anomalies. Our review of these issues has focused on our own work, but international macroeconomics has been one of the most active areas of business cycle research and includes studies that go far beyond our theoretical economies. Although these studies have addressed a wide range of issues, let's review them from the perspective of the two anomalies.

Recent studies in international business cycle research have extended the theory in at least five ways.

One of the more popular has been to introduce nontraded goods. We are often reminded that haircuts and other services cannot be traded across cities, much less across countries, so this approach has some natural appeal. However, adding nontraded goods to models like ours does not seem to help explain either anomaly.

Consider the quantity anomaly. Including nontraded goods can, in principle, lower the cross-country consumption correlation, since the correlations between the nontraded components of consumption are not directly connected by trade in goods. Adding nontraded goods may, in addition, lower the correlation of the consumption of traded goods if the utility function is nonseparable between traded and nontraded goods consumption, as it is in the work of Stockman and Tesar (1991). The effect is similar to that of leisure in our models when utility is not additively separable between consumption and leisure. But in both our work and that of Stockman and Tesar (1991), the effect of the nonseparability is quantitatively small. In Stockman and Tesar 1991, the result of adding nontraded goods is that traded goods consumption, rather than total

Table 7

The Price and Quantity Effects of Exchange Rate Regimes*

			Volatility: Standard Deviation						Comovement: Correlation With the Same U.S. Variable	
Country	Period	Rate Regime	Terms of Trade	Output	Net Exports	Imports	Exports	Import Ratio	Output	Consumption
Canada	1955–90	—	2.44%	1.48%	.79%	5.25%	5.52%	3.85%	.71	.52
	1955–71	Fixed	1.19	1.38	.78	4.83	2.89	4.13	.53	.59
	1972–90	Floating	3.05	1.54	.79	5.44	4.64	4.75	.79	.48
Japan	1955–90	—	5.69%	1.61%	1.01%	6.64%	4.50%	6.29%	.20	.27
	1955–71	Fixed	2.29	1.93	1.06	7.54	3.74	7.01	–.07	–.02
	1972–90	Floating	7.12	1.19	.92	5.87	4.91	5.63	.57	.36
United Kingdom	1955–90	—	2.64%	1.48%	1.07%	3.85%	3.15%	3.50%	.46	.35
	1955–71	Fixed	1.45	1.25	.74	3.04	2.85	2.53	.15	.05
	1972–90	Floating	3.05	1.67	1.22	4.34	3.36	4.16	.57	.35
United States	1955–90	—	2.92%	1.70%	.45%	4.90%	5.52%	3.85%	1.00	1.00
	1955–71	Fixed	1.26	1.23	.32	3.38	5.23	3.16	1.00	1.00
	1972–90	Floating	3.79	1.94	.54	5.88	5.61	4.38	1.00	1.00

*Statistics are based on Hodrick-Prescott filtered data. All but the net exports data have been logged. Imports and exports are in real terms, and the import ratio is real imports divided by the difference between real output and real exports. Other variables are defined in a note on Table 1.

Sources of basic data: OECD and IMF

consumption, is more highly correlated across countries in the model than in the data. The anomaly, in other words, is simply pushed onto the traded component of consumption. Backus and Smith (forthcoming) note, as well, that these models imply close connections between consumption differentials and relative prices that are not observed in aggregate data.

A second extension of international business cycle theory has been a byproduct of the first: a reconsideration of the impulses (or shocks) generating fluctuations. Costello and Praschnik (1992), for example, introduce oil price shocks, which increases the variability of the terms of trade in oil-importing countries and lowers the correlation of consumption across countries. In this work, however, the terms of trade for manufactured goods remains less variable in the model than in the data and the cross-country correlation of manufactured goods consumption is much higher than in the data. Stockman and Tesar (1991) suggest shocking preferences instead. They add a shock to the first-order condition that links consumption quantities and relative prices. Adding this shock lowers the correlation of aggregate consumption across countries and of consumption of traded goods alone. It has little effect, however, on the variability of the terms of trade. So far, no one has attempted to quantify such shocks, which makes assessing the effects of adding them to our models difficult. One step in this direction might be to compute taste shocks as residuals from agents' first-order conditions, much as we compute productivity shocks as residuals from production functions.

