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DYNAMICS OF THE TRADE BALANCE AND THE TERMS OF TRADE: THE S-CURVE

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ABSTRACT

We provide a theoretical interpretation of two features of international data: the countercyclical movements in net exports and the tendency for the trade balance to be negatively correlated with current and future movements in the terms of trade, but positively correlated with past movements. We document these same properties in a two-country stochastic growth model in which trade fluctuations reflect, in large part, the dynamics of capital formation. We find that the general equilibrium perspective is essential: The relation between the trade balance and the terms of trade depends critically on the source of fluctuations.

We document some of the properties of short-term fluctuations in the trade balance and the terms of trade in 11 OECD countries and interpret them from the perspective of a two-country stochastic growth model. The terms of trade, in this paper, is the relative price of imports to exports and the trade balance is the ratio of net exports to output. We find that the trade balance is uniformly countercyclical and, in general, is negatively correlated with current and future movements in the terms of trade, but positively correlated with past movements. We call this asymmetric shape of the cross-correlation function for net exports and the terms of trade the S-curve, since it looks like a horizontal S. This finding is reminiscent of earlier work on the J-curve (Junz and Rhomberg 1973, Magee 1973, and Meade 1988).

Our objective is to provide a dynamic general equilibrium interpretation of these properties. The theoretical structure extends earlier work on trade and price dynamics by Hodrick (1988) and Stockman and Svensson (1987), who develop simple general equilibrium models in which both the trade balance and the terms of trade are endogenous. In our economy, two countries produce imperfectly substitutable goods with capital and labor, and fluctuations arise from persistent shocks to aggregate productivity and government purchases. We find that with plausible parameter values, this theoretical economy generates both countercyclical trade and an S-curve. The dynamic responses to productivity shocks suggest a straightforward explanation for both properties. A favorable domestic productivity shock leads to an increase in domestic output, a decrease in its relative price, and a rise in the terms of trade. Because the productivity shock is persistent, we also see a rise in consumption and a temporary boom in investment, as capital is shifted to its most productive location. The increases in consumption and investment together are greater than the gain in output, and the economy experiences a trade deficit during this period of high output. This dynamic response pattern gives rise to countercyclical movements in the balance of trade and an asymmetric cross-correlation function much like the ones seen in the data.

Investment dynamics play a central role in generating these properties of our theoretical economy. If we eliminate capital, the trade balance is simply a reflection of output dynamics and consumption smoothing. Consider, once more, the dynamic responses to a domestic productivity shock. In this economy, preference for smooth consumption results in a smaller increase in consumption than in output and an improvement in the balance of trade. Thus, the trade balance is procyclical rather than countercyclical, as it is in the economy with capital. At the same time, the price of domestic goods falls and the terms of trade rises. Since the shocks (and hence the fluctuations in trade and prices) are persistent, the economy generates a tent-shaped cross-correlation function: The asymmetric pattern we call the S-curve does not arise when the economy has no capital.

We find that the general equilibrium perspective is essential, in the sense that the correlations between trade and relative prices depend critically on the source of fluctuations. Although this implication of the theory is, in some ways, obvious, it differs sharply from the large body of work in international macroeconomics based on the small open economy assumption, in which relative price movements are exogenous. Because the source of relative price movements is not specified in these models, the relation between trade and prices is independent of them by assumption. In our general equilibrium setting, the source is critical. We illustrate this feature of the theory in an economy with shocks to government spending rather than productivity. In this case, the cross-correlation function for net exports and the terms of trade is tent-shaped, rather than S-shaped. The difference between cross-correlation functions with shocks to productivity and government spending makes it clear that there is no simple structural relation, in our economy, between the trade balance and the terms of trade and suggests that one cannot characterize the relation between trade and prices without specifying the source of their fluctuations.

These points are developed in the rest of the paper. We start, in Section I, with a description of postwar quarterly data, including the cyclical behavior of net exports and the correlations between net exports and the terms of trade, for 11 developed countries. In Section II, we describe a theoretical economy with two countries that produce different goods with capital and labor and that face shocks to productivity and government purchases. In Section III, we discuss the selection of parameter values and our method of computing equilibrium time paths for net exports, the terms of trade, and other variables. In Section IV, we turn to the model's properties, including the correlation between net exports and the terms of trade. Section V is devoted to two extreme experiments: the economy without capital and investment, and with shocks to government spending alone. Section VI is devoted to some additional features of the theory, including two that we term anomalies: properties for which there remains a substantial difference between theory and data. We conclude with a few remarks on the usefulness of our theoretical framework for interpreting trade and price movements and other features of international time series data.

I. Properties of the Data

We start by looking at postwar quarterly trade statistics for 11 developed countries. The data are from the Organization for Economic Cooperation and Development's (OECD's) *Quarterly National Accounts* and are described more completely in the Appendix. We measure the trade balance, labeled nx, as the ratio of net exports to output, with both measured in current prices as reported in national income and product accounts. The terms of trade, labeled p, is the ratio of the implicit price deflators for imports and exports -- the relative price of imported goods. Real output is either GNP or GDP in constant prices, and is labeled y. Statistics for both p and y refer to logarithms of those variables. Throughout the paper, properties of both international time series data and theoretical economies refer to Hodrick-Prescott filtered variables. The properties of this filter are described in some detail by Hassler et al. (1992) and King and Rebelo (1989). We simply note that the filter leaves us with short-term fluctuations in the variables being studied.

In Table 1, we report some of the salient properties of fluctuations in the trade balance and the terms of trade. We list, first, the standard deviations of net exports, the terms of trade, and output. A fair amount of heterogeneity exists across countries in the magnitudes of these statistics, particularly in the trade variables. The standard deviation of the ratio of net exports to output ranges from a low of 0.45 percent for the United States to a high of 1.75 for Finland. The median value, in our sample, is 1.06 percent. The standard deviation of the terms of trade varies somewhat more, from 1.63 in Austria to 5.86 in Japan.

Second, both the trade balance and the terms of trade are highly persistent. The autocorrelation of net exports extends from 0.29 in Austria to 0.90 in Switzerland, with a median of 0.71. The autocorrelation of the terms of trade ranges from 0.50 for Austria to 0.88 in Japan and Switzerland, with a median of 0.80.

Third, net exports are countercyclical in every country in our sample. This feature has been noted elsewhere by Blackburn and Ravn (1991) and Danthine and Donaldson (1991), among others, and is implicit in the strong relations between imports and income in most macroeconometric models.

Fourth, the contemporaneous correlation between net exports and the terms of trade varies somewhat across countries, but is negative more often than not. In Finland, France, Italy, Japan, Switzerland, and the United Kingdom, the correlations are less than -0.4. The United States is the only country in our sample for which these two variables have a sizable positive contemporaneous correlation. Mendoza (1990) provides evidence for additional countries at an annual frequency.

The contemporaneous correlations between net exports and the terms of trade ignore, however, the complex dynamic relation between these variables suggested by earlier work. In Figure 1, we graph cross-correlation functions for these two variables, for leads and lags up to two years: the correlations, that is, between p_t and nx_{t+k} for k between -8 and 8. This function is typically negative for negative values of k (the left side of the horizontal axis), but turns positive for k between 2 and 4. This general pattern, moreover, does not seem to be the result of the sample periods used. In Figure 2, we report cross-correlation functions for the periods before and after 1972 for the four countries for which we have data going back to 1955. Japan and the United Kingdom exhibit the same shape in both the Bretton Woods period (1955-71) and the more recent floating-rate period (1972-90). Canada shows little relation between the two variables, at any lead or lag, for either period. For the United States, the cross-correlation function for the earlier period is similar to that of Japan and the United Kingdom, as well as 8 of the 11 countries in Figure 1. The United States in this period differs slightly from these other countries in that the function crosses the axis to the left of k=0, rather than the right, but the shape is otherwise similar. The United States in the latter period, however, displays a substantially different pattern. If we further divide the post-1972 period into the 1970s and 1980s, we find (not reported) that this change in U.S. trade and price performance applies to both decades: In neither decade is the shape of the cross-correlation like that of the Bretton Woods period in the United States, the United Kingdom, and Japan in both subperiods, or in 8 of the 11 countries of Figure 1.

We label the characteristic asymmetric shape of the cross-correlation function for net exports and the terms of trade the S-curve, since it resembles a horizontal S, but readers may notice a resemblance to the J-curve of earlier work. In studies of devaluations, it was frequently noted that unfavorable movements in the terms of trade (increases, in our terminology) were generally associated with declines in the balance of trade that reversed themselves 6 to 24 months later. This pattern was referred to as the J-curve. A classic example is the 1967 sterling devaluation described by Artus (1975). This property of devaluations spawned subsequent studies, including those cited by Junz and Rhomberg (1973), Magee (1973), and Meade (1988), in which observed trade and price dynamics were attributed to, among other things, lags between order and delivery of imported goods and the time required for exporters to change capacity. We return to these issues in Section IV.

In short, we find a number of regularities in the behavior of net exports and the terms of trade: both are highly autocorrelated; the trade balance is consistently countercyclical; and the cross-correlation function for net exports and the terms of trade has an asymmetrical shape we call the S-curve.

II. A Theoretical Economy

We compare these properties of international data to those of a stochastic growth model with two countries, each inhabited by a large number of identical agents. This world economy is a streamlined two-country version of Kydland and Prescott's (1982) closed economy, in which each country produces a different good with its own technology and labor is internationally immobile. Fluctuations are driven by stochastic shocks to productivity and government purchases of goods and services.

Preferences of the representative agent in each country i are characterized by utility functions of the form

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

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

With respect to the technology, each country specializes in the production of a single good, labeled "a" for country 1 and "b" for country 2. The goods are produced using capital, k, and labor, n, with linear homogeneous production functions of the same form. This gives rise to the resource constraints,

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

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

in countries 1 and 2, respectively, with $F(k,n) = k^{\theta}n^{1-\theta}$. The quantity y_{it} denotes GDP 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. Thus a_{2t} denotes exports from country 1 to country 2, and b_{1t} represents imports into country 1. The vector $z_t = (z_{1t}, z_{2t})$ is a stochastic shock to productivity whose properties will be described shortly.

Consumption, investment, and government purchases -- denoted c, x, and g, respectively -- are composites of foreign and domestic goods:

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

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

where $G(a,b) = [\omega_1 a^{-\rho} + \omega_2 b^{-\rho}]^{-1/\rho}$ is homogeneous of degree one and $\rho \geq -1$. Hence, all three final uses of goods and services have both foreign and domestic content, and in the same proportions. The elasticity of substitution between foreign and domestic goods is $\sigma = 1/(1+\rho)$. This device for aggregating domestic and foreign goods was suggested by Armington (1969) and is a standard feature of general equilibrium trade models (Whalley 1985, Deardorff and Stern 1990). Accordingly, we refer to G as an Armington aggregator. The weights ω_i in the aggregator function G allow us to specify the domestic and foreign content of domestic spending. Government purchases, g, are stochastic; we describe their behavior below.

