WP/00/203

IMF Working Paper

El Niño and World Primary Commodity Prices: Warm Water or Hot Air?

Allan D. Brunner

INTERNATIONAL MONETARY FUND

 WP/00/203

IMF Working Paper

IMF Institute

El Niño and World Primary Commodity Prices: Warm Water or Hot Air?

Prepared by Allan D. Brunner[1]

Authorized for distribution by Reza Vaez-Zadeh

December 2000

Abstract

This paper examines the historical effects of the El Niño-Southern Oscillation (ENSO) cycle on world prices and economic activity. The analysis indicates that ENSO has economically-important and statistically-significant effects on world real commodity prices. A one-standard-deviation positive surprise in ENSO, for example, raises real commodity price inflation about 3-1/2 to 4 percentage points. Moreover, ENSO appears to account for almost 20 percent of commodity price inflation movements over the past several years. ENSO also has some explanatory power for world consumer price inflation and world economic activity, accounting for about 10 to 20 percent of movements in those variables.

JEL Classification Numbers: F41, Q11, C32

Keywords: ENSO, El Niño, primary commodity prices

Author's E-Mail Address: abrunner@imf.org

[1] This paper is forthcoming in *The Review of Economics and Statistics*. I would like to thank Neil Ericsson, Caroline Freund, Bill Helkie, Dave Howard, Karen Johnson, Eric Leeper, Andy Levin, John Rosine, Ted Truman, and three anonymous referees for extensive comments on earlier versions of this paper. This paper was written while I was a staff economist at the Board of Governors of the Federal Reserve System. The views expressed in this paper are mine and do not necessarily reflect those held by any member of either institution. I am responsible for any errors.

Contents

Page

I. Introduction

This paper examines the historical effects of the El Niño-Southern Oscillation (ENSO) cycle on world primary commodity prices, as well as other measures of world economic activity. There is, of course, an extensive literature devoted to estimating the effects of weather on economic activity. The bulk of this work concerns the effects of relatively high-frequency changes in weather on economic activity. While the importance of weather varies by geographic region and by industrial sector,[2] a plethora of studies have documented the effects of precipitation and temperature on agricultural production,[3] energy demand,[4] and construction activity.[5] In addition, Saunders (1993) found that Wall Street weather has significant psychological effects on daily stock market returns.

There is also a great deal of interest in the effects of low-frequency weather developments on economic activity. Following Jevons (1884), a number of studies examined the relationship between sunspot cycles (11-year to 100-year cycles) and atmospheric changes, crop production, and broader measures of economic activity. More recently, economists have turned their attention to the possible economic consequences of global warming—see Mendelsohn et al. (1994), Cline (1996), and their cited references.

Surprisingly, there has been little attention directed toward understanding the significance of medium-frequency weather fluctuations, such as ENSO events. Some of the notable exceptions are Handler (1983), Adams, et al. (1995), Debelle and Stevens (1995), and Solow, et al. (1997). These studies are of only limited use, however, in understanding the importance of ENSO to the *world* economy. First, they focused on a small number of commodities and certain geographical areas thought to be significantly affected by ENSO. Consequently, one cannot conclude whether ENSO has any implications for broader measures of prices and economic activity. Second, none of these studies put confidence bounds on their calculated effects. As a result, it is difficult to draw any firm conclusions about the *statistical* importance of these phenomena for prices and economic activity. Finally, these studies used dummy variables to designate years in which there was unusual climactic activity.[6] Thus, relatively weak ENSO events were averaged with more severe

---

[2] See Norrbin and Schlagenhauf (1988).

[3] This literature dates back to at least Day (1965).

[4] See Lawrence and Aigner (1979), EPRI (1981, 1983), Engle et al. (1986), and Maddala et al. (1997).

[5] See, for example, Solomou and Wu (1997).

[6] Debelle and Stevens—using a continuous measure to model Australian output—is one exception.

episodes, and La Niña events were either ignored or were treated as symmetric to El Niño events. In any case, this likely biased the estimated effects toward zero and toward insignificance.

This paper makes several important contributions to this literature. First, several simple econometric models are constructed to study the global economic consequences of the ENSO cycle. The primary focus of these models is on the effects on world real non-oil primary commodity prices (as measured by IMF commodity price indexes), although the effects on G-7 consumer price inflation and GDP growth are also considered. Second, the models include continuous measures of ENSO intensity (sea surface temperature and sea-level air pressure anomalies in the Pacific Ocean) rather than dummy variable measures. Finally, confidence intervals are constructed for all estimated effects of ENSO on world prices and economic activity.

The analysis indicates that ENSO has economically-important and statistically-significant effects on world commodity prices. A one standard-deviation positive surprise in ENSO, for example, raises real commodity price inflation about 3-1/2 to 4 percentage points. Moreover, ENSO appears to account for almost 20 percent of commodity price inflation movements over the past several years. ENSO also has some explanatory power for world consumer price inflation and world economic activity, accounting for about 10 to 20 percent of movements in those variables.

The remainder of this paper is organized as follows. Section II briefly reviews the general characteristics of ENSO events and describes the ENSO measures used in the econometric analysis. Section III describes the econometric approach, and section IV discusses the estimated effects of ENSO on commodity prices, world consumer price inflation, and world economic activity. Concluding remarks are provided in section V.

II. ENSO and World Commodity Prices

During "normal" seasons in the tropical Pacific, there is a persistent high pressure system located off the west coast of South America and a persistent low pressure system off the east coast of Australia. As a result, the prevailing surface winds in the tropical Pacific are "easterlies," blowing from east to west. These winds tend to push warm surface water from the eastern and central regions of the equatorial Pacific toward Asia and Australia, providing these regions with precipitation that is useful for both agricultural and industrial uses. In the eastern regions of the Pacific, cold, nutrient-rich water comes up from below to replace the displaced warmer water, leading to ideal living conditions for many cold-water tropical fish and providing an economic livelihood for the South American fishing industry.

Periodically, these patterns are disrupted by anomalous shifts in atmospheric pressures and sea surface temperatures in the Pacific. Occasionally, during La Niñas, the high and low pressure systems intensify, the prevailing easterlies become stronger, and ocean temperatures plummet. At other times, during El Niños, the low and high pressure systems actually switch positions, causing the easterlies to weaken and often become westerlies. In that case, warm surface water accumulates and often gets pushed toward the Pacific coasts of the Americas. This complex, cyclical interaction between the atmosphere and the ocean in the Pacific is called the El Niño-Southern Oscillation (ENSO).

There are several ways to measure the intensity of an ENSO event. Two widely cited measures of an ENSO's severity are sea surface temperature (SST) anomalies—deviations between sea surface temperatures in a given region and the region's historical average—and Southern Oscillation Index (SOI) anomalies—deviations between air pressure differentials in the South Pacific and their historical averages.[7] SOI anomalies for the Pacific and SST anomalies for the so-called "Niño3.4" region (a central region of the Pacific) are illustrated in Figure 1.[8] As the chart shows, the two measures are highly but not perfectly correlated. Indeed, the measures offer a somewhat different view of the 1997–98 El Niño event. The SST anomaly measure reached an all-time high in late 1997, while the SOI anomaly measure is in line with previous El Niño episodes.

The chart also indicates that the time-series properties of ENSO events are similar to those for business cycles. Most importantly, the ENSO cycle is characterized by two alternating but persistent phases—the El Niño and the La Niña phases. El Niños, for example, typically occur at three-to-seven year intervals and last about two years. They also vary greatly in their intensity. The 1982–83 and 1997–98 El Niños were quite severe and had devastating effects in many regions of the world. The 1994–95 El Niño was relatively mild.

Although ENSO events arise in the Pacific Ocean, they have far-reaching effects on the world's weather. The experience of the 1982–83 El Niño highlights the possible consequences of a severe ENSO event.[9] That episode began in May of 1982, when easterly winds weakened and shifted to westerlies. As warm surface water accumulated off the Pacific coasts of the Americas, many tropical fish were killed and others were sent to colder regions, thus harming fishing industries (especially anchovy and sardine industries) from Chile to British Columbia.

In addition, the 1982–83 El Niño created important global atmospheric disturbances, as high-altitude jet stream winds were altered, affecting weather patterns in Asia, in North and South America, and as far away as Africa. Ecuador and Peru, for example, received

---

[7] Other measures of ENSO's severity include sea-level air temperature and wind speed anomalies.

[8] This paper uses SST and SOI data from 1950 to the present. Although these measures are available intermittently back to the late 1800s, data prior to WWII are not directly comparable to more recent data, and they are often deemed unreliable.

[9] The most recent El Niño paralleled the 1982–83 episode in most respects. La Niñas generally produce climate anomalies that are opposite to those of El Niños.

about seven years worth of rain in four months, causing extensive flooding and the destruction of several cities. In contrast, India, Indonesia, Malaysia, and Australia suffered droughts and disastrous forest fires. Abnormal wind patterns steered typhoons toward Hawaii and Tahiti rather than toward the Asian continent. In the United States, winter storms battered southern California and caused widespread flooding across many of the southern states, while more northern states experienced unseasonably mild weather.

