# COMMODITY PRICE DYNAMICS: EVIDENCE AND THEORY

By

Chih-Wei Wang

Dissertation

Submitted to the Faculty of the

Graduate School of Vanderbilt University

in partial fulfillment of the requirements

for the degree of

DOCTOR OF PHILOSOPHY

in

Economics

December, 2008

Nashville, Tennessee

Approved:

Professor Mario J. Crucini

Professor Craig M. Lewis

Professor Peter L. Rousseau

Professor Mototsugu Shintani

ACKNOWLEDGMENTS

I would like to thank my dissertation committee—Mario J. Crucini (chair), Craig M. Lewis, Peter L. Rousseau, and Mototsugu Shintani for helpful comments and insightful suggestions. I owe great gratitude to my advisor, Mario J. Crucini, for his guidance, patience and encouragement. This dissertation would not have been completed without his constant support.

I would also like to express my appreciation to my family, not only those in Taiwan (my parents, Tsung-Ming Wang and Ching-Sz Tsai, and younger brother, Chih-Hao Wang), but mainly my wife Lihong Han. They have always been the inspiration and motivation that moves me forward.

I have been benefited from seminar participants at Vanderbilt University, 7th EWC International Graduate Student Conference in Honolulu, HI, 72nd Midwest Economics Association Annual Meeting in Chicago, IL, and 2nd Small Open Economies in a Globalized World Conference in Waterloo, ON Canada. In particular, I thank Kevin X.D. Huang and Gregory W. Huffman for helpful comments. I also thank Kathleen Finn for her kindness and assistance during my stay in Nashville.

Finally, I gratefully acknowledge financial support from School of Arts and Science, Graduate School, Center for Ethics, and Department of Economics at Vanderbilt University, Cultural Division TECRO in the United States, and the National Science Foundation (through Mario J. Crucini).

TABLE OF CONTENTS

## LIST OF TABLES

LIST OF FIGURES

# CHAPTER I

# INTRODUCTION

The price movements of primary commodities such as rice, wheat, iron and crude petroleum have been one of the most crucial economic and social issues in a globalized world. Recent high oil prices have received particular attention among policymakers and in the popular press as consumers are worried that together with other primary good prices, constantly high oil prices may hamper overall economic growth and increase the risk of worldwide inflation, given that oil is now an indispensable raw material used in a wide range of areas. The frequent and wide fluctuations of raw and processed foodstuffs have directly influenced stability of food prices. According to World Bank's report, for about 2 billion people, high food prices are now a matter of daily struggle, sacrifice and even survival. Some 100 million people have been pushed into poverty as a result of high prices over the last several years. Soaring food prices not only cause food riots but also the potential for social unrest, strikes and protests in some developing countries.

The causes and consequences of rapid changes in commodity prices continue to be debated by economists and policymakers. Generally, commodity prices affect the world economy in several ways. On the one hand, primary goods constitute a very large fraction of total exports in some developing countries that heavily depend on a small set of primary products.[1] Fluctuations in commodity prices would have a substantial impact on the national income and the terms of trade of these economies (Bidarkota and Crucini 2000). On the other hand, primary goods are key inputs used in manufactured production; accord-

[1] According to World Bank Trade data, there are 11 developing countries in which the single most important export accounts for more than 50% of their total national exports.

ingly, an increase in the prices of primary goods exported by developing countries leads to a rise of the production costs in industrial countries. Commodity price dynamics therefore can have nontrivial implications for industrial and developing country business cycle fluctuations. In terms of the price level, commodity price indexes are often argued to be an indicator of inflation. Understanding the dynamic relationships between commodity prices and inflation is essential for monetary policies.

While the importance of commodity price dynamics is widely agreed upon, the sources of fluctuations and trends in these markets remain poorly understood. My dissertation addresses this issue by analyzing the dynamics of price and quantity determination in the international market for primary commodities empirically and theoretically. A major theme of my investigation is the application of a stochastic dynamic general equilibrium model as a means of understanding macro and micro features of primary commodity markets.