A third popular extension of the theory is to introduce restrictions on asset trade. Economies with incomplete markets would seem to have the potential to account for low correlations of consumption across countries. After all, with complete markets, as in our models, agents use asset markets to equate marginal rates of substitution across time and states of nature. With separable preferences, this leads, as we have seen, to a perfect correlation of consumption across countries. When agents have limited ability to use international financial markets to share risk, marginal rates of substitution are not equated for all times and states. One might guess, then, that the consumption correlation would be smaller in such models than in those with complete markets.

This guess is correct, but the difference is not great enough. Conze, Lasry, and Scheinkman (1991) show that in an economy in which agents can trade a single asset, the consumption correlation falls and the output correlation rises. Yet they still find that the consumption correlation exceeds the output correlation for most parameter values. Our autarky experiment makes the same point in an economy with even more limited trading opportunities. Kollmann (1990, Table 1.1.3) studies an economy in which two agents trade a single riskfree bond. In this economy, he finds much smaller consumption correlations than with incomplete markets, but the correlation of investment across countries is sharply negative when productivity shocks are persistent, as they are in the data, and the consumption correlation remains higher than the output correlation. Baxter and Crucini (forthcoming, Table 4) also consider an economy in which agents trade a single riskfree bond; they find that output is more highly correlated across countries than consumption is, but that the correlations of consumption, investment, and employment are negative. Thus, these models have, to some extent, transferred the quantity anomaly from consumption, output, and productivity onto other variables.

A fourth extension of the theory is to add money to economies that are otherwise much like ours, in an attempt to dissolve the price anomaly. Both Grilli and Roubini (1992) and Schlagenhauf and Wrase (1992) adapt Lucas' (1990) liquidity model to the open economy. In these economies, asset markets and goods markets are separated for one period, and shocks to the stock of money have a one-period effect on interest rates, currency prices, and relative prices of goods. Thus, the theory generates greater volatility of relative prices than would exist in an analogous model without the segmented market structure. In its current form, however, this structure generates relative price movements with very little persistence and thus fails to mimic this important feature of the data. The next step in this line of research is to specify a mechanism to generate that persistence.

Another class of monetary models considers labor or goods contracts that fix wages or prices in advance. In closed-economy studies, like that of Cho and Cooley (1991), this magnifies the effects of some shocks on employment and output. In open economies, one might guess that it could generate additional relative price variability, particularly if segmentation across national markets is added. This intuition has yet to be tested, but Cho and Roche (1993) and Ohanian and Stockman (1993) have made some progress on developing international business cycle models of this sort.

A fifth, final extension of the theory is to introduce imperfect competition. If imperfectly competitive firms sell their output in markets that are internationally segmented, then price discrimination might lead to greater changes in relative prices than we see with perfect competition. Studies of industries by Giovannini (1988) and Lapham (1991) show that this change can lead to persistent movements in relative prices across countries, but the theory has yet to be extended to general equilibrium settings at the level of aggregation considered in our models. Perhaps Hornstein's (1991) or Rotemberg and Woodford's (forthcoming) general equilibrium treatment of monopolistic competition in a closed economy could be adapted to the open economy.

All of these innovations help bring the quantitative implications of the theory closer to observed properties of international time series data. As yet, however, they have not resolved the two anomalies.

Final Thoughts

Recent work on international business cycles focuses on two striking differences between theory and data. One we call the *quantity anomaly:* in the data the correlation across countries of output fluctuations is generally larger than the analogous consumption and productivity correlations; in theoretical economies, meanwhile, for a wide range of parameter values, the consumption correlation exceeds the productivity and output correlations. The other anomaly we call the *price anomaly.* It concerns relative price movements: the standard deviation of the terms of trade is considerably larger in the data than in theoretical economies.

These anomalies have been met with a large and imaginative body of work in which the dynamic general equilibrium framework has been extended in ways that go well beyond the two-country versions of Kydland and Prescott (1982) that started this line of study. Our guess is that five years from now the models that have been developed will be fundamentally different.

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