There is a substantial amount of anecdotal evidence suggesting that ENSO events have an important influence on the world's production of primary commodities. Some of ENSO's effects on commodity production are direct. For example, during the most recent El Niño, extensive rainfall washed away rice crops in Ecuador and flooded copper mines in Chile and Peru. Drought conditions parched Australian wheat crops and resulted in forest fires in Indonesia. The El Niño had important indirect influences, as well. For example, excess moisture led to pestilential attacks on California vegetables. Drought shut down some mining firms in Indonesia that relied on hydroelectric power and waterway transportation, and drought prevented heavy ships from passing through the Panama Canal, which relies on water from nearby lakes to raise and lower ships. Analogously, La Niñas also have both direct and indirect influences.

Despite the ample anecdotal evidence, however, only a few economic studies have focused on the possible consequences of ENSO for world economic activity—for world production, prices, and international trade. This paper provides a important step in that direction by focusing on the link between ENSO and world commodity prices and, to a lesser extent, world inflation and economic activity.

Figure 2 charts the recent historical relationship between a measure of *real* commodity price inflation (the solid line) and the SST measure of ENSO intensity (the dash line).[10] The commodity price measure is derived using the IMF's index of non-oil primary commodity prices and the average CPI inflation rate for the G-7 countries.[11] There is a surprisingly close association between SST anomalies and commodity price changes, given the large array of other factors that are likely to affect commodity prices (for example, world economic activity). As Figure 2 indicates, El Niño are generally associated with subsequent real commodity price increases, while La Niñas are associated with price declines. The 1982–83 El Niño had a very dramatic effect on commodity prices, although the 1972–73 and 1986–87 El Niño events were also important contributors to commodity price inflation in those years. For La Niñas, the 1973–74 and 1987–88 La Niña events were particularly influential on commodity price deflation in those years.

---

[10] Since most measures of ENSO are highly correlated, most of the following analysis focuses on just the SST measure. Results using the SOI measure are available upon request.

[11] With the exception of the ENSO measures, all variables were constructed using the IMF's *International Financial Statistics.* See Appendix I for a description of the data.

Much of the correlation between ENSO and commodity prices is accounted for by the food component of the overall index—not graphed—although there is a weaker correlation between the ENSO indexes and agricultural raw material prices and metals prices. These results are roughly consistent with the anecdotal evidence discussed above. During the 1982–83 El Niño event, for example, grain and oilseed prices rose sharply in late 1982 and early 1983, both because of droughts in Asia and Australia and because of the displaced fish population (soybean meal is a close substitute for fishmeal). Supply disruptions in Southeast Asia (droughts) and South America (floods) also put some upward pressures on copper prices. Finally, cocoa and, to a lesser extent, coffee prices were pushed up due to dry conditions in Malaysia and Indonesia and due to excessive rainfall in South America.

Figure 3 charts the historical relationship between SST anomalies and G-7 inflation and GDP growth rates. These relationships are not as tight as the relationship between measures of ENSO and world commodity prices. Nevertheless, there is a small positive relationship between the ENSO and both inflation and economic growth, especially during the particularly strong phases of the cycle that were discussed earlier.

III. The Econometric Approach

In order to better gauge the effects of ENSO events on world prices and growth, several vector autoregressive (VAR) models were estimated. Each four-variable VAR model contained $ENSO_t$, a measure of ENSO intensity. $ENSO_t$ was either the SST anomaly or the SOI anomaly measure. Each model also included the average CPI inflation rate (π_t^g) and the average GDP growth rate (Δy_t) for the G-7 countries. Finally, each VAR contained a measure of real commodity price inflation (π_t^{cp}-π_t^g). The real commodity price inflation measures were based either on the IMF's five index measures of non-oil primary commodity prices: (i) foods, (ii) beverages, (iii) agricultural raw materials, (iv) metals, and (v) all non-oil commodities or on one of the 33 individual commodity prices that comprise the overall index.

The models were of the following form:

$$\begin{aligned} ENSO_t &= \mu_s + A_{11}(L)ENSO_{t-1} && + \quad \varepsilon_t \\ X_t &= \Phi_s + A_{21}(L)ENSO_t + A_{22}(L)X_{t-1} && + \quad \eta_t \end{aligned} \qquad (1)$$

where

$$\begin{bmatrix} \varepsilon_t \\ \eta_t \end{bmatrix} \sim N(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_\varepsilon^2 & 0 \\ 0 & \Sigma_\eta \end{bmatrix}) \qquad (2)$$

and where $ENSO_t$ represents a measure of ENSO intensity; $X_t = [\pi_t^{cp} - \pi_t^g \ \pi_t^g \ \Delta y_t]$; μ_s and Φ_s are seasonally-varying constants; $A_{11}(L)$, $A_{21}(L)$ and $A_{22}(L)$ are polynomials in L, the lage operator; ε_t is an exogenous shock to $ENSO_t$; and η_t is a 3 x 1 vector of innovations to X_t.

Several aspects of the specification in (1) and (2) deserve discussion. First, it seems reasonable that ENSO events are not influenced contemporaneously by economic events. Thus, $ENSO_t$ is assumed to be weakly exogenous, affecting X_t contemporaneously but not vice versa. This assumption also identifies the ENSO shocks (ε_t) as being orthogonal shocks; that is, ε_t and η_t are assumed to be uncorrelated. Second, the idea that ENSO events are *strictly* exogenous—as shown in (1)—is a testable hypothesis given the assumption of weak exogeneity. Indeed, Wald tests revealed $ENSO_t$ is uncorrelated with lags of Xt at conventional significance levels. Third, $\sum_\eta$ is expected to be non-diagonal; that is, the individual innovations within η_t are correlated. However, since the focus of this analysis is entirely on the role of ε_t (which is uncorrelated with η_t), it is not necessary to make any orthogonalizing assumptions about η_t. Finally, it should be noted that the economic variables in (1) are expressed as first differences. Augmented Dickey-Fuller tests indicated that the ENSO measures are I(0), while the economic variables are I(1) in log levels and I(0) in first differences. Since there was no evidence of cointegration among the variables in log levels, the economic variables were expressed in first-difference form.

The VAR models were estimated using quarterly data from 1963 through 1998. Based on a sequence of general-to-specific likelihood ratio tests, it was determined that an appropriate lag length for all of the VARs is six quarterly lags.[12] The estimated model coefficients showed some evidence of instability, mostly associated with the equations describing the evolution of consumer price inflation. This is not too surprising given the high and volatile inflation rates seen in the 1970s relative to the lower and fairly stable rates seen in the rest of the sample period (see Figure 3).

IV. The Estimation Results

Does ENSO have any explanatory power for the economic variables in the models? Table 1 presents the results of Granger causality tests for the importance of ENSO for each of the ten VAR models. The first column of the table denotes the commodity price measure (π_t^{cp}) used in the VAR model, while columns two and three represent the two different measures of ENSO intensity ($ENSO_{t,}$). Each of the ten entries in the table denotes the respective significance level of a χ^2 test for whether $A_{21}(L)$ in equation (1) is statistically different from zero.

There are a couple of aspects of the results in Table 1 worth noting. The SOI anomaly measure of ENSO intensity appears to have a much stronger statistical relationship with the economic variables than the SST anomaly measure does. This is true regardless of which

---

[12] The Schwarz and Akaike Information Criteria yielded the same lag length choice.

commodity price measure is being used. On the other hand, the statistical significance of the SST measure is somewhat sensitive to the commodity price measure that is being included in the VAR model. In particular, the SST measure is not statistically significant at the 5 percent level when all primary commodity prices or when agricultural raw material prices are included in the model. The statistical importance of the SST measure is somewhat stronger, however, when prices of food, beverages, and metals are included.

Figure 4 report the impulse response functions associated with surprises in ENSO for one of the ten estimated models. The model illustrated by Figure 4 included SST anomalies and the real commodity price inflation rate for all primary commodities, as well the average CPI inflation rate and GDP growth rate for the G-7 countries. The solid lines in the figure indicate the impulse responses for a one standard deviation surprise in the SST measure, while the dashed lines denote two-standard-deviation confidence intervals for each impulse response function.

As shown in the upper left panel, a positive ENSO surprise has very persistent effects, leading to raised sea surface temperatures (above their historical averages) for four subsequent quarters after the initial surprise. The upper right panel shows that a one standard deviation positive ENSO surprise raises commodity price inflation (in real terms) an estimated 3-1/2 to 4 percentage points two quarters after the initial surprise. Commodity prices fall by a similar amount in the second and third years after the initial surprise.[13] A similar pattern is evident for other measures of commodity prices (not shown). Not surprisingly, prices for food commodities are affected the most by ENSO, although prices of beverages, agricultural raw materials, and metals are also pushed up and then down.

The lower left panel of Figure 4 indicates that ENSO has a similar "up-then-down" effect on overall prices among the G-7 countries, although the effect is much weaker and only marginally significant from zero for SOI measure. This relatively subdued influence on overall consumer prices is not unexpected since primary commodities account for only a fraction of overall finished good costs. Finally, as shown in the lower right panel, economic activity in the G-7 countries appears to be *stimulated* by a positive ENSO shock—raising GDP growth as much as one-half of a percentage point—although these effects are significant at only the 10 percent level. The stimulatory effects of an El Niño event on G-7 economic activity are somewhat surprising. One possible explanation for this result is that there is a measurable increase in investment spending (especially residential construction). The United States, for example, experiences wind storms and flooding during El Niño, which generally increase residential investment afterwards. On the other hand, this result could be capturing increased aggregate demand from other countries (for food, housing materials, machinery, equipment, etc) that are devastated by El Niño events. In any case, this possible relationship deserves further investigation.