In Chapter II, I provide empirical evidence on the time series behavior of commodity price movements. Although the high volatility and persistence of commodity prices have been extensively documented in the literature, the order of their stochastic integration continues to be debated. Researchers using univariate time series models such as ARMA processes usually have difficulty rejecting the unit root null hypothesis. This finding indicates that the relative price changes of commodities are permanent and commodity price paths followed are not predictable. For economists, this finding seems very puzzling since it requires that all shocks to commodity prices are permanent. In this study, I employ monthly commodity prices for 36 individual goods and find that commodity prices and CPI are cointegrated and therefore the commodity price to CPI ratio is a more potent variable to forecast future commodity price inflation than the lagged commodity price inflation typically included in univariate models. With the aid of the bivariate error-correction model, I evaluate the relative importance of permanent and transitory shocks for commodity price movements. I find that temporary disturbances play a dominant role in price variability, accounting for an estimated 90-99 percent of the variance of commodity price inflation, independent of the forecast horizon. The half-life of a unit transitory shock in commodity prices indicates that the persistence of transitory shocks varies greatly across commodities but most of the shocks are short-lived.

Chapter III examines the driving forces of commodity price dynamics. Why are the movements in commodity prices so large and persistent? The conventional wisdom is that these movements are the result of supply and demand shocks. Yet, in most of the existing literature these two channels are studied separately. In this study, I build a stochastic dynamic general equilibrium model with the North-South trade structure to investigate the relative importance of supply and (derived) demand channels and the extent to which they can account for the observed volatility and persistence of commodity prices. I model the commodity price dynamics in an environment in which the developing South exports primary commodities to the industrial North in exchange for imports of manufactured products. The results from impulse response analysis show that both supply and (derived) demand shocks play important roles in price movements but (derived) demand shocks can generate larger price responses than supply shocks. The simulation results indicate that the model can generate highly persistent commodity prices and capture certain qualitative features of North-South business cycles but can not fully explain the high volatility observed in the data. The model also shares some of the counterfactual features of existing IRBC models such as the quantity anomaly problem.

CHAPTER II

TREND-CYCLE DECOMPOSITIONS OF COMMODITY PRICES

## Introduction

An important question concerning commodity price dynamics is whether commodity relative prices are themselves stationary. This issue is essential for risk management and forecasting and has been extensively examined in the literature. Economic theory suggests that commodity prices should be stationary because the biological nature of commodity production, inventory, and the behavior of rational profit-maximizing speculators all generate some intertemporal price dependence. Deaton and Laroque (1992) argue that commodity prices are stationary in levels but highly persistent. They write: "...from an economist's point of view, the random walk hypothesis seems very implausible, at least for commodities where the weather plays a major role in price fluctuations; a random walk requires that *all* fluctuations in price be permanent. Nor would an LDC government be wise to treat commodity booms as permanent, although there are occasions when some appear to have done so."

Although economic theory points to stationary commodity price series, the empirical literature on the time series properties of primary commodity prices frequently finds that price series are non-stationary. Various tests for unit roots in commodity prices have been undertaken. The empirical analysis usually fits univariate time series models such as autoregressive models with a constant term and a time trend to the price series and tests for unit roots using an augmented Dickey–Fuller (ADF) test. They have difficulty rejecting the unit root null hypotheses in many commodities and conclude that commodity prices are pure random walks. Cuddington and Urzua (1989), for instance, cannot reject the null that the ratio of agricultural good to manufactured good prices has a unit root and conclude that the relative commodity prices are difference stationary. Accordingly, the paths followed are not predictable and the shocks are argued to be permanent. This finding indicates that relative commodity price changes are largely permanent. A problem with this approach is that conclusions from hypothesis tests are conditional on the underlying models and are, of course, subject to specification errors. Hence despite some evidence of unit roots in commodity prices found, there is an ongoing debate about the stationarity of commodity prices.[1]