Capital formation embodies the time-to-build structure of Kydland and Prescott (1982). As in their economy, it takes J quarters to augment the productive capital stock. A unit increase in the capital stock J quarters from now involves purchases of 1/J units of the final good for J consecutive quarters. To express this mathematically, let s_{it} be planned additions to the capital stock of country i in period t+J. The capital stocks then evolve according to

$$k_{it+1} = (1-\delta)\, k_{it} + s_{it-J+1},$$

where δ is the depreciation rate. In period t, total expenditure on gross capital formation is

$$x_{it} = J^{-1} \Sigma_{j=0}^{J-1} s_{it-j},$$

the sum of capital expenditures on all currently active projects. In all experiments but one, we set J=1, so investment expenditures made in period t increase the stock of capital in period t+1.

Finally, the underlying shocks to our economy are independent bivariate autoregressions. The technology shocks follow

$$z_{t+1} = A\ z_t + \varepsilon^z_{t+1},$$

where ε^z is distributed normally and independently over time with variance V_z. The correlation between the technology shocks, z_1 and z_2, is determined by the off-diagonal elements of A and V_z. Similarly, shocks to government spending are governed by

$$g_{t+1} = B\ g_t + \varepsilon^g_{t+1},$$

where $g_t = (g_{1t}, g_{2t})$ and ε^g is distributed normally with variance V_g. Technology shocks, z, and government spending shocks, g, are independent.

From these elements, we can construct national income and product accounts for each country of our theoretical world economy. GDP in country 1 at date t, in units of the domestically produced good, is y_{1t}; the resource constraint equates this to the sum $a_{1t}+a_{2t}$. We relate national output to expenditure components as follows. The Armington aggregator expresses absorption, $c_{1t}+x_{1t}+g_{1t}$, as a function of a_{1t} and b_{1t}. Since the aggregator, G, is homogeneous of degree one, we have, in equilibrium,

$$c_{1t} + x_{1t} + g_{1t} = q_{1t}a_{1t} + q_{2t}b_{1t},$$

where q_{1t} and q_{2t} are the prices of the two goods at date t. Using the resource constraint, we can express output as

$$y_{1t} = (c_{1t}+x_{1t}+g_{1t})/q_{1t} + (a_{2t}-p_tb_{1t}),$$

where $p_t = q_{2t}/q_{1t}$ is the terms of trade. Thus output is the sum of absorption, $(c_{1t}+x_{1t}+g_{1t})/q_{1t}$, and net exports, $a_{2t}-p_tb_{1t}$. We measure the trade balance in the model just as we do in the data, as the ratio of net exports to output, with both measured in current prices:

$$nx_t = (a_{2t} - p_t b_{1t})/y_{1t}.$$

We compute the terms of trade in country 1 from

$$p_t = q_{2t}/q_{1t} = \{\partial G(a_{1t},b_{1t})/\partial b_{1t}\}/\{\partial G(a_{1t},b_{1t})/\partial a_{1t}\},$$

the marginal rate of transformation between the two goods in country 1, evaluated at equilibrium quantities.

III. Parameter Values, Steady State, and Computation

We describe, briefly, our procedures for selecting the benchmark parameter values, listed in Table 2, and for computing a competitive equilibrium. Both are adapted to the open economy from Kydland and Prescott's (1982) closed economy study; for details, see their paper (Sections 4 and 5) and Backus, Kehoe, and Kydland (1992a, Sections II and III). As a rule, share parameters for preferences and production are chosen to equate means of ratios of aggregate U.S. time series to analogous ratios for the theoretical economy's steady state. Curvature parameters are selected from existing statistical studies. We use Solow residuals for the United States and an aggregate of European countries to estimate the parameters of the technology process, which result in productivity shocks that are highly persistent and positively correlated across countries. The only new elements are the parameters of the Armington aggregator and those that govern the behavior of shocks to government spending, both of which we describe below. Given values for the model's parameters, we compute an equilibrium by solving numerically a quadratic approximation to a social planner's problem that weights equally the utility of consumers in the two countries.

The most important parameters in this paper are those of the Armington aggregator, which govern the elasticity of substitution between foreign and domestic goods and the average ratio of imports to output. The elasticity of substitution is $\sigma=1/(1+\rho)$, and there is some uncertainty about what value of this parameter is indicated by the data; see, for example, the survey of estimates provided by Stern, Francis, and Schumacher (1976). The most reliable studies seem to indicate that for the United States, the elasticity is between one and two, and values in this range are generally used in empirical trade models. For Japan and an aggregate of European countries, the elasticity seems to be smaller; see, for example, the discussions in Deardorff and Stern (1990, ch. 3) and Whalley (1985, ch. 5). We use $\sigma=1.5$ as our starting point, but experiment with other values as well. We determine ω_1 and ω_2 from observed ratios of imports and exports to GDP using the first-order condition

$$p = (\omega_2/\omega_1)\ (a_1/b_1)^{1/\sigma}.$$

In a symmetric steady state with $y_1=y_2$, $b_1=a_2$, and $p=1$, the ratio a_1/b_1 can be expressed as $(1-b_1/y_1)/(b_1/y_1)$, where b_1/y_1 is the ratio of imports to GDP in country 1. With $p=1$, this determines the ratio ω_2/ω_1. We set the levels of ω_1 and ω_2 so that the steady-state value of y_1 is one, a convenient normalization. We use an import share of 0.15, which is slightly greater than its average value in the United States, Japan, and Europe (in aggregate, with intra-European trade excluded) over the last decade. We postpone discussion of government spending shocks until they are used in the next section.

We use these parameter values as a benchmark, but also consider alternative values in the following sections.

IV. Properties of the Theoretical Economy

We are now in a position to compute equilibrium time paths for variables in our theoretical economy and compare their properties to those of the aggregate data we reviewed earlier. We do this for the benchmark parameter values, described in the previous section and summarized in Table 2, and also for some other values. This analysis helps us to assess the role of various parameters in generating specific properties of the theoretical economy and gives us some feeling for the robustness of these properties. It also provides some intuition for the model's behavior.

Our primary objective is to document the theoretical relation between net exports and the terms of trade and to determine, in particular, whether the theory can account for the asymmetric cross-correlation function for the trade balance and the terms of trade -- what we have called the S-curve. We find it useful to start, however, with some summary statistics. These statistics shed light on aspects of the model that play a role in the dynamics of net exports and the terms of trade, and may also have some independent interest. Thus we report, in Table 3, the same properties of the theoretical economy that we documented for 11 OECD countries in Table 1. The first row, which we refer to as the *benchmark* economy, uses the parameter values specified in the last section and listed in Table 2.

We find, first, that both net exports and the terms of trade are highly autocorrelated in our theoretical economy. The autocorrelation of net exports is somewhat less than we see in the data (0.61 in the model v. a median of 0.71 in the data), but is within the range observed for other countries. The autocorrelation of the terms of trade in the model (0.83) is very close to its median value in the data (0.80). Neither of these properties is surprising: The variables of the model inherit to a large extent the high degree of persistence in the technology shocks.

We turn next to correlations between net exports and other variables. In the benchmark economy, net exports are countercyclical: The contemporaneous correlation with output is -0.64. This characteristic is stronger than we see in U.S. data (-0.22), but is within the range of variation observed across the 11 countries of our sample (-0.17 to -0.68). There is a sense in which investment is essential in generating these countercyclical fluctuations in net exports. The trade balance and investment are connected, as we know, by an identity: Net exports is the difference, in our economy, between output and the sum of consumption and investment at market prices. Consumers' desire for smooth consumption will lead, as seen in Section VI, to a standard deviation of consumption about half that of output. As a result, output net of consumption is procyclical. Countercyclical movements in the balance of trade also require strong procyclical movements in investment. In the model, as in the data, these fluctuations are large enough to make absorption more variable than output over the cycle and thus give rise to a negative correlation between net exports and output.

A third feature of the benchmark economy is a strong inverse relation between net exports and the terms of trade: The trade balance is generally positive when the relative price of foreign goods is low. This correlation is generally negative in the data, too, with the United States being a notable exception. We also find that the correlation between the terms of trade and output is strongly positive in the theoretical economy; in the data, there is no obvious regularity.

With this background, we turn to the cross-correlation function for net exports and the terms of trade. We see, in Figure 3, that this function takes the S-curve shape that we documented for 8 of 11 countries in Figure 1. Thus, the theory delivers one of the striking features of the data. We can get some intuition for the behavior underlying this correlation from Figure 4, where we graph the dynamic responses of the terms of trade and other variables to a one-time positive shock to domestic productivity. On impact, we see an increase in domestic output and thus a decrease in its relative price, the inverse of the terms of trade. In the second panel of the figure we see that this shock also raises consumption, but by less than half the increase in output. Investment, on the other hand, grows by more than consumption and the trade balance moves initially into deficit. As time passes, the investment boom dissipates and the trade deficit turns to a surplus. This impulse response pattern gives rise, in the benchmark economy, to a negative contemporaneous correlation between net exports and the terms of trade. The correlation between p_t and nx_{t+k} increases with k in the neighborhood of k=0, reflecting the positive slope of the dynamic response function for net exports in Figure 4. The reasoning behind the left side of the cross-correlation function is somewhat different. To make this as simple as possible, suppose the economy has only one shock and that the terms of trade is autoregressive of order one, with autocorrelation coefficient α. Then the cross-correlation function for lags $k<0$ approaches zero geometrically at rate α. In the benchmark economy, the dynamics are slightly more complex, and this example provides only an approximation to the pattern reported in Figure 3.

We see, then, that the theory produces an S-curve and that the dynamics of net exports and the terms of trade in our theoretical economy reflect, to a large extent, the influence of capital formation on the balance of trade. We return to this issue in the next section. The remaining experiments of Table 3 illustrate the sensitivity of these properties to values of particular parameters and the influence on the economy of shocks to government purchases.

Perhaps the most important parameter for the trade-balance/terms-of-trade relation is the elasticity of substitution between foreign and domestic goods. In the benchmark economy, this elasticity is 1.5; in the next two experiments we choose larger and smaller values. In the *large elasticity* experiment (σ=2.5), the contemporaneous correlation between net exports and the terms of trade is weaker, moving from -0.41 in the benchmark case to -0.05. In the *small elasticity* experiment (σ=0.5), the correlation is more strongly negative. Evidently the elasticity parameter, σ, has a significant influence on this correlation. In Figure 5, we plot the correlation for values of σ between zero and five. We find that the correlation is negative for small elasticities and positive for large elasticities, with the sign change occurring at about σ=2.7.