---

[13] The hypothesis of no long-run effect on commodity price levels cannot be rejected.

While the Granger causality tests and the impulse response functions point to a strong statistical relationship between ENSO and world commodity prices and, to a lesser extent, to a statistically-significant relationship between ENSO and world inflation and economic activity, they provide no indication of *economic* significance. Table 2 and Figure 5 provide evidence that ENSO has substantial economic importance. Each of the ten estimated VARs was used to calculate k-step-ahead dynamic forecasts for real commodity price inflation, world CPI inflation and world economic activity for each time period in the data sample. The resulting forecast errors were then decomposed into the portion attributable to ENSO (ε_t) and the portion attributable to all other factors (η_t). The variances of these forecast errors were also decomposed in a similar manner.[14]

The results of the variance decomposition exercise for four- and sixteen-quarter-ahead forecasts are presented in Table 2 for the case of SST anomalies.[15] The results can be summarized as follows. First, ENSO appears to account for a substantial amount of variation in the economic variables, regardless of which measure of ENSO is used, although the SOI anomalies generally have a stronger and more statistically-significant influence. Second, in the short run, ENSO's influence is mostly on food prices, accounting for between 12 and 14 percent of the four-quarter-ahead forecast error variance in these prices. ENSO appears to have little effect on G-7 economic activity, and the two ENSO measures provide conflicting information about the short-run effects on G-7 inflation.

Third, ENSO's influence is much stronger over the longer horizon, accounting for almost 20 percent of the variation in real primary commodity prices, which is quite consistent with the anecdotal evidence discussed previously: Most of the effects on commodity prices are attributable to ENSO's effects on food prices; over 20 percent of the variation in these prices are accounted for by ENSO shocks. Beverage, metal and agricultural raw material prices are also moved around a bit by both ENSO measures, although the confidence bounds for these estimates are somewhat wider and the two ENSO measures do not agree as closely. Similarly, the ENSO measures also provide a wide range of estimates for the effects on CPI inflation (13-18 percent) and economic activity (10-13 percent).

Table 3 shows the contribution of SST anomalies to those commodities most affected by ENSO events. The table conforms well with the anecdotal evidence discussed in section II. Coconut oil is the most affected commodity, with ENSO accounting for about one-third of its variance. Other oils (palm, soybean, and groundnut) are also highly affected, as are several other food items (rice, wheat, soybeans, and maize). Other tropical commodity

[14] The only assumption required to calculate these decompositions is that ENSO is weakly (contemporaneously) exogenous with respect to the other three variables in the VAR. As discussed previously, however, this paper models ENSO as strictly exogenous.

[15] SOI anomalies produced very similar results. Appendix II presents those results and impulse response functions for all individual commodities.

prices (fish meal and rubber prices) and some metals (iron ore and copper) also appear to be influenced by ENSO events.

Finally, Figure 5 presents the historical decomposition of the forecast errors for the three economic variables with respect to SST anomalies. The solid line in each panel represents the four-quarter-ahead forecast error for each variable at each point in time, while the dashed line denotes the portion of that error than can be attributed to SST shocks. The results are consistent with the previous ones. The upper panel shows that most of the estimated effects of ENSO on commodity prices are associated with the 1982–83 and 1986–87 El Niño events. Although ENSO likely had important effects on commodity prices during the 1970s, these effects were overwhelmed by other factors, such as the oil price shocks and subsequent goods price inflation. The lower panels indicate that, although ENSO has had some influence on overall price inflation and economic activity in the past couple of decades, that influence is not as economically and statistically important as its influence on commodity prices.

V. Conclusion

This paper examined the historical effects of ENSO on world prices and world economic activity. The primary focus was on world real non-oil primary commodity prices, although the effects on G-7 consumer price inflation and GNP growth were also considered. This paper has several distinct advantages over previous studies. First, econometric models were estimated using fairly broad measures of economic activity. Second, the models included continuous measures of ENSO intensity (sea surface temperature and sea-level air pressure anomalies in the Pacific Ocean) rather than dummy variable measures. Finally, confidence intervals were constructed for all estimated effects of ENSO on world prices and economic activity.

The analysis indicate that ENSO has a economically-important and statistically-significant effect on world real commodity prices. A one standard-deviation positive surprise in ENSO, for example, raises commodity price inflation about 3-1/2 to 4 percentage points. Moreover, ENSO appears to account for almost 20 percent of real commodity price inflation movements over the past several years. ENSO also has some explanatory power for world consumer price inflation and world economic activity, accounting for about 10 to 20 percent of movements in those variables.

References

Adams, Richard M., Kelly J. Bryant, Bruce A. McCarl, David Legler, James O'Brien, Andrew Solow, and Rodney Weiher, 1995, "Value of Improved Long-Range Weather Information," *Contemporary Economic Policy*, 13, pp.10–19.

Cline, William R., 1996, "The Impact of Global Warming on Agriculture: Comment" *The American Economic Review*, 86, pp.1309–11.

Day, R. H., 1965, "Probability Distributions of Field Crops," *Journal of Farm Economics*, 47, pp. 713–43.

Debelle, Guy, and Glenn Stevens, 1995, "Monetary Policy Goals for Inflation in Australia", Reserve Bank of Australia Research Discussion Paper No. 9503.

Engle, Robert F., C. W. J. Granger, John Rice, and Andrew Weiss, 1986, "Semiparametric Estimates of the Relation between Weather and Electricity Sales," *Journal of the American Statistical Association,* 81, pp. 310–20.

Electric Power Research Institute, 1981, "Regional Load-Curve Models: QUERI's Model Specification, Estimation and Validation," EA-1672, Palo Alto, CA.

———, 1983, "Weather Normalization of Electricity Sales," EA-3142, Palo Alto, CA.

Handler, Paul, 1983, "Climatic Anomalies in the Tropical Pacific Ocean and Corn Yields in the United States," *Science*, 20:1155–6.

Jevons, W. Stanley, 1884, "Commercial Crises and Sunspots" in *Investigations in Currencies and Finance*, edited by H.S. Foxwell, London: McMillan and Company, Ltd.

Lawrence, Anthony, and Dennis Aigner, 1979, "Modelling and Forecasting Time-of-Day and Seasonal Electricity Demands," *Journal of Econometrics*, 9:xx-xx.

Maddala, G. S., Robert P. Trost, Hongyi Li, and Frederick Joutz, 1997, "Estimation of Short-run and Long-run Elasticities of Energy Demand from Panel Data Using Shrinkage Estimators," *Journal of Business and Economic Statistics*, 15:90–100.

Mendelsohn, Robert, William Nordhaus, and Daigee Shaw, 1994, "The Impact of Global Warming on Agriculture: A Ricardian Analysis," *The American Economic Review*, 84, pp. 753–771.

Norrbin, Stefan C., and Don E. Schlagenhauf, 1988, "An Inquiry Into the Sources of Macroeconomic Fluctuations," *Journal of Monetary Economics*, 22, pp. 43–70.

Saunders, Edward M. (1993), "Stock Prices and Wall Street Weather," *The American Economic Review*, 83, pp. 1337–1345.

Solomou, Solomos and Weike Wu, 1997, "The Impact of Weather on the Construction Sector Output Variations, 1955–1989," DAE Working Papers, No. 9722, University of Cambridge, Cambridge, UK.

Solow, Andrew, Richard F. Adams, Kelly J. Bryant, David Legler, James O'Brien, Bruce A. McCarl, William Nayda, and Rodney Weiher, 1997, "The Value of Improved ENSO Prediction to U.S. Agriculture," *Climatic Change*, forthcoming.