This chapter uses a large cross-sectional panel to contribute to the well-developed empirical literature on the time series properties of primary commodity prices. In contrast to the existing literature, we focus on the issue of decomposing changes in primary commodity prices into permanent and transitory changes. We employ a bivariate cointegration model of inflation and commodity prices to the analysis of commodity price movements. The idea is to impose the null hypothesis that inflation is the trend in nominal commodity prices and then use the movements in commodity prices relative to the inflation trend to decompose each of the series into transitory and permanent shocks.

In our approach, the commodity price to CPI ratio defines the long-term steady state; that is, commodity price and CPI are cointegrated. All deviations from the long-run equilibrium are transitory, because commodity price and inflation will converge back to the equilibrium ratio eventually. As a result, if commodity price deviates from the long-run relationship, the commodity price must be forecasted to decline or rise until the ratio is

[1] See, for example, Bidarkota and Crucini 2000, Bleaney and Greenaway 1993, Cuddington and Urzua 1989, Deaton and Miller 1996, Reinhart and Wickham 1994 and Tomek and Wang 2007.

restored. In this way, CPI is the trend for commodity prices and deviations of commodity price from CPI are transitory. For example, when the price of oil rises above the CPI index, one would expect declines in oil price inflation as oil works its way back to a more normal level. Using this relationship, we are able to capture the long-run trend-reverting behavior of commodity prices and separate the commodity prices into permanent and transitory components. Even if commodity prices are pure random walks as previous studies suggest the commodity price to CPI ratio would be stationary in the long run. The commodity price to CPI ratio, therefore, becomes a more potent variable to forecast future commodity price inflation than the lagged commodity price inflation usually included in the univariate time series models.

With the bivariate long-term relationship between commodity price and inflation, we examine the commodity price dynamics and address two empirical questions: (i) how important are permanent and transitory shocks for commodity price movements?; (ii) how persistent are the shocks to commodity prices? In contrast to the existing empirical literature, we find that the temporary disturbances play a dominant role in commodity price volatility; they account for an estimated 90-95 percent of the variance of commodity price inflation, independent of the forecast horizon. The estimated half-life of a unit transitory shock in commodity prices shows that the persistence of transitory shocks varies greatly across commodities but most of shocks are short-lived.

The remainder of the chapter is organized as follows. We first summarize the scope of the available data and present three prominent features of commodity prices observed in the data: (i) commodity prices exhibit enormous volatility, comparable to asset price variation; (ii) commodity prices are subject to dramatic increases; (iii) commodity price are highly persistent. We then discuss in detail the methodology used in the study and present the empirical results including estimates, impulse responses, half-lives and variance decompositions. The last section concludes.

# Data

## Description

Our analysis is carried out by using U.S. monthly commodity prices obtained from the Commodity Research Bureau's *The CRB Commodity Yearbook 2006*. We include both agricultural and industrial goods such as sugar, wheat, aluminum, and petroleum. Specifically, our data panel contains 36 individual price series of primary commodities measured in U.S. dollars per physical unit. Most commodity prices have been collected for the period January 1910 to December 2005, leaving us with a maximum of 1116 time series observations.

Data Appendix provides the specification of each price series in the panel. Some commodity price series consist of two (or more than two) sub-commodities, which are similar but not exactly identical. Examples include: No. 2 and No. 3 yellow corn in the corn price series, and No. 2 red and No. 2 soft wheat in the wheat series. This feature of data raises concerns that there could exist structural changes in some price series. To deal with this problem, we add year dummies and test the structural break null hypothesis. The results indicate that the parameters of models are stable in most commodity prices series. Another issue is that some price series were collected from different locations (cities) for different time periods. We argue that primary commodities basically are undifferentiated products which are traded based solely on their