We get a more complete picture of the effect of the elasticity of substitution on trade and price dynamics from the cross-correlation function. In Figure 6, we report such functions for the trade balance and the terms of trade for the first three theoretical economies. We find that for each of the three values of the substitution elasticity, the cross-correlation function exhibits an S-curve. It is clear, then, that the value of the elasticity does not change this implication of the theory. What changing the elasticity does is shift the function left and right: as we decrease σ, the cross-correlation function shifts to the right. Thus, the elasticity of substitution between foreign and domestic goods affects the contemporaneous correlation between the trade balance and the terms of trade, but not the asymmetric shape of the cross-correlation function.

This dependence of the timing of the S-curve on the elasticity of substitution suggests a more subtle interpretation of the data: that there is a relation between the timing of the crossing point of the cross-correlation function and the elasticity of substitution. Studies that estimate the elasticity of substitution between foreign and domestic goods typically find larger values for the United States than for Europe and Japan; see, for example, Whalley's (1985, ch. 5) survey of the evidence. We also see that the cross-correlation function for the United States in Figure 1 is shifted to the left relative to those for other countries. Perhaps further work will indicate the robustness of the relation between these two properties.

To this point, we have considered experiments in which productivity shocks are the only source of fluctuations. Another potential source of shocks is government purchases, which have been emphasized in related contexts by Hodrick (1988), Obstfeld (1989), and Yi (1991). In our next experiment, labeled *two shocks*, we consider shocks to both productivity and government spending. The parameter values for the government spending process are derived from international data and from Chari, Christiano, and Kehoe's (1991) estimates for the United States. The mean value of g in each country is 20 percent of steady-state output, which we have normalized at one. We set B = diag(0.95,0.95), so that shocks are highly persistent. The innovations are assigned standard deviations equal to 2 percent of mean government spending, or 0.004. These shocks are independent across countries and of the productivity shocks, as they tend to be in international data.

In most respects, the properties of the economy with government shocks are similar to those of the benchmark economy. Net exports remain countercyclical. The cross-correlation function between net exports and the terms of trade, pictured in Figure 7, is flatter than that with only shocks to productivity, but has the same general shape. Introducing shocks to government spending, then, does not change these two features of the theory.

Thus, our theoretical economy generates both the countercyclical movements of net exports and the asymmetrical pattern of cross-correlations between net exports and the terms of trade that we see in the data. With the benchmark parameter values, however, the dynamics of the theory are less persistent than those in the data, with the cross-correlation function changing its sign one to two quarters faster in our theoretical economy than in the data. One approach to this issue is, as we have seen, to postulate smaller values of the elasticity of substitution: When we lower σ from 1.5 to 0.5 (Figure 6), the point at which the cross-correlation function crosses the axis shifts to the right by one to two quarters. Another approach is to consider additional dynamic mechanisms. Common examples range from sluggishness in adding new productive capacity (Helkie and Hooper 1988, Junz and Rhomberg 1973, and Magee 1973 provide typical examples of this story) to the fixed costs of changing export quantities of recent work on hysteresis (Dixit 1989 or Baldwin and Krugman 1990). We look at an example of each.

We consider, first, modifications of the dynamics of capital formation. Most studies posit either adjustment costs or multiperiod construction for the technology of capital formation. Baxter and Crucini (1992) and Mendoza (1991), for example, consider convex costs of changing the capital stock. Kydland and Prescott (1982), on the other hand, argue for "time to build" and suggest that a four-quarter construction period (J=4, in the notation of our theory) is closer to what we see in the U.S. economy. We consider an intermediate experiment with J=2, labeled *time to build* in Table 3. We find, for this experiment, that the pattern of cross-correlations is not much different from the benchmark economy. As we see in Figure 8, this modification shifts the cross-correlation function to the right about one quarter, bringing the theory closer to what we see in the data for most countries.

A second modification is a one-period lag in the trading process: Goods exported from country 1, say, in period t cannot be used in country 2 until period t+1. We think of this delay as including both time in transit and in clearing customs. The Armington aggregators in period t, in this case, are $G(a_{1t},b_{1t-1})$ and $G(a_{1t-1},b_{1t})$, respectively, in the domestic and foreign countries. We label this one-period delivery lag *time to ship.*

This shipping lag introduces a subtle measurement issue: It is not clear what concept of price corresponds most closely to that used in constructing import price indexes. One possibility is the "delivery" price, which in our framework would give rise to a terms of trade in country 1 of

$$p_t = \{\partial G(a_{1t},b_{1t-1})/\partial b_{1t-1}\}/\{\partial G(a_{1t},b_{1t-1})/\partial a_{1t}\}.$$

This relative price corresponds to the value of imports once they clear customs. An alternative is the "contract" price prevailing at the time the import goods are ordered. In this case, the equilibrium terms of trade would be

$$p_t = E_t \{m_{t+1} \; \partial G(a_{1t+1},b_{1t})/\partial b_{1t}\}/\{\partial G(a_{1t},b_{1t-1})/\partial a_{1t}\},$$

where

$$m_{t+1} = \beta \{\partial U(c_{1t+1},1-n_{1t+1})/\partial c_{1t+1}\}/\{\partial U(c_{1t},1-n_{1t})/\partial c_{1t}\}$$

is the intertemporal marginal rate of substitution for the domestic composite good. We report properties of the latter definition in Table 3, since this seems a better approximation of how prices are constructed in international data.

We find that the delivery lag in *time to ship* does influence the timing of the relation between the trade balance and the terms of trade. We see in Figure 8 that the cross-correlation function is shifted to the right by about one quarter relative to the benchmark economy, again making it more similar to those in the data for many countries. In this sense, both *time to build* and *time to ship* are useful extensions of the benchmark economy.

V. Two Extreme Experiments

All of the experiments considered in the previous section are based on parameter values that we consider reasonable. Here we conduct two experiments with parameter settings that we regard as unreasonable in order to illustrate two central features of the theory.

The first feature is the relation between investment and trade dynamics. In the last section we stressed, as do Brock (1988), Gavin (1990), Matsuyama (1988), Murphy (1986), and Sachs (1981), the close connection between fluctuations in trade and investment in physical capital. To emphasize this connection, we set the capital share parameter θ equal to 0.001 in the experiment labeled *no capital*, which effectively eliminates capital from the economy. The behavior of trade and prices changes dramatically. We find, in contrast to the benchmark economy, that the trade balance is procyclical and the contemporaneous correlation of net exports and the terms of trade is strongly positive. The cross-correlation function, pictured in Figure 9, is tent-shaped: There is no evidence of the S-curve that appeared in the economy with capital formation. These differences between the economy with and without capital indicate that capital formation plays a central role in the dynamics of trade and relative prices for the benchmark economy.

The properties of the *no capital* economy can be understood, for the most part, as reflections of consumption smoothing. Consider the cyclical behavior of trade. We will see in the next section that in this economy, consumption is less variable than income; as a result, the trade balance, which is the difference between output and consumption at market prices, is procyclical. With respect to comovements between trade and prices, the dynamic response functions again provide some intuition. A favorable shock to domestic productivity leads to an increase in domestic output, a smaller rise in domestic consumption and, with these parameter values, a trade surplus. With greater output of the domestic good, its relative price falls and the terms of trade rises. This leads to a positive contemporaneous correlation between the trade balance that decays monotonically in both directions (see Figure 9).

A second feature of the theoretical economy is the dependence of trade and price dynamics on the type of shocks hitting the economy. In the experiment labeled *government shocks*, shocks to government purchases serve as the sole impulse. With only government shocks we find, again, that the properties of the model are much different from our benchmark experiment. The contemporaneous correlation between net exports and the terms of trade, for example, changes from -0.41 in the benchmark economy to 1.00. But the most interesting aspect of these differences concerns the cross-correlation function for the trade balance and the terms of trade. With government spending shocks alone, the cross-correlation function, pictured in Figure 9, is tent-shaped: It is consistently positive, peaks at lag zero, and declines in both directions. As in the *no capital* economy, there is no sign of an S-curve.

Once more we can get some intuition for this behavior from the dynamic responses of the economy to a one-time shock, reported in Figure 10. The striking difference between government and productivity shocks shows up largely in the response of investment. There is no tendency, as with productivity shocks, for an investment boom to follow the shock; we see, in fact, the opposite with these parameter values. This sharp difference between the economy with productivity and government spending shocks illustrates the hazard of predicting comovements between the terms of trade and the trade balance without specifying the shock that gives rise to these movements. Galor and Lin (1991) and Stulz (1988) make similar points in different contexts.

This result is much different from that obtained from deterministic small open-economy analysis, in which price movements are exogenous. In prominent papers by Dornbusch (1983), Obstfeld (1982), and Svensson and Razin (1983), for example, as well as most of the papers cited earlier in connection with trade and investment dynamics, the source of relative price movements is not specified. The relation between trade and relative price movements, then, is assumed to be independent of their source. This is clearly not the case in our economy, where price movements resulting from shocks to government purchases are associated with much different trade responses than those resulting from shocks to productivity.

In short, the economy generates an S-curve when capital formation is an important part of the propagation mechanism and fluctuations are driven by shocks to productivity. Without capital, or with shocks only to government spending, it does not. In this sense, both capital formation and the source of price and trade fluctuations are critical factors in determining the shape of the cross-correlation function for net exports and the terms of trade in our theoretical framework.

VI. Anomalies

We have emphasized the implications of the theory for the cross-correlation function between the trade balance and the terms of trade. Here we expand our study to other properties and point out two discrepancies between quantitative properties of theory and those of the data.

The first discrepancy is evident from Tables 1 and 3: For our benchmark parameter values and a wide range of alternatives, the variability of the terms of trade is significantly smaller in our theoretical economy than it is in the data. Zimmerman (1991) notes a similar discrepancy in an analogous economy with three countries of different sizes, as do Stockman and Tesar (1991) in an economy with both traded and nontraded goods. The standard deviation of the terms of trade is 0.48 percent in our benchmark economy (see Table 3) and 2.92 percent in U.S. data (Table 1), a difference of a factor of six. If we compare the theory to data for Japan, the difference is even larger. The difference is smaller if we use a smaller elasticity of substitution (*small elasticity*) or add shocks to government purchases (*two shocks*), but even in these cases the discrepancy between theory and data is substantial. Alternatively, we might argue that the standard deviations of relative prices in the data are overstated. Alterman (1991), for example, has constructed improved indexes of U.S. import and export prices. Using these indexes, the terms of trade exhibits about 30 percent less variability than the data used in our Table 1. We think it unlikely, however, that measurement error is large enough to account for most of the substantial difference in price variability between theory and data.