Table 1. Granger Causality Tests for Importance of ENSO to World Economic Activity

$$X_t = \phi_s + A_{21}(L)\ ENSO_t + A_{22}(L)\ X_{tl} + \eta_t$$

IMF Commodity Price Index	Significance Level of $\chi^2(18)$ Test for $A_{21}(L)=0$ where: $ENSO_t = SST_t$	$ENSO_t = SOI_t$
All Primary Commodities	.07	< .01
Food	< .01	< .01
Beverages	.03	.01
Ag. Raw Materials	.20	.01
Metals	< .01	< .01

Table 2. Contribution of SST to the Variances of the Economic Variables

(Standard errors are in parentheses, boldface indicates significance at 5 percent level)

Economic Variable	Percentage of K-step-ahead Forecast Error Variance Attributable to SST			
	k = 4		k = 16	
Commodity Price Inflation				
All Primary Commodities	**9.3**	(4.7)	**18.1**	(7.3)
Food	**12.3**	(5.0)	**21.3**	(6.9)
Beverages	4.2	(3.0)	**10.9**	(4.8)
Ag. Raw Materials	6.3	(3.7)	**13.8**	(6.2)
Metals	**9.3**	(4.2)	**17.6**	(6.6)
CPI Inflation (G-7 countries)	3.7	(2.6)	**13.0**	(6.0)
GDP Growth (G-7 countries)	5.3	(3.4)	**10.0**	(4.7)

Table 3. Primary Commodities Most Affected by SST

(Standard errors are in parentheses, boldface indicates significance at 5 percent level)

	Percentage of K-step-ahead Forecast Error Variance Attributable to SST			
Commodity	k = 4		k = 16	
Coconut Oil	**9.8**	(4.8)	**33.7**	(9.4)
Tobacco	**13.8**	(6.4)	**27.3**	(9.4)
Fish Meal	8.7	(5.0)	**26.1**	(9.9)
Palm Oil	**8.4**	(4.2)	**23.1**	(7.5)
Rice	**16.3**	(6.4)	**20.8**	(6.8)
Soybean Oil	**11.3**	(4.8)	**19.7**	(7.1)
Iron Ore	**16.7**	(5.6)	**19.1**	(5.9)
Rubber	3.9	(2.5)	**18.8**	(7.9)
Wheat	6.6	(3.6)	**18.8**	(6.4)
Soybeans	**13.7**	(5.4)	**17.4**	(5.5)
Maize	8.5	(4.5)	**17.3**	(6.4)
Zinc	4.6	(3.0)	**16.0**	(6.8)
Wool -- Fine	10.9	(6.0)	**15.6**	(7.2)
Groundnut Oil	5.8	(3.5)	**15.1**	(6.4)
Copper	**8.3**	(3.9)	**15.0**	(5.5)

Figure 1. Two Measures of ENSO Intensity

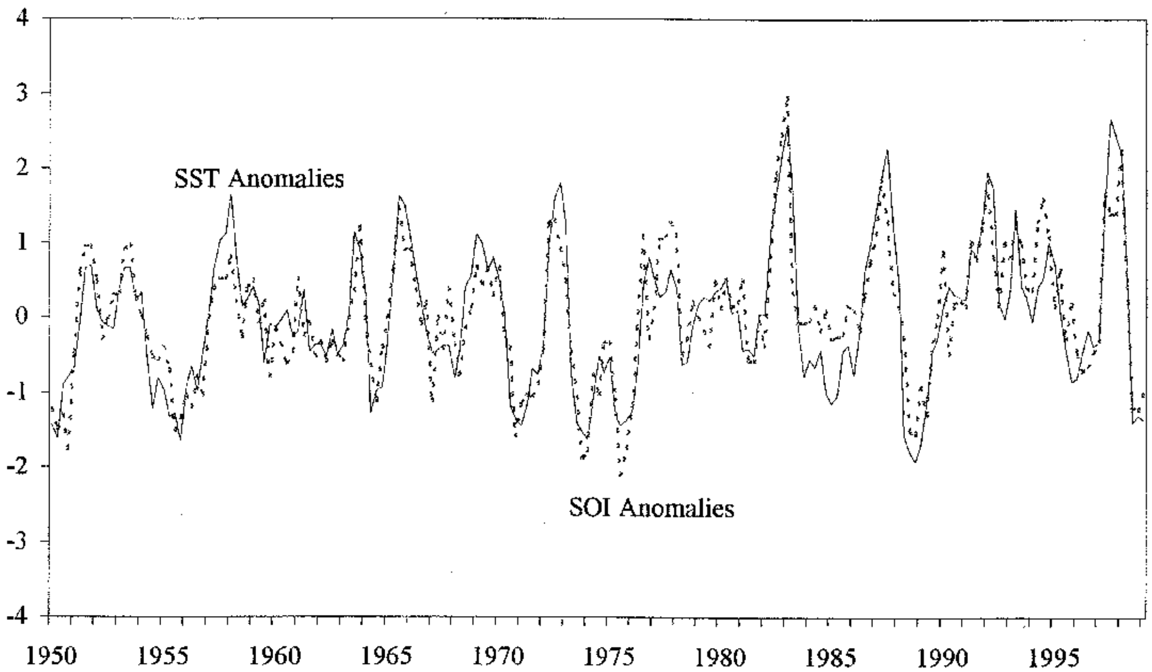


Figure 2. IMF Commodity Price Inflation and SST Anomalies

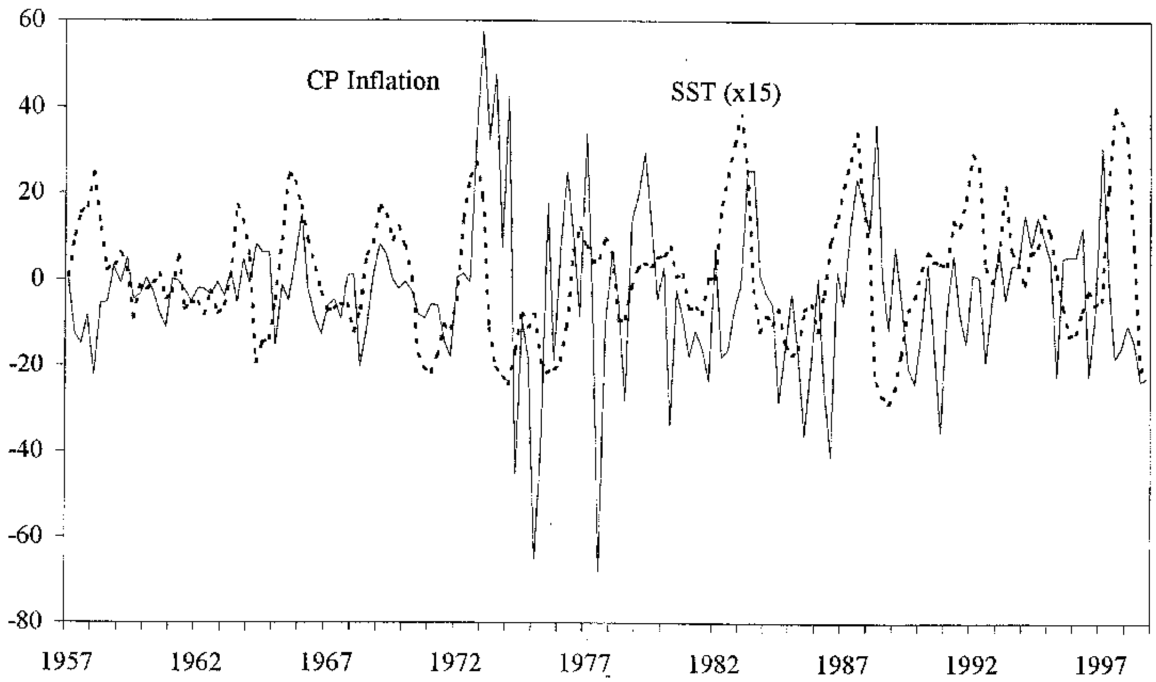
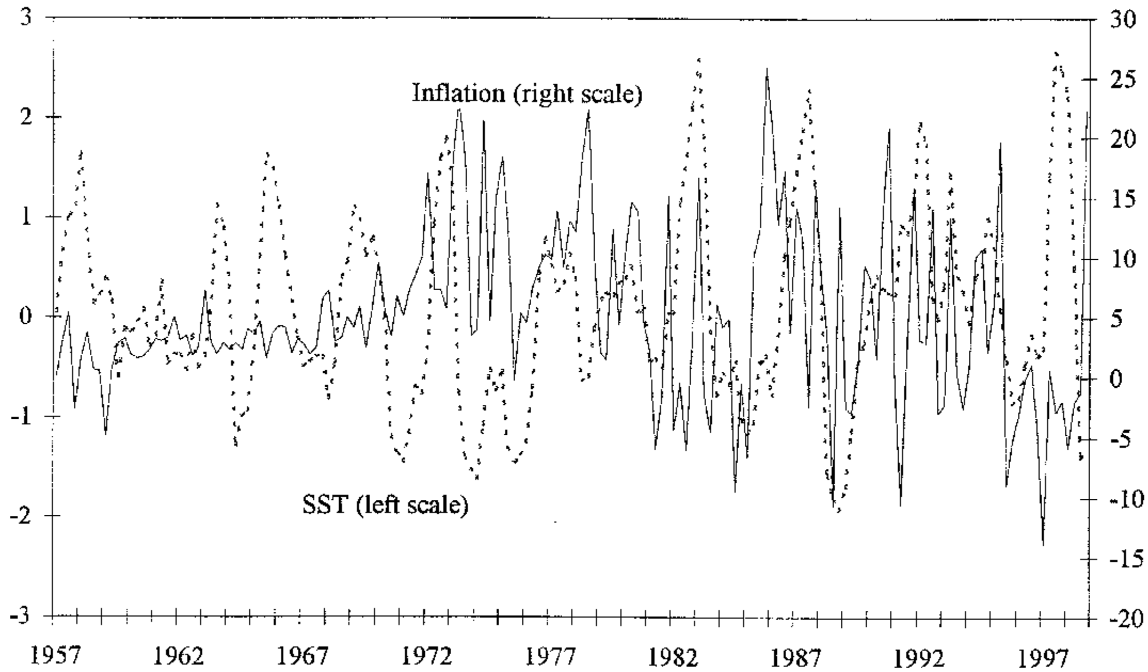