A second class of discrepancies concerns the magnitude and character of fluctuations in aggregate quantities: the standard deviations of consumption and investment, for example, and the correlations of output and consumption across countries. We report these properties in Table 4 for all of the parameter settings used in Table 3. With respect to the variability of investment, we found in our earlier study (Backus, Kehoe, and Kydland 1992a) that when foreign and domestic goods are perfect substitutes and goods can be shipped costlessly between countries, the variability of investment is much greater than we see in the data. In U.S. data, reported in the first row of Table 4, the standard deviation of investment is 3.15 times the standard deviation of output. When the time to build parameter J is one, as it is in the economy of this paper, this ratio is 31.5 (Backus, Kehoe, and Kydland 1992a, Table 5). We approximate this economy in the experiment labeled *perfect substitutes*, where we set σ=100 and $\omega_1=\omega_2$. In this case, the standard deviation of investment, relative to that of output, is 30.3. In the benchmark economy, however, investment is much less variable: The standard deviation, relative to output, is 3.48. Apparently, the concavity of technology implied by imperfect substitutability, even for values of σ as large as 2.5 (our *large elasticity* experiment), is sufficient to bring the theory close to the data in this respect. For this reason, we do not view investment variability as an anomaly of the theory.

A more robust discrepancy is what we termed, in our earlier paper, the consumption/output anomaly: In the data, the correlation of consumption across countries is generally smaller than that of output; in our theoretical economies, we see the reverse. In data for the United States and an aggregate of European countries, for example, the consumption correlation is 0.46, the output correlation 0.70; see the data row of Table 4. In our *perfect substitutes* economy, these correlations are 0.67 and -0.58, respectively, so there is clearly a large difference between theory and data. With imperfect substitutability between foreign and domestic goods (the *benchmark* experiment, for example), the consumption correlation (0.77) remains substantially larger than the output correlation (0.02), although the difference between them is smaller. Complementarity between foreign and domestic goods reduces this discrepancy even more (see the *small elasticity* experiment, in which σ is reduced to 0.5 from 1.5 in the benchmark case), but does not eliminate it. Stockman and Tesar (1991) do somewhat better in this regard using nontraded goods and taste shocks, but they understate the correlation across countries of consumption of traded goods alone.

In short, work to date has documented two robust discrepancies between properties of the data and those of this class of theoretical economies. The first concerns relative price variability: The terms of trade appears much more variable in the data than in the theoretical economies. The second concerns international comovements: In the theory, we generally find that the correlation of output across countries is stronger than that of consumption; in the data we see the reverse. These anomalies, in our opinion, are two of the central issues in international business cycle research and stand as clear challenges to future work in this area.

The question in the present context is how these anomalous features affect our assessment of the dynamics of the trade balance and the terms of trade. This is probably impossible to answer without knowing how those anomalies are resolved. Nevertheless, we suspect that the countercyclical movements in trade and the S-shaped cross-correlation function for trade and relative prices may be robust properties of the theory, since they rely primarily on the persistence of productivity shocks and the dynamics of capital formation, features that apply to a much broader class of economies than ours. Thus, we suspect that this account of the S-curve may survive the changes that are called for by anomalies in other dimensions of the model's properties.

VII. Concluding Remarks

This study adds to a growing literature in which properties of international time series data are compared to those of dynamic general equilibrium models. Prominent examples include Baxter and Crucini (1992), Cardia (1991), Mendoza (1991), and Stockman and Tesar (1991); Backus, Kehoe, and Kydland (1992b) provide a more complete list. These studies look at a wide range of issues. The first three papers, for example, examine the correlation between saving and investment rates within countries. Stockman and Tesar (1991) study, among other things, the correlations of output and consumption across countries. We add to this list a consideration of the short-run dynamics of trade and relative prices. We find that while the theory mimics the cross-correlation function for the trade balance and the terms of trade, in two other respects the theory differs sharply from the data. Future work should tell us how these discrepancies between theory and data are resolved and how further developments bear on the dynamics of trade and relative prices.

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APPENDIX

Data Sources and Definitions

The data used in Table 1 and Figures 1 and 2 were taken from the Organization for Economic Cooperation and Development's *Quarterly National Accounts.* These are reported quarterly in a publication of the same name; our numbers come from a machine-readable data base supported by the Board of Governors of the Federal Reserve System. The variables of interest are

real output: output in base-year prices, either GNP or GDP, depending on the country;

net exports in current prices: exports minus imports in current prices;

terms of trade: ratio of the implicit price deflator for imports to the implicit price deflator for exports, with deflators computed as ratios of current-price imports and exports to base-year-price imports and exports.

The sample periods noted in Table 1 are the complete samples from the January 1991 version of the data base. We seasonally adjusted the data for Australia, Austria, and Finland using the X-11 method.

Table 1

Properties of Net Exports, Real Output, and the Terms of Trade

in 11 OECD Countries

	Std. Deviation (percent)			Autocorrelation			Correlation		
Country	nx	y	p	nx	y	p	(nx,y)	(nx,p)	(y,p)
Australia	1.36	1.53	5.25	.74	.65	.82	−.19	−.09	−.27
	(.15)	(.16)	(.70)	(.18)	(.19)	(.23)	(.17)	(.11)	(.11)
Austria	1.11	1.20	1.63	.29	.60	.50	−.44	−.16	.13
	(.09)	(.13)	(.20)	(.12)	(.18)	(.15)	(.12)	(.12)	(.11)
Canada	.79	1.52	2.44	.59	.76	.85	−.42	.04	−.10
	(.06)	(.18)	(.35)	(.13)	(.22)	(.25)	(.19)	(.08)	(.10)
Finland	1.75	1.62	1.96	.40	.56	.73	−.60	−.46	.17
	(.19)	(.24)	(.23)	(.21)	(.22)	(.20)	(.24)	(.11)	(.10)
France	.83	.91	3.54	.71	.76	.75	−.29	−.50	−.12
	(.10)	(.14)	(.54)	(.19)	(.27)	(.21)	(.22)	(.22)	(.15)
Germany	.80	1.50	2.64	.60	.69	.86	−.17	.00	−.13
	(.08)	(.19)	(.26)	(.19)	(.23)	(.18)	(.13)	(.16)	(.10)
Italy	1.34	1.69	3.52	.80	.85	.79	−.68	−.66	.38
	(.19)	(.28)	(.40)	(.26)	(.29)	(.19)	(.28)	(.21)	(.21)
Japan	1.01	1.68	5.86	.81	.74	.88	−.18	−.47	−.12
	(.10)	(.16)	(.86)	(.17)	(.17)	(.27)	(.12)	(.13)	(.16)
Switzerland	1.33	1.93	2.92	.90	.90	.88	−.68	−.61	.40
	(.23)	(.38)	(.32)	(.32)	(.36)	(.20)	(.29)	(.19)	(.19)
U.K.	1.06	1.47	2.66	.67	.56	.75	−.23	−.54	.19
	(.13)	(.15)	(.47)	(.21)	(.15)	(.32)	(.08)	(.27)	(.07)
U.S.	.45	1.83	2.92	.80	.82	.80	−.22	.27	.03
	(.04)	(.17)	(.42)	(.14)	(.16)	(.24)	(.14)	(.11)	(.15)
Median	1.06	1.53	2.92	.71	.74	.80	−.29	−.46	.03

Definition of Variables:
nx = the ratio of net exports to output
y = the logarithm of real output
p = the logarithm of the ratio of the import deflator to the export deflator

NOTES: Data are quarterly, from the Organization for Economic Cooperation and Development's *Quarterly National Accounts.* Numbers in parentheses are Newey-West standard errors. All statistics refer to Hodrick-Prescott filtered variables. Sample periods are Australia, 1960:IQ–1990:IQ; Austria, 1964:IQ–1990:IQ; Canada, 1955:IQ–1990:IQ; Finland, 1975:IQ–1990:IQ; France, 1970:IQ–1990:IQ; Germany, 1968:IQ–1990:IQ; Italy, 1970:IQ–1990:IQ; Japan, 1955:IIQ–1990:IQ; Switzerland, 1970:IQ–1990:IQ; United Kingdom, 1955:IQ–1990:IQ; and United States, 1950:IQ–1990:IIQ.
SOURCE: Authors' calculations.

Table 2

Benchmark Parameter Values

Preferences	$\beta = .99, \ \mu = .34, \ \gamma = -1.0$
Technology	$\theta = .36, \ \delta = .025, \mathrm{J} = 1,$
	$\sigma = 1/(1+\rho) = 1.5$, import share = .15
Forcing processes	$\mathrm{A} = \begin{bmatrix} a_{11} & a_{12} \\ a_{12} & a_{11} \end{bmatrix} = \begin{bmatrix} .906 & .088 \\ .088 & .906 \end{bmatrix}$
	$\mathrm{var}\ \epsilon_1^z = \mathrm{var}\ \epsilon_2^z = .00852^2, \ \mathrm{corr}(\epsilon_1^z, \epsilon_2^z) = .258$
	$g_t = 0.$

SOURCE: Authors' calculations.

Table 3

Properties of Net Exports, Real Output,

and the Terms of Trade in Theoretical Economies

Economy	Std. Deviation (percent) nx	y	p	Autocorrelation nx	y	p	Correlation (nx,y)	(nx,p)	(y,p)
Benchmark	.30	1.38	.48	.61	.63	.83	−.64	−.41	.49
	(.02)	(.18)	(.06)	(.07)	(.10)	(.05)	(.07)	(.08)	(.14)
Large Elasticity	.33	1.41	.35	.63	.64	.88	−.57	−.05	.43
	(.03)	(.18)	(.05)	(.07)	(.18)	(.03)	(.08)	(.09)	(.14)
Small Elasticity	.37	1.33	.76	.61	.63	.77	−.66	−.80	.51
	(.03)	(.18)	(.07)	(.07)	(.10)	(.05)	(.07)	(.09)	(.16)
Two Shocks	.33	1.33	.57	.62	.65	.78	−.57	−.05	.39
	(.03)	(.15)	(.07)	(.08)	(.08)	(.06)	(.15)	(.17)	(.17)
Time to Build	.28	1.34	.51	.60	.63	.52	−.61	−.40	.50
	(.02)	(.17)	(.06)	(.17)	(.10)	(.16)	(.07)	(.08)	(.12)
Time to Ship	.24	1.35	.48	.65	.66	.66	−.56	−.51	.61
	(.02)	(.18)	(.05)	(.07)	(.08)	(.09)	(.08)	(.09)	(.11)
No Capital	.18	1.14	1.29	.71	.61	.64	.66	.99	.68
	(.01)	(.15)	(.09)	(.06)	(.11)	(.07)	(.06)	(.00)	(.06)
Government Shocks	.16	.17	.30	.67	.67	.67	−.55	1.00	−.55
	(.03)	(.02)	(.05)	(.11)	(.08)	(.11)	(.13)	(.00)	(.13)
Perfect Substitutes	16.90	2.22	---	−.10	.76	---	.10	---	---
	(1.14)	(.29)		(.18)	(.05)		(.04)		

NOTES: Statistics are based on Hodrick-Prescott filtered data. Entries are averages over 20 simulations of 100 quarters each; numbers in parentheses are standard deviations. Parameters are as in Table 2, except for large elasticity, $\sigma = 2.5$; small elasticity, $\sigma = 0.5$; two shocks, mean of g = diag (0.2, 0.2), B = diag (0.95, 0.95), and V_g = diag (0.004^2, 0.004^2); government shocks, as in two shocks plus $z_t = 1$, all t; time to build, J = 2; no capital, $\theta = 0.001$; time to ship, one-period shipping lag, as described in the text; and perfect substitutes, $\theta = 100$, and import share = 0.5.
SOURCE: Authors' calculations.

Table 4

Business Cycle Properties of Theoretical Economies

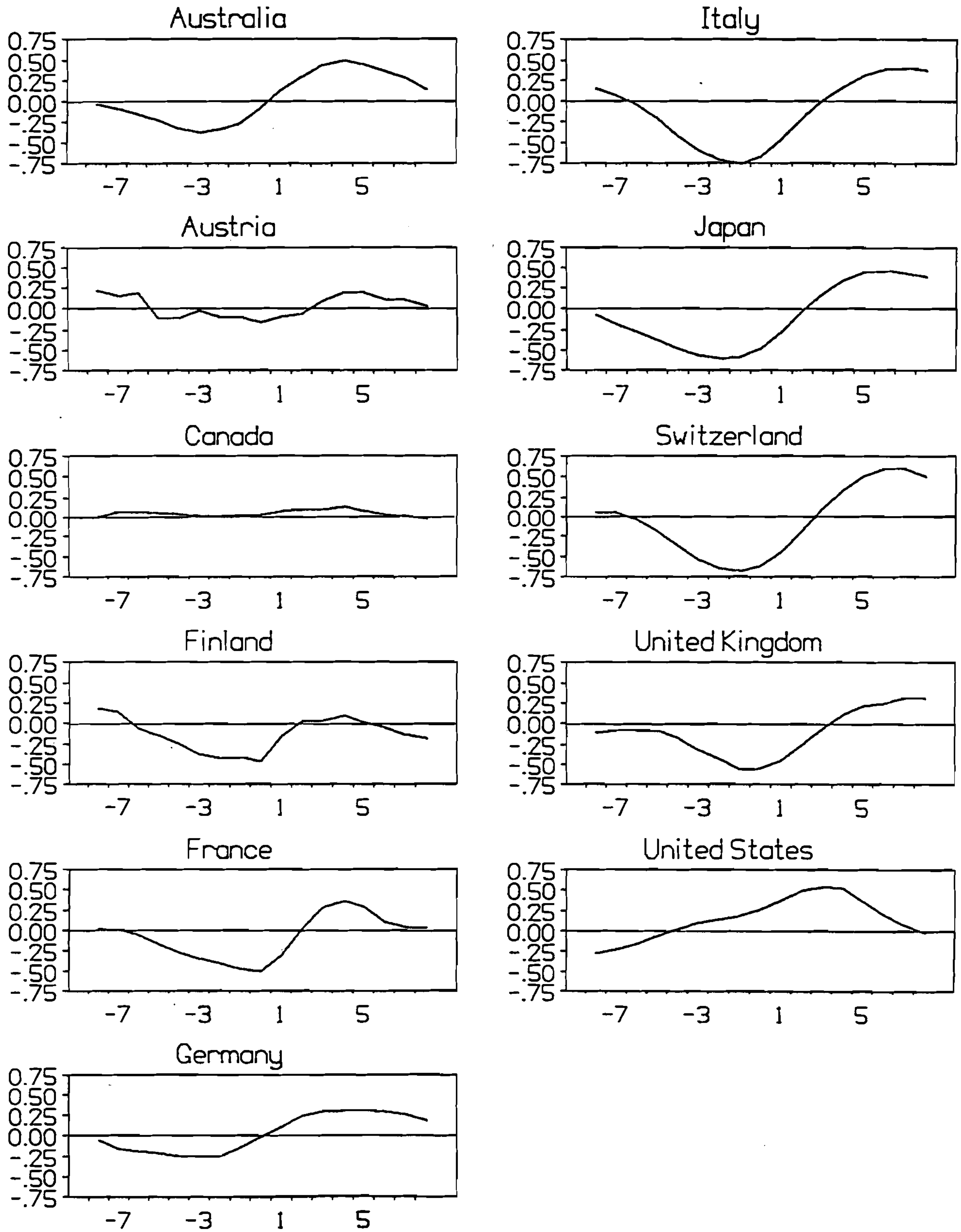
	Ratio of Std. Dev. to that of Output		Correlation			
Economy	c	x	(c,y)	(x,y)	(y_1,y_2)	(c_1,c_2)
Data	.49	3.15	.76	.90	.70	.46
Perfect Substitutes	.31	30.32	.75	.01	−.58	.67
	(.06)	(1.07)	(.12)	(.05)	(.15)	(.17)
Benchmark	.47	3.48	.88	.93	.02	.77
	(.08)	(.31)	(.06)	(.02)	(.18)	(.10)
Large Elasticity	.46	3.59	.85	.92	−.02	.81
	(.08)	(.31)	(.07)	(.02)	(.18)	(.10)
Small Elasticity	.50	3.41	.92	.93	.10	.68
	(.08)	(.31)	(.04)	(.02)	(.17)	(.11)
Two Shocks	.62	4.29	.78	.89	.00	.83
	(.09)	(.59)	(.11)	(.04)	(.23)	(.06)
Time to Build	.49	3.35	.88	.93	.04	.77
	(.08)	(.30)	(.06)	(.02)	(.18)	(.10)
Time to Ship	.47	3.21	.86	.93	.02	.79
	(.08)	(.31)	(.07)	(.02)	(.18)	(.10)
No Capital	.72	---	.73	---	.03	1.00
	(.11)		(.10)		(.17)	(.00)
Government Shocks	.93	3.66	−.95	−.95	.42	.79
	(.12)	(.47)	(.02)	(.02)	(.16)	(.08)

Definition of Variables:
c = the logarithm of real consumption
x = the logarithm of real fixed investment
y = the logarithm of real output
Subscripts 1 and 2 refer to the domestic and foreign countries, respectively.

NOTES: Parameter values are described in Tables 2 and 3. The data row is taken from Backus, Kehoe, and Kydland (1992a, Table 5); entries refer to the United States, except for the correlations between foreign and domestic output and consumption, which refer to the United States and Europe. As in Table 3, numbers in parentheses are standard deviations of the relevant statistic over 20 simulations of 100 periods each.
SOURCE: Authors' calculations.

Figure 1

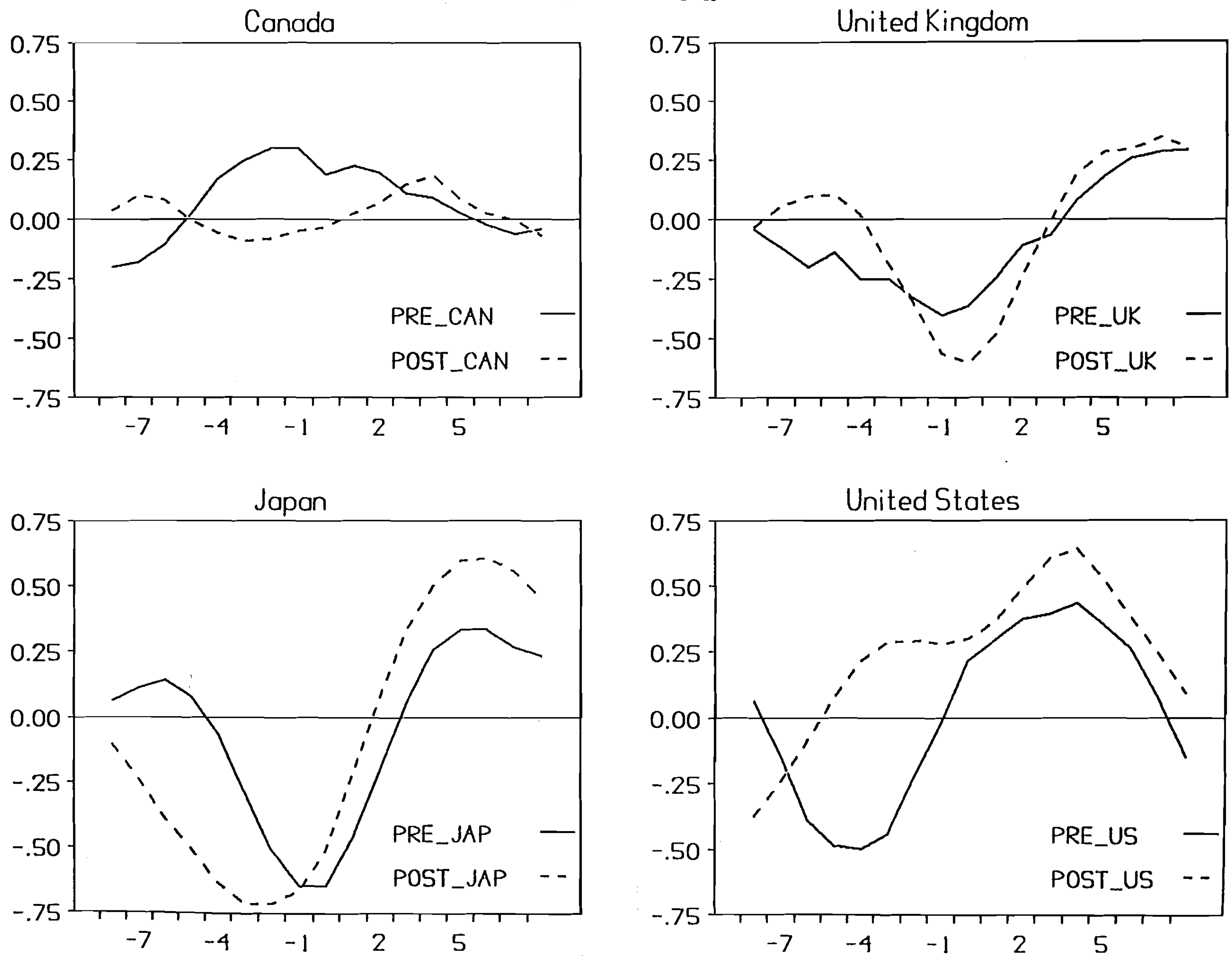
Correlation of p_t and nx_{t+k}



SOURCE: Authors' calculations.