Figure 3. G7 Inflation and GDP and SST Anomalies



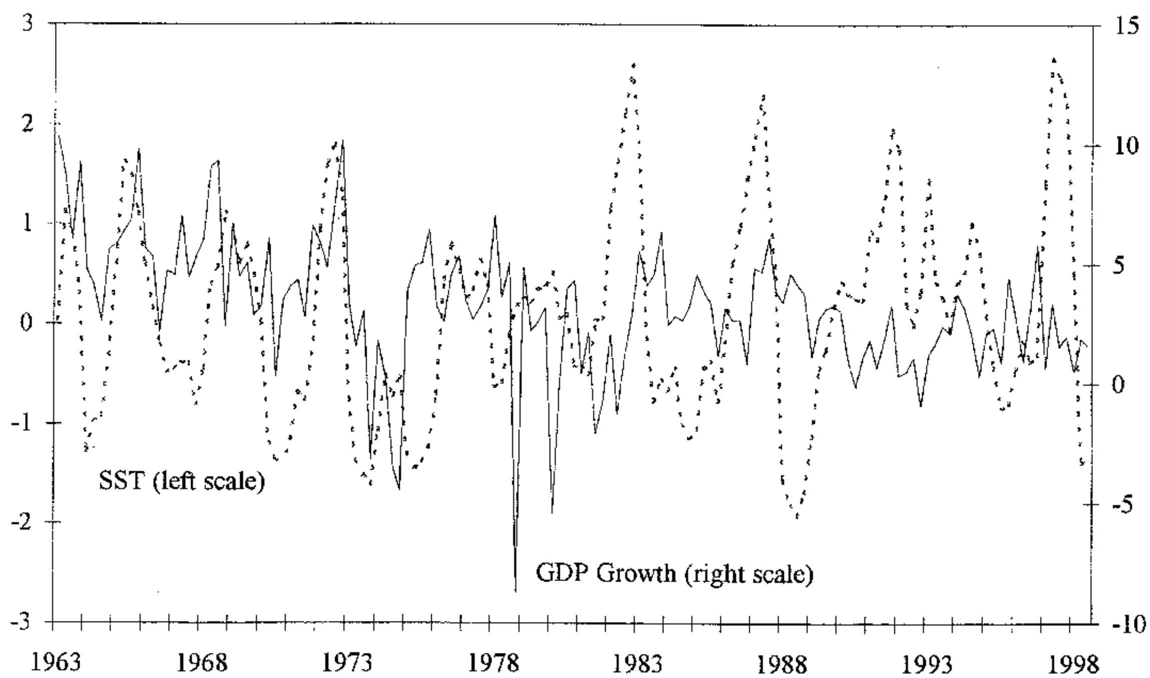


Figure 4. The Effects of a Surprise in SST
(Dashed lines denote 2-standard deviation confidence bounds)

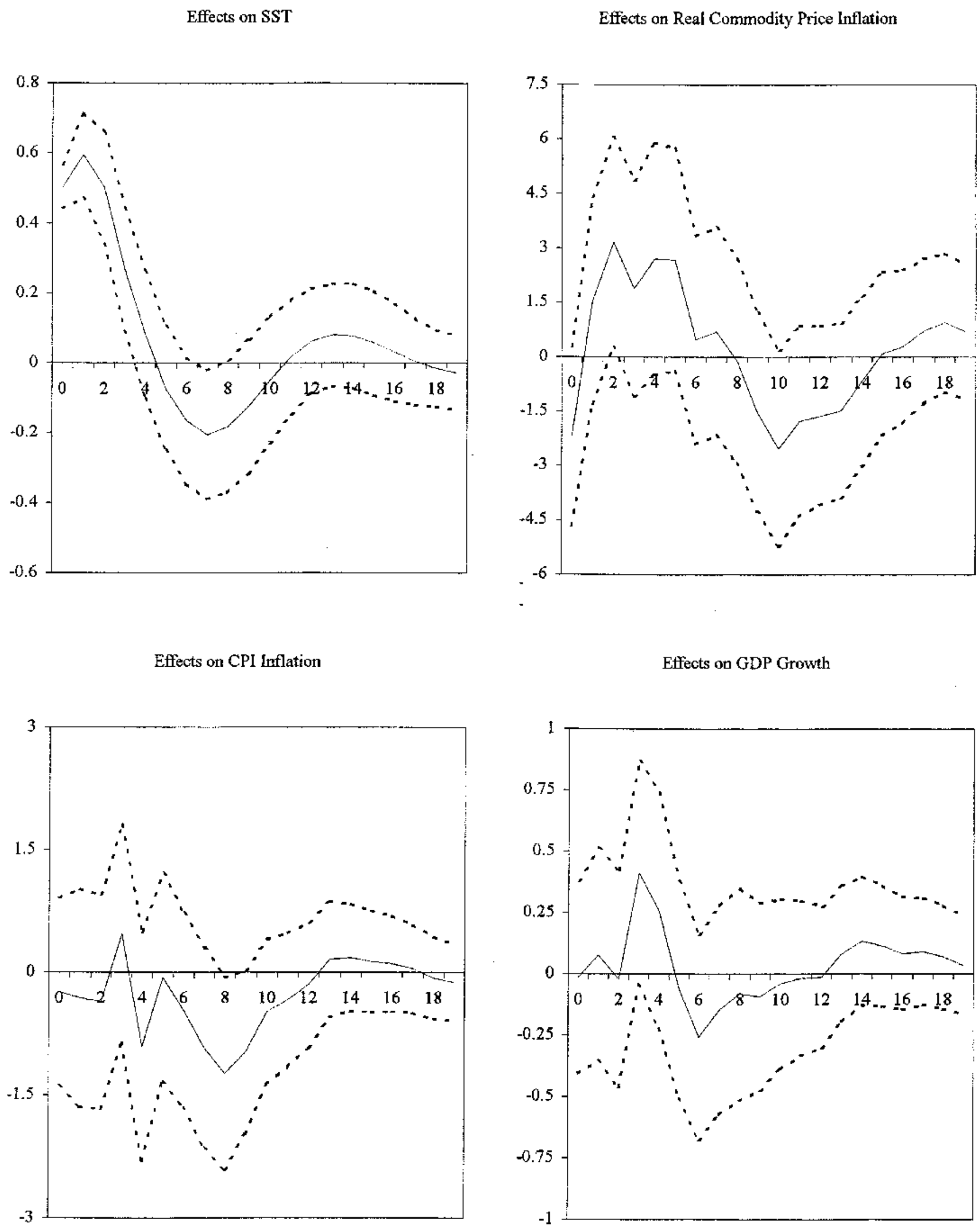
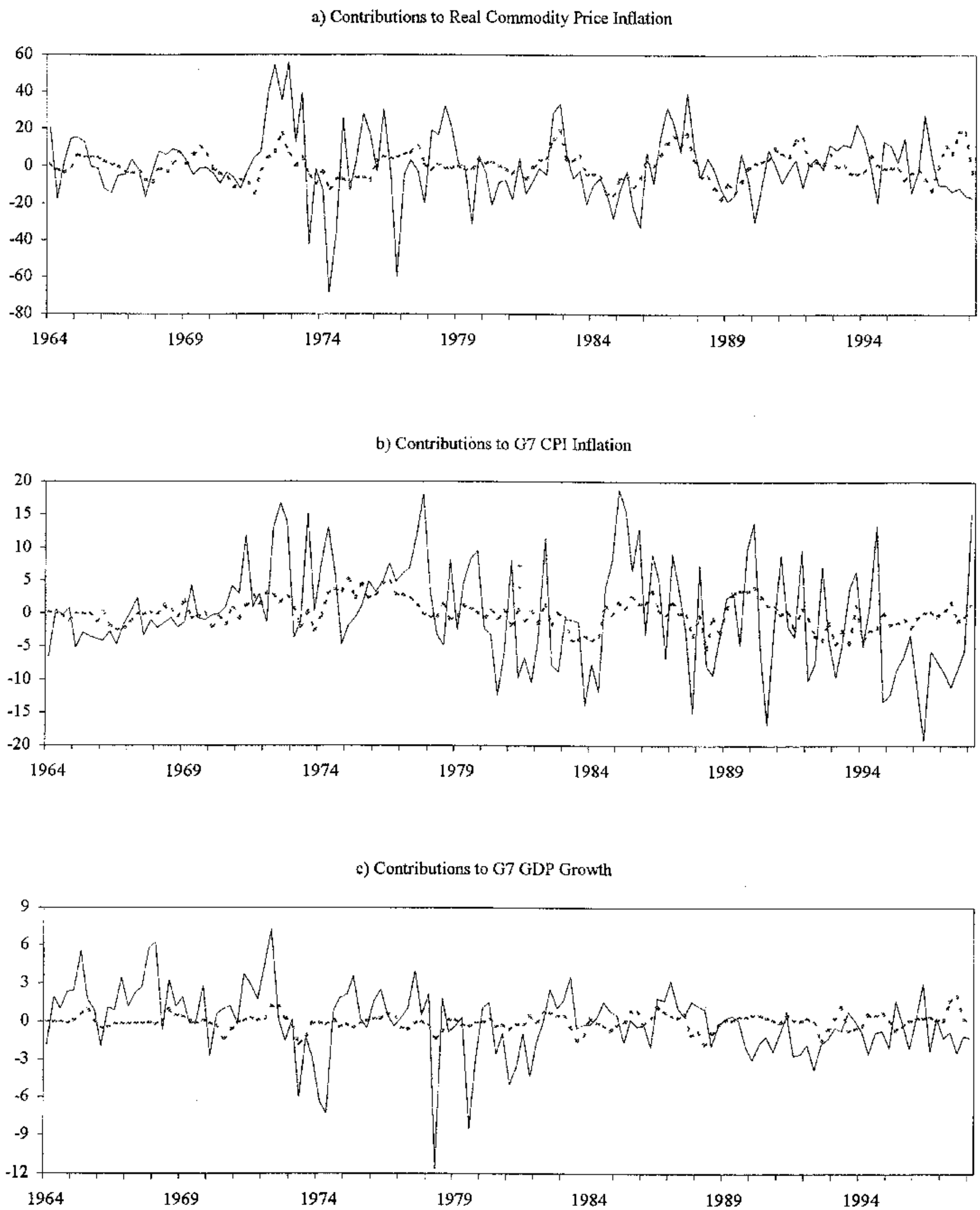