Figure 2

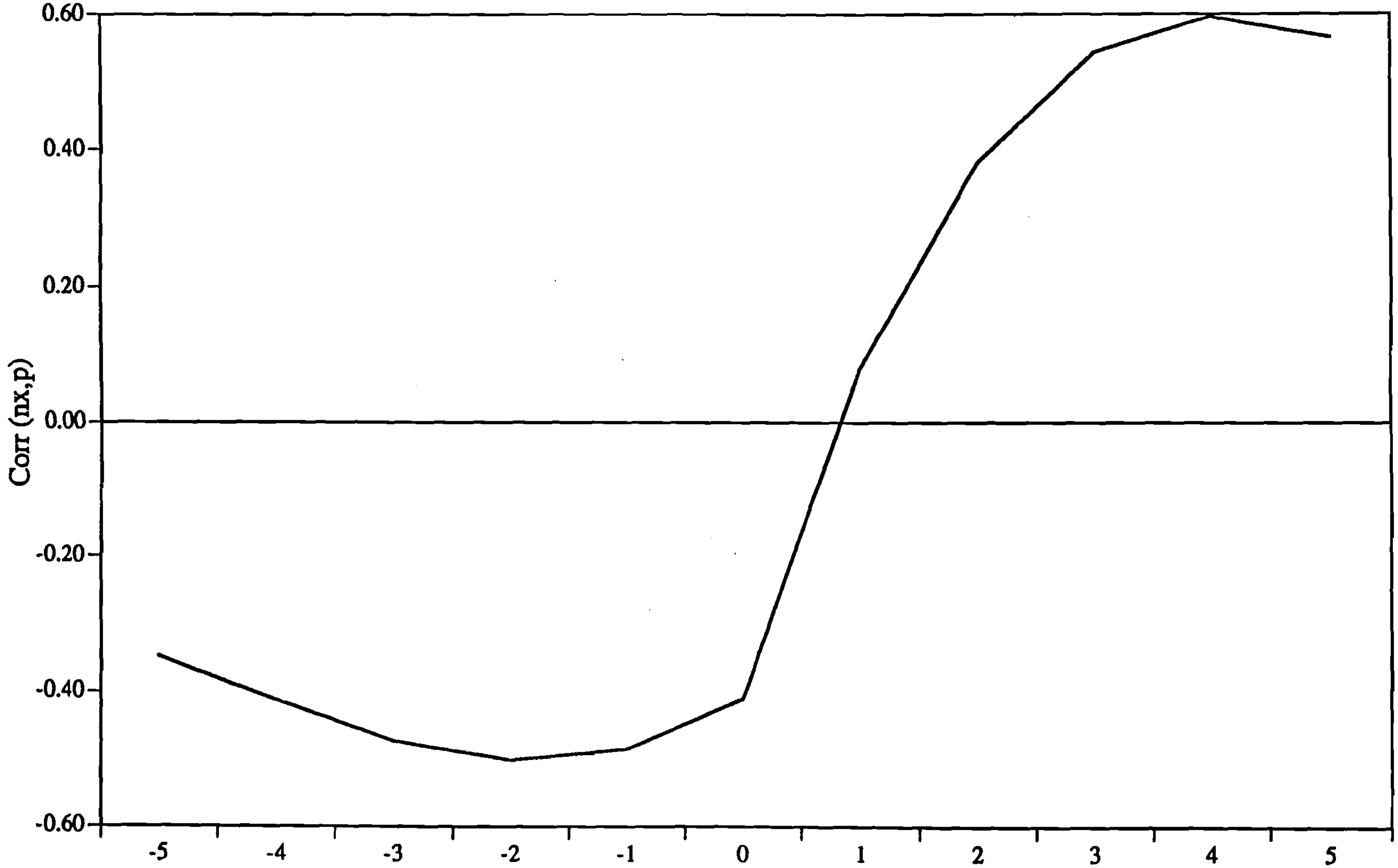
Correlation of p_t and nx_{t+k} by Subperiod



SOURCE: Authors' calculations.

Figure 3

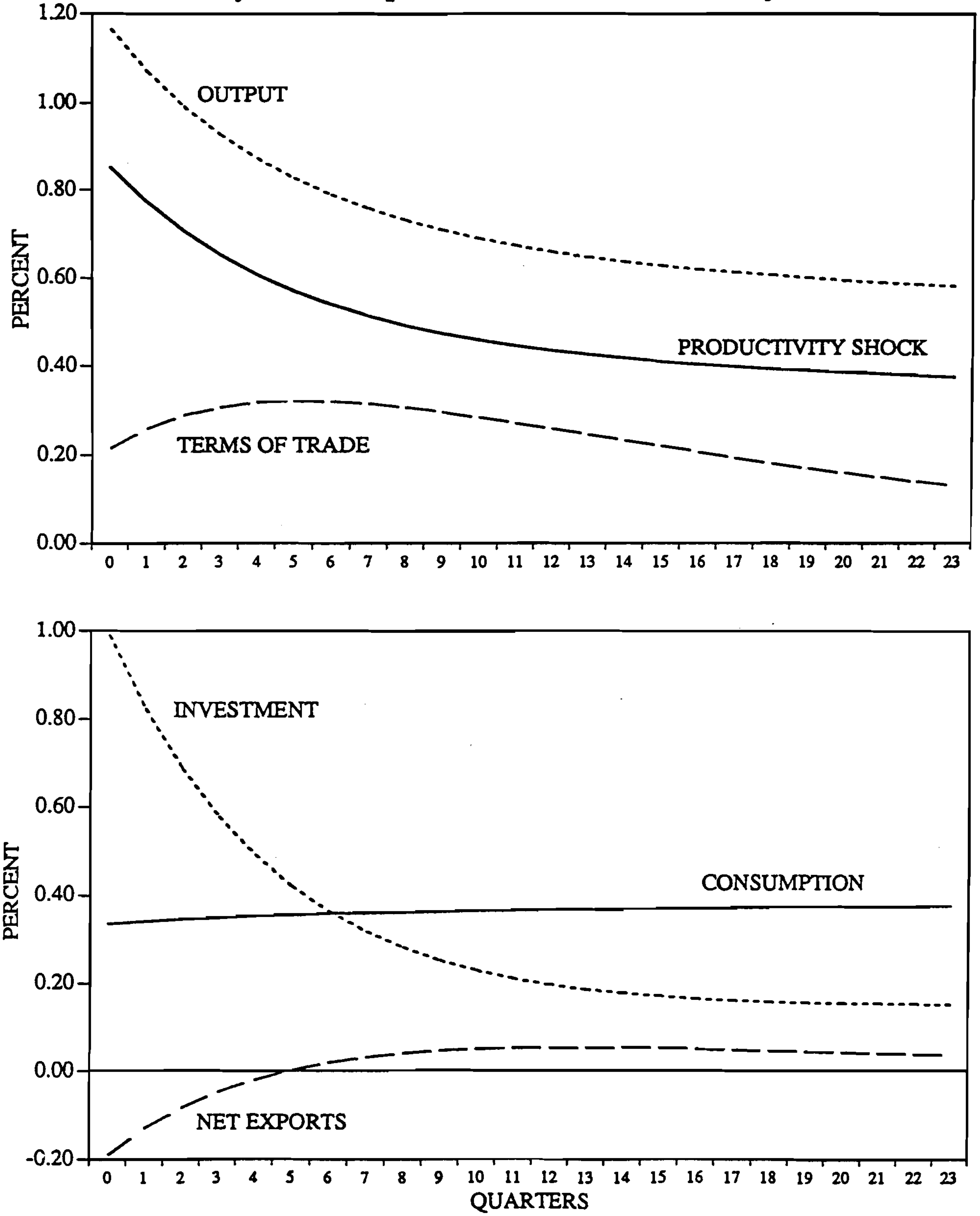
Cross-Correlation Function for the Benchmark Economy



SOURCE: Authors' calculations.

Figure 4

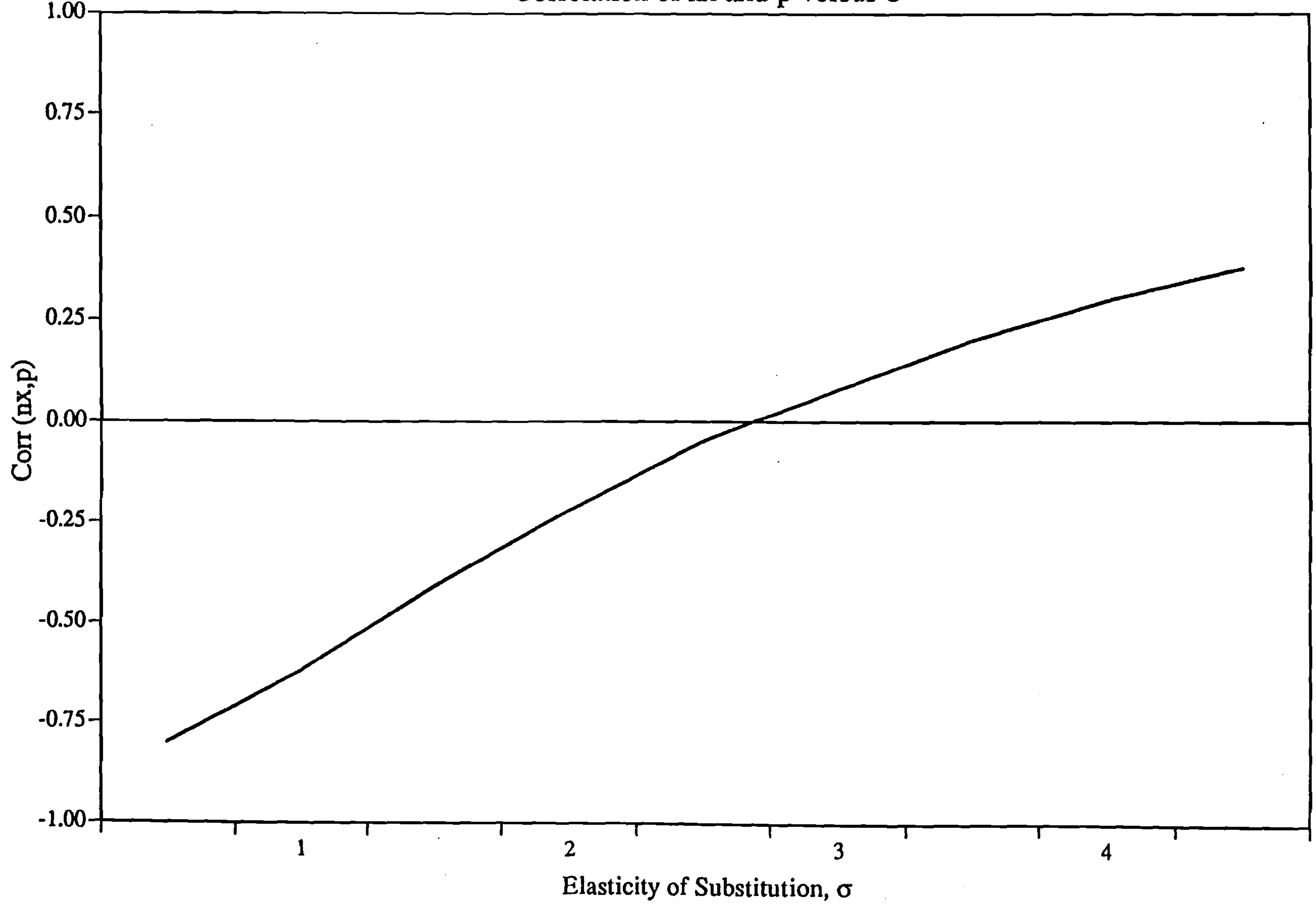
Dynamic Responses to Domestic Productivity Shock



SOURCE: Authors' calculations.

Figure 5

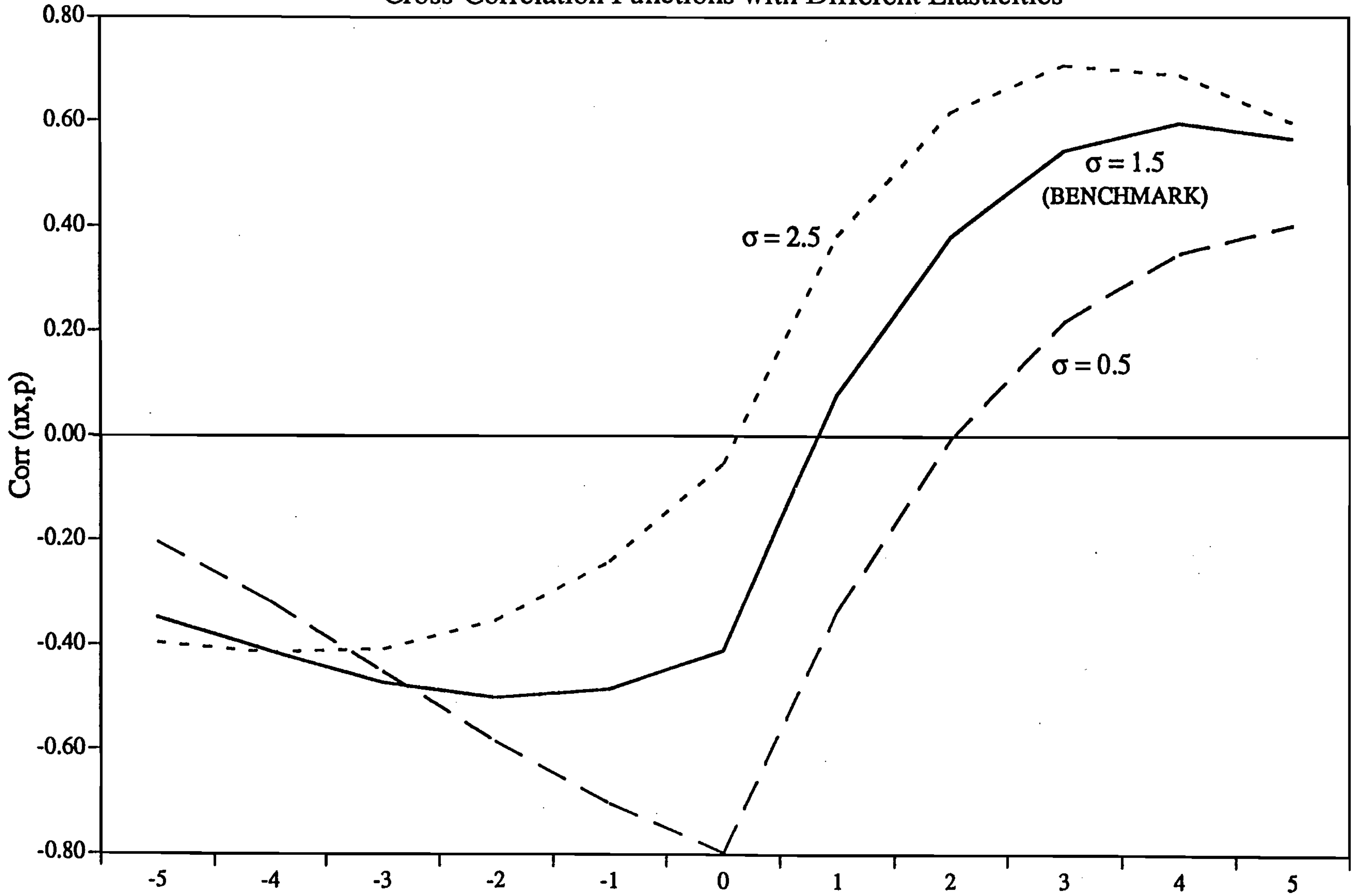
Correlation of nx and p versus σ



SOURCE: Authors' calculations.

Figure 6

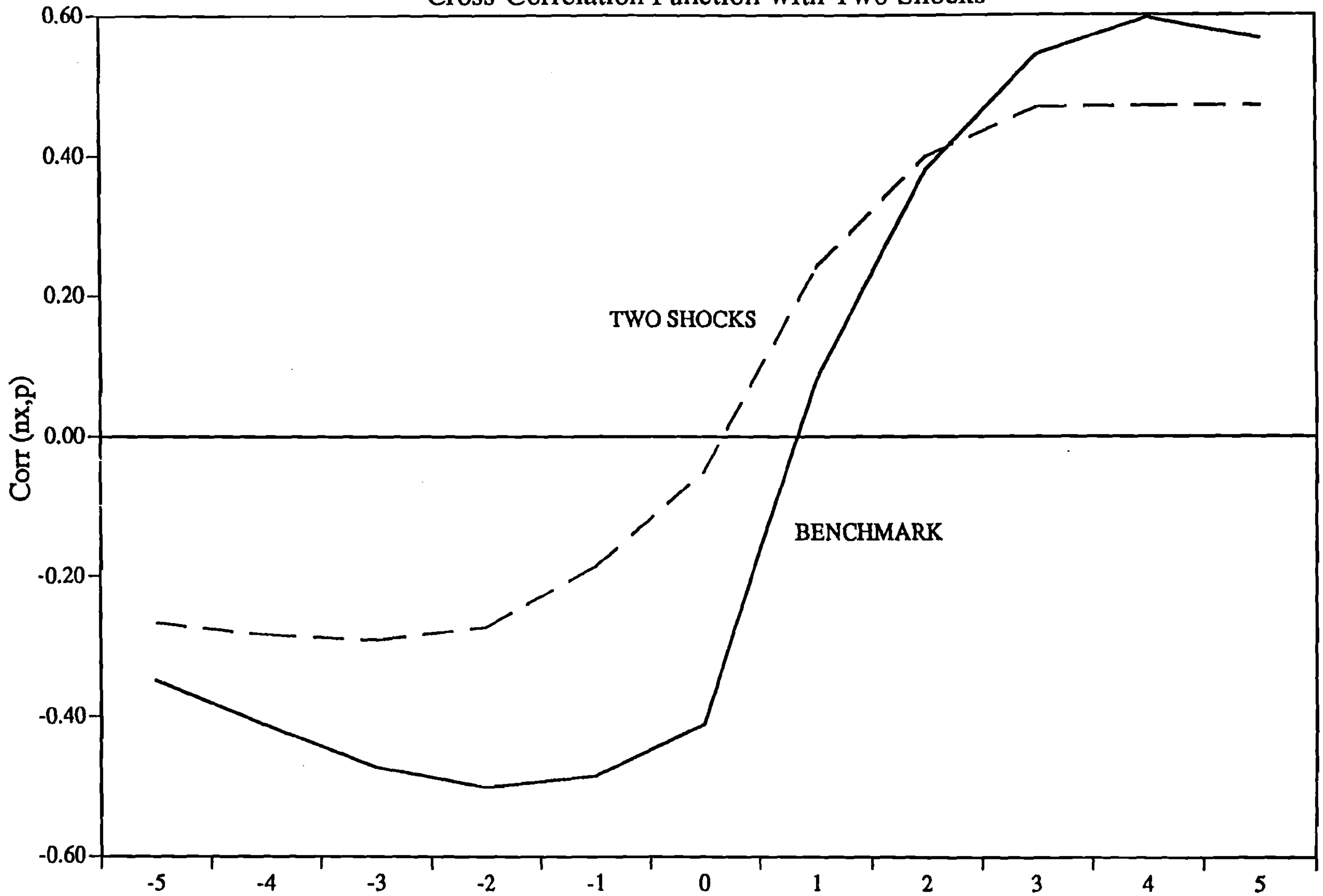
Cross-Correlation Functions with Different Elasticities



SOURCE: Authors' calculations.