Figure 5. The Historical Contributions of SST Anomalies
(Solid line represents 4-quarter-ahead forecast error; dashed line represents contribution of SST)



Data

This appendix describes the data that were used in this paper.

ENSO Measures

Sea surface temperatures (SST) and Southern Oscillation index (SOI) measures were obtained from NOAA's Climate Prediction Center database. The data were standardized by subtracting seasonal means and dividing by seasonal standard deviations.

Commodity Prices

The commodity price indexes were obtained from the IMF's International Financial Statistics database. The overall index, for example, is a weighted average of over 30 non-oil primary commodity prices, including foods (33 percent), beverages (7 percent), agricultural raw materials (32 percent), metals (27 percent), and fertilizers (1 percent). The weights are based on world export earnings for each commodity.

Consumer Prices and GDP

Consumer price and GDP indexes for the G-7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States) were also obtained from the IMF's International Financial Statistics database. Weighted indexes for the G-7 as a whole were constructed using weights based on PPP-adjusted income for each country.

Supplemental Regression Results

Each of the following tables and figures (using SOI as the measure of ENSO) corresponds to a figure or table in the main section of the paper (using SST as the measure of ENSO).

Table A2. Contribution of SOI to the Variances of the Economic Variables

(Standard errors are in parentheses, boldface indicates significance at 5 percent level)

	Percentage of K-step-ahead Forecast Error Variance Attributable to SOI			
Economic Variable	k = 4		k = 16	
Commodity Price Inflation				
All Primary Commodities	**9.8**	(4.7)	**17.2**	(7.3)
Food	**13.9**	(5.6)	**21.5**	(7.1)
Beverages	4.1	(3.1)	**9.7**	(4.7)
Ag. Raw Materials	7.6	(4.5)	**14.6**	(6.3)
Metals	5.3	(3.7)	**13.1**	(6.1)
CPI Inflation (G-7 countries)	**10.6**	(4.6)	**17.5**	(6.4)
GDP Growth (G-7 countries)	6.4	(3.7)	**13.3**	(5.8)

Table A3. Primary Commodities Most Affected by SOI

(standard errors are in parentheses, boldface indicates significance at 5 percent level)

	Percentage of K-step-ahead Forecast Error Variance Attributable to SOI			
Commodity	k = 4		k = 16	
Coconut Oil	**11.3**	(5.0)	**31.3**	(9.6)
Tobacco	**19.2**	(7.5)	**30.2**	(9.4)
Fish Meal	10.8	(5.0)	**26.1**	(9.9)
Palm Oil	4.8	(5.9)	**22.4**	(9.6)
Rice	11.2	(5.8)	**16.5**	(6.6)
Soybean Oil	6.2	(3.5)	**16.3**	(6.5)
Iron Ore	**15.3**	(5.5)	**17.2**	(5.8)
Rubber	6.6	(4.1)	**20.1**	(8.0)
Wheat	6.6	(3.9)	**17.9**	(6.5)
Soybeans	**10.1**	(4.9)	**13.8**	(5.2)
Maize	**14.4**	(5.9)	**19.8**	(6.7)
Zinc	3.7	(2.7)	**16.7**	(7.0)
Wool: Fine	9.4	(5.7)	**13.6**	(6.4)
Groundnut Oil	**9.0**	(4.5)	**14.5**	(6.2)
Copper	5.6	(3.6)	**10.8**	(4.7)

Table A4. Response of Commodity Price Inflation to SST Surprise

(Percent, boldface indicates significance at 5 percent level)

Commodity	+0	+1	+2	+3	+4	+5	+6
Foods	-1.6	0.4	**6.4**	4.1	**5.5**	2.5	1.2
Wheat	2.4	**-5.6**	2.6	2.4	**7.3**	3.1	4.4
Maize	-1.9	-2.8	**7.1**	4.8	6.7	3.8	2.4
Rice	-2.4	-0.9	**8.9**	**13.5**	2.5	1.2	2.0
Soybeans	**-7.4**	3.1	**9.7**	4.8	6.0	-1.1	-1.8
Soybean Meal	**-8.3**	1.3	7.4	7.0	2.1	-1.0	-3.6
Soybean Oil	-5.5	-1.1	**10.6**	5.9	7.0	7.3	5.0
Palm Oil	-2.4	-1.6	**9.7**	6.7	**12.1**	**10.7**	4.0
Coconut Oil	-4.8	3.1	**10.1**	5.5	**11.1**	**12.1**	**11.3**
Fish Meal	0.9	3.9	5.7	**6.5**	3.4	0.2	-5.9
Groundnut Oil	-5.6	-2.2	1.8	-5.3	2.1	7.7	5.2
Beef	0.7	0.3	3.3	1.4	4.4	0.1	-1.2
Lamb	-0.1	-0.9	-1.5	-2.3	0.1	1.7	-0.2
Sugar	-5.1	5.4	**14.7**	-4.2	1.7	2.1	1.3

Table A4 (Cont.). Response of Commodity Price Inflation to SST Surprise

(Percent, boldface indicates significance at 5 percent level)

Commodity	+0	+1	+2	+3	+4	+5	+6
Beverages	-3.8	-2.9	1.2	0.0	-6.6	0.5	0.2
Coffee: Milds	-3.9	-4.7	-0.7	-1.1	-9.3	0.9	0.7
Coffee: Robustas	-0.9	0.9	1.8	-0.9	-6.5	-0.8	0.8
Cocoa	-4.9	2.4	3.1	2.3	-0.6	-0.4	-3.2
Tea	0.2	-1.8	4.4	2.4	-3.4	-1.5	0.9
Ag. Raw Materials	0.9	**2.9**	1.9	0.0	2.5	0.6	0.4
Timber	1.8	3.7	0.6	-0.9	0.7	1.0	0.9
Cotton	**-6.4**	-0.7	-0.1	1.3	6.6	2.1	-0.1
Wool: Coarse	3.7	3.1	0.5	-2.9	0.0	1.3	-1.1
Wool: Fine	**5.9**	4.9	4.3	**6.4**	1.2	-3.6	-3.0
Rubber	-1.9	-1.0	2.6	1.6	**6.2**	3.9	1.1
Tobacco	-0.1	-1.8	-1.1	**-5.2**	**-3.3**	-2.0	0.2
Hides	0.0	5.3	3.3	-0.6	1.1	**-8.2**	-2.2

Table A4 (Cont.). Response of Commodity Price Inflation to SST Surprise

(percent, boldface indicates significance at 5 percent level)

Commodity	+0	+1	+2	+3	+4	+5	+6
Metals	-3.7	4.1	0.3	4.2	1.3	3.5	1.3
Copper	-6.7	6.7	0.8	6.5	-2.7	6.0	1.5
Aluminum	-1.5	4.1	0.4	**7.3**	2.9	1.7	-1.1
Iron Ore	-2.5	-2.7	1.7	**-7.2**	-2.3	-1.9	1.5
Tin	0.4	2.9	0.3	2.2	1.6	3.6	3.7
Nickel	-3.6	5.6	0.0	4.6	7.2	0.7	1.5
Zinc	-2.9	-0.3	-5.7	0.2	**9.0**	5.9	6.5
Lead	-4.2	3.3	-0.6	-3.3	-1.6	3.6	1.0

Table A5. Response of Commodity Price Inflation to SOI Surprise

(Percent, boldface indicates significance at 5 percent level)