Figure 7

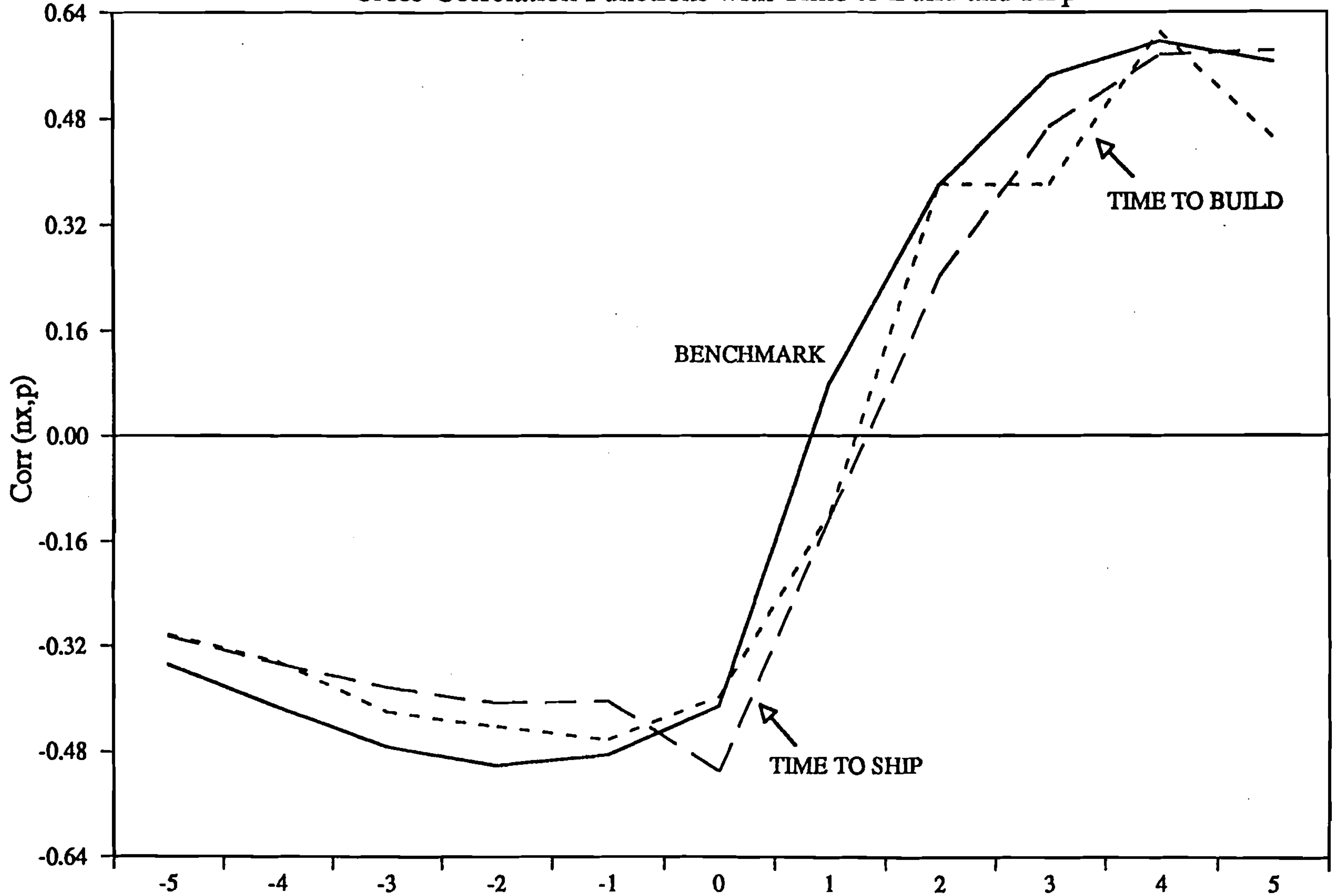
Cross-Correlation Function with Two Shocks



SOURCE: Authors' calculations.

Figure 8

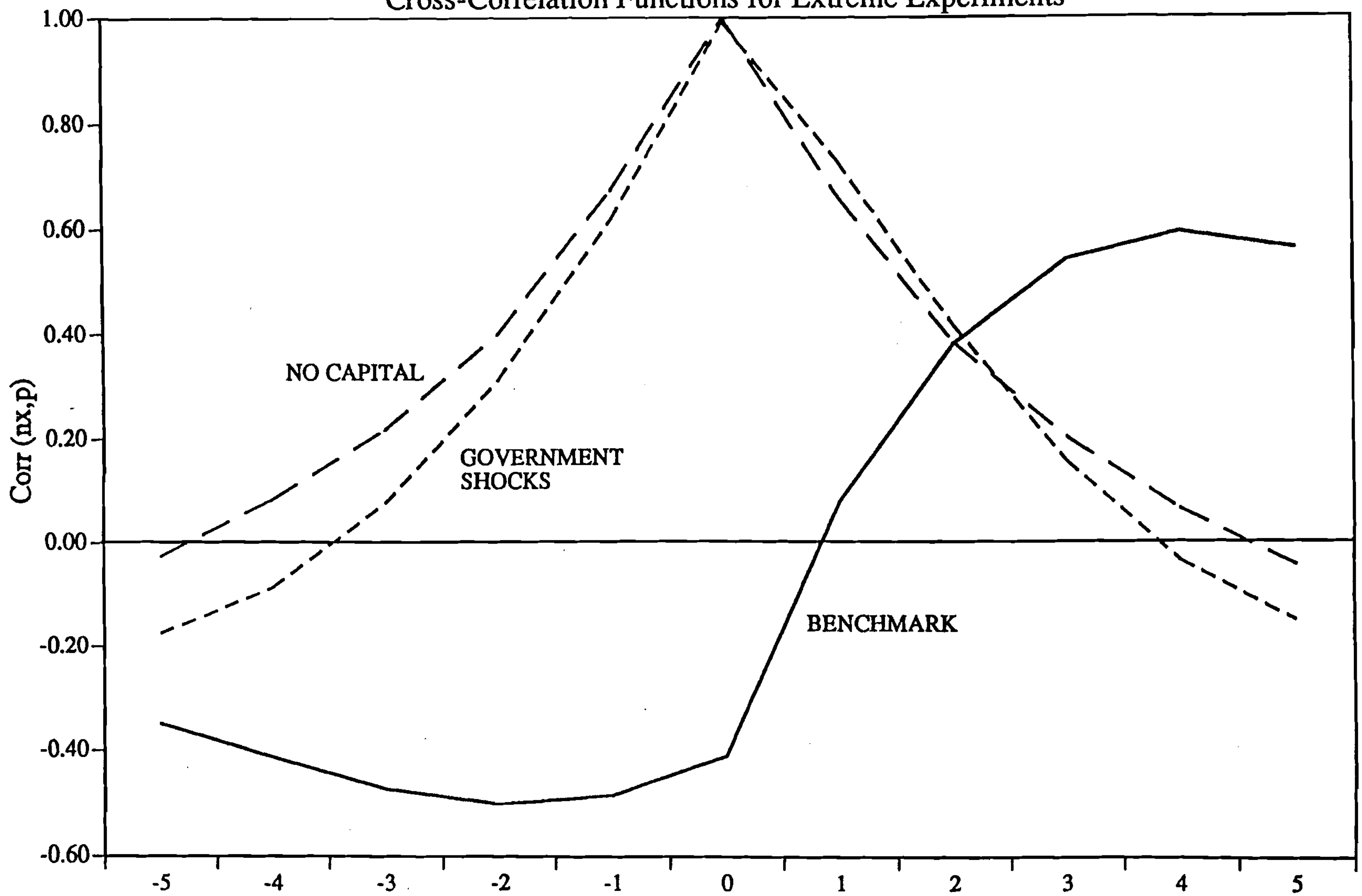
Cross-Correlation Functions with Time to Build and Ship



SOURCE: Authors' calculations.

Figure 9

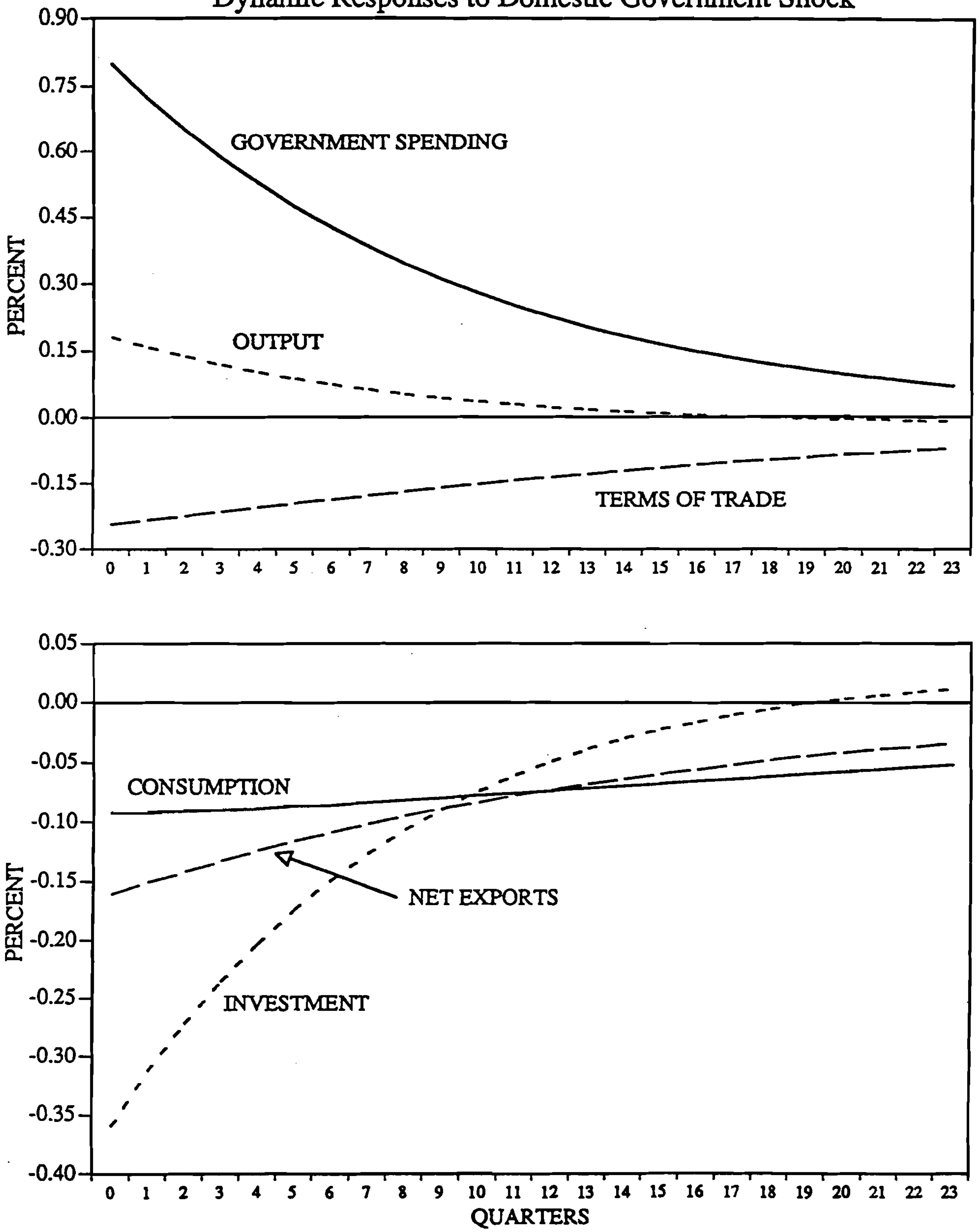
Cross-Correlation Functions for Extreme Experiments



SOURCE: Authors' calculations.

Figure 10

Dynamic Responses to Domestic Government Shock



SOURCE: Authors' calculations.