Commodity	+0	+1	+2	+3	+4	+5	+6
Foods	-1.6	0.4	**6.4**	4.1	**5.5**	2.5	1.2
Wheat	2.4	**-5.6**	2.6	2.4	**7.3**	3.1	4.4
Maize	-1.9	-2.8	**7.1**	4.8	6.7	3.8	2.4
Rice	-2.4	-0.9	**8.9**	**13.5**	2.5	1.2	2.0
Soybeans	**-7.4**	3.1	**9.7**	4.8	6.0	-1.1	-1.8
Soybean Meal	**-8.3**	1.3	7.4	7.0	2.1	-1.0	-3.6
Soybean Oil	-5.5	-1.1	**10.6**	5.9	7.0	7.3	5.0
Palm Oil	-2.4	-1.6	**9.7**	6.7	**12.1**	**10.7**	4.0
Coconut Oil	-4.8	3.1	**10.1**	5.5	**11.1**	**12.1**	**11.3**
Fish Meal	0.9	3.9	5.7	**6.5**	3.4	0.2	-5.9
Groundnut Oil	-5.6	-2.2	1.8	-5.3	2.1	7.7	5.2
Beef	0.7	0.3	3.3	1.4	4.4	0.1	-1.2
Lamb	-0.1	-0.9	-1.5	-2.3	0.1	1.7	-0.2
Sugar	-5.1	5.4	**14.7**	-4.2	1.7	2.1	1.3

Table A5 (Cont.). Response of Commodity Price Inflation to SOI Surprise

(Percent, boldface indicates significance at 5 percent level)

Commodity	+0	+1	+2	+3	+4	+5	+6
Beverages	-3.8	-2.9	1.2	0.0	-6.6	0.5	0.2
Coffee: Milds	-3.9	-4.7	-0.7	-1.1	-9.3	0.9	0.7
Coffee: Robustas	-0.9	0.9	1.8	-0.9	-6.5	-0.8	0.8
Cocoa	-4.9	2.4	3.1	2.3	-0.6	-0.4	-3.2
Tea	0.2	-1.8	4.4	2.4	-3.4	-1.5	0.9
Ag. Raw Materials	0.9	**2.9**	1.9	0.0	2.5	0.6	0.4
Timber	1.8	3.7	0.6	-0.9	0.7	1.0	0.9
Cotton	**-6.4**	-0.7	-0.1	1.3	6.6	2.1	-0.1
Wool: Coarse	3.7	3.1	0.5	-2.9	0.0	1.3	-1.1
Wool: Fine	**5.9**	4.9	4.3	**6.4**	1.2	-3.6	-3.0
Rubber	-1.9	-1.0	2.6	1.6	**6.2**	3.9	1.1
Tobacco	-0.1	-1.8	-1.1	**-5.2**	**-3.3**	-2.0	0.2
Hides	0.0	5.3	3.3	-0.6	1.1	**-8.2**	-2.2

Table A5 (Cont.). Response of Commodity Price Inflation to SOI Surprise

(Percent, boldface indicates significance at 5 percent level)

Commodity	+0	+1	+2	+3	+4	+5	+6
Metals	-3.7	4.1	0.3	4.2	1.3	3.5	1.3
Copper	-6.7	6.7	0.8	6.5	-2.7	6.0	1.5
Aluminum	-1.5	4.1	0.4	**7.3**	2.9	1.7	-1.1
Iron Ore	-2.5	-2.7	1.7	**-7.2**	-2.3	-1.9	1.5
Tin	0.4	2.9	0.3	2.2	1.6	3.6	3.7
Nickel	-3.6	5.6	0.0	4.6	7.2	0.7	1.5
Zinc	-2.9	-0.3	-5.7	0.2	**9.0**	5.9	6.5
Lead	-4.2	3.3	-0.6	-3.3	-1.6	3.6	1.0

Figure A2. IMF Commodity Price Inflation and SOI Anomalies

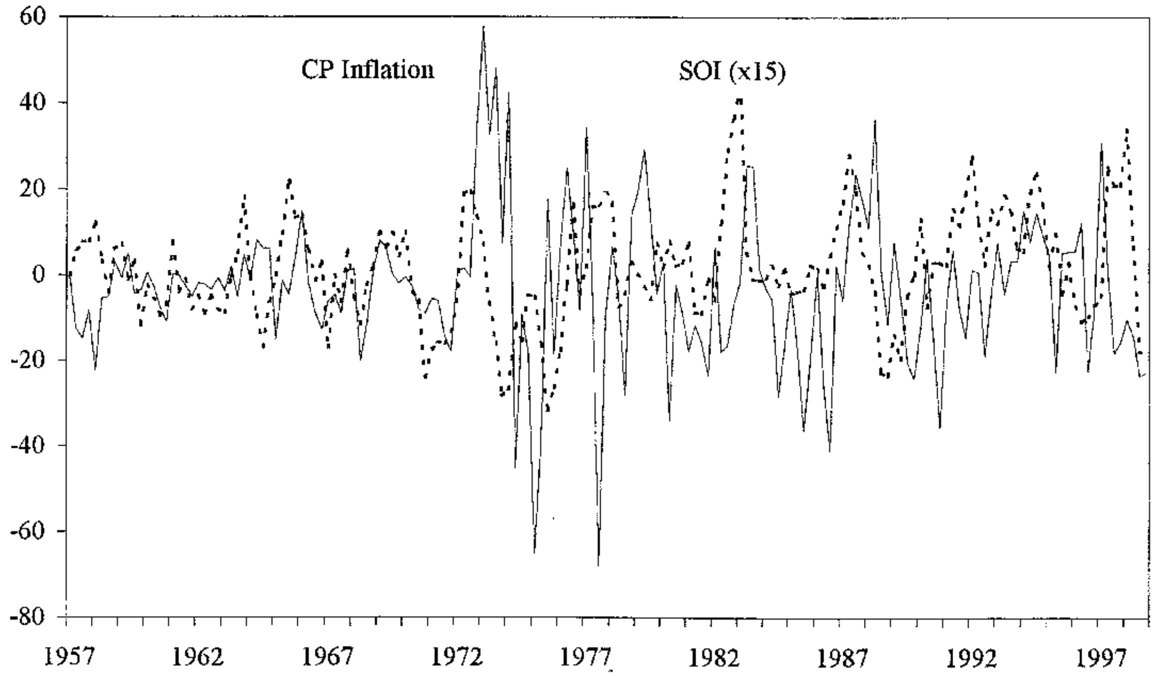
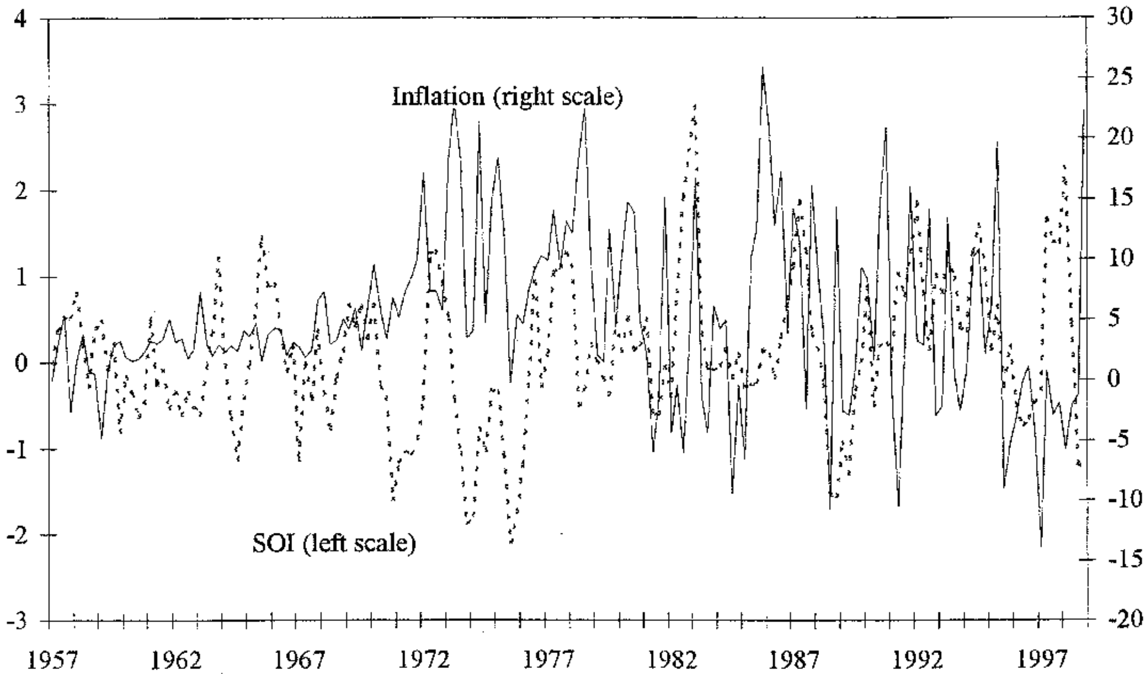


Figure A3. G7 Inflation and GDP and SOI Anomalies



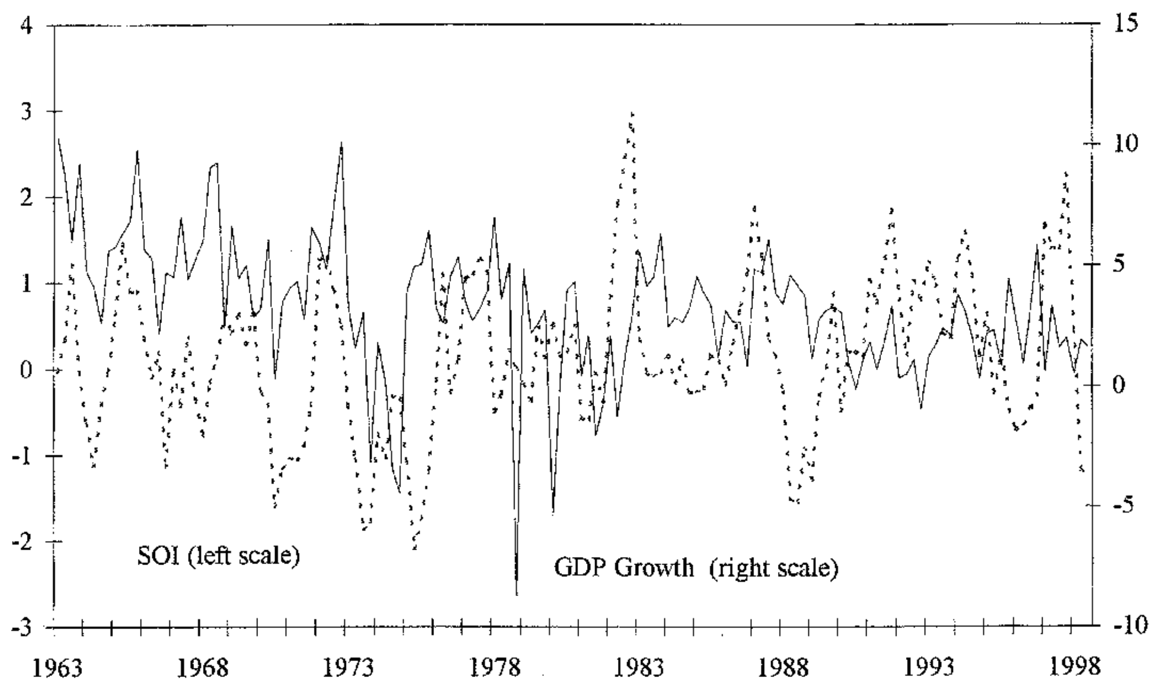


Figure A4. The Effects of a Surprise in SOI

(Dashed lines denote 2-standard deviation confidence bounds)

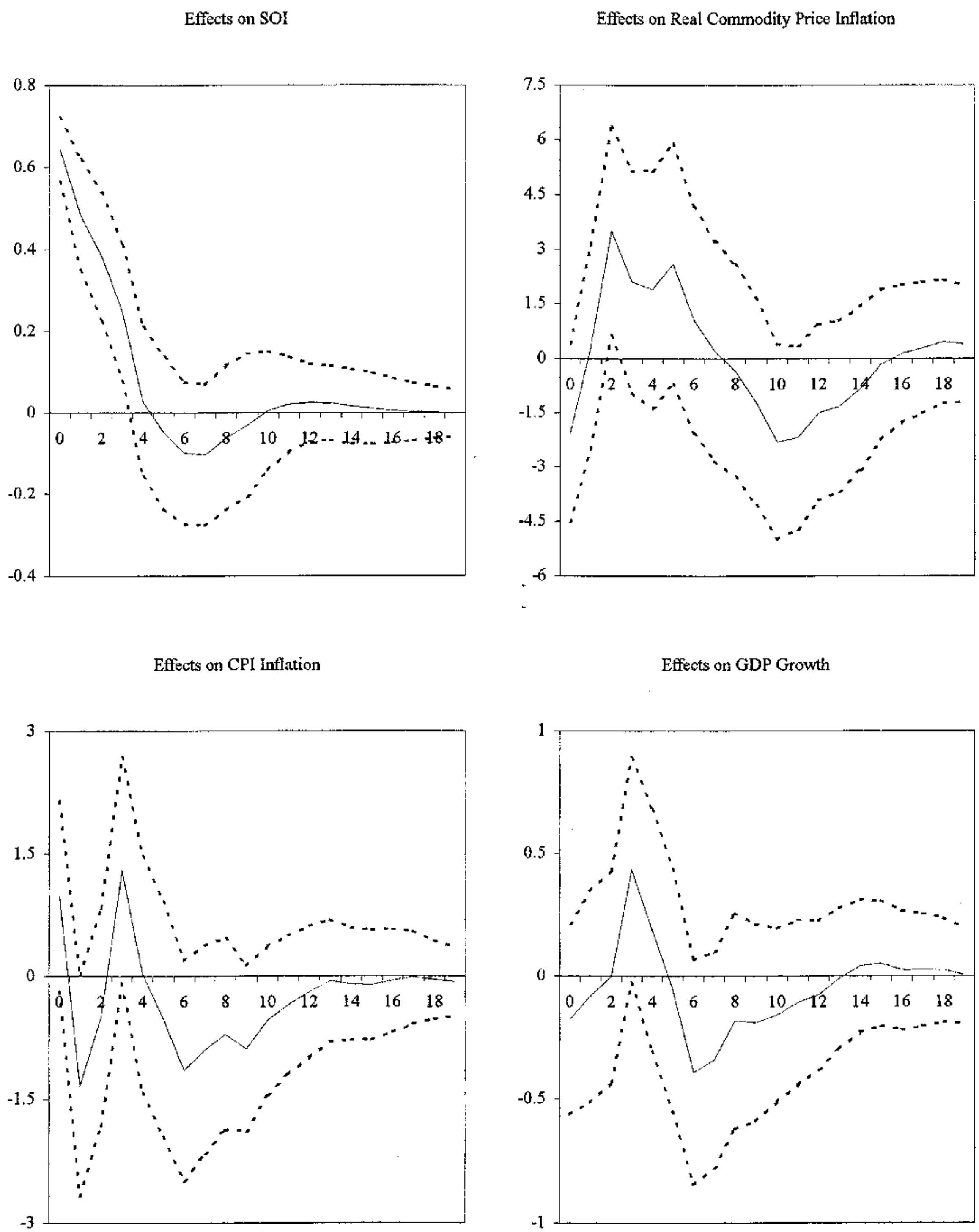
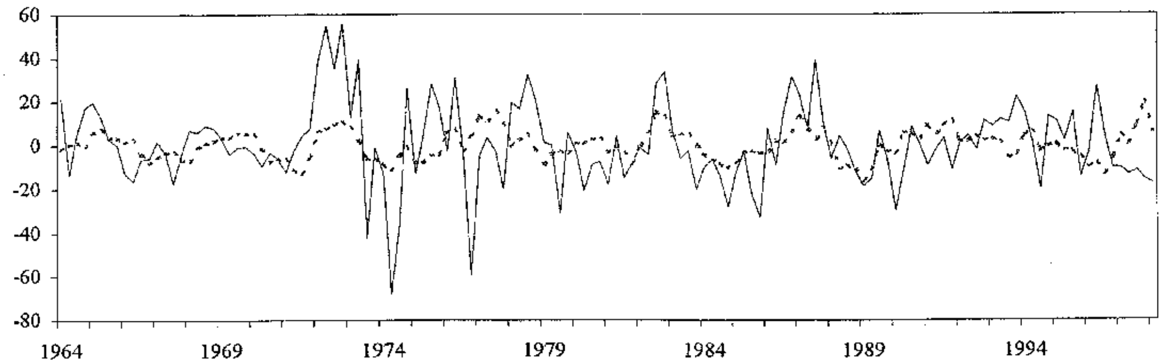


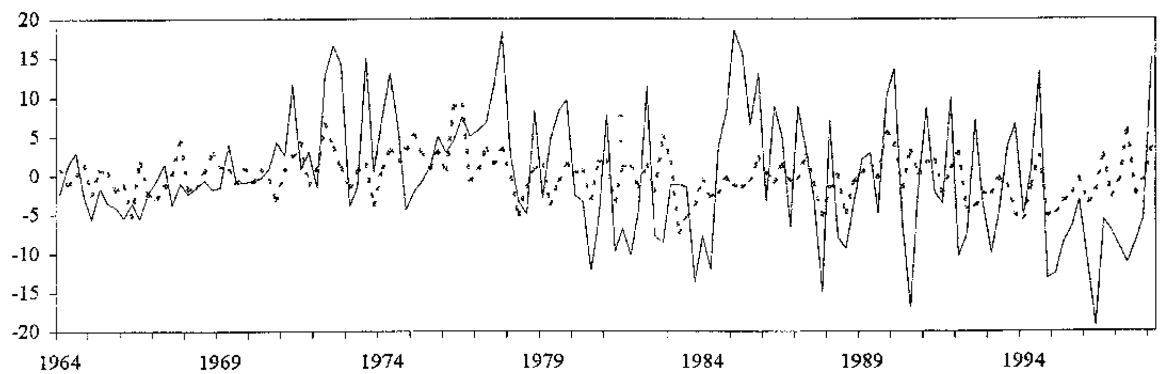
Figure A5. The Historical Contributions of SOI Anomalies

(Solid line represents 4-quarter-ahead forecast error; dashed line represents contribution of SOI)

a) Contributions to Real Commodity Price Inflation



b) Contributions to G7 CPI Inflation



c) Contributions to G7 GDP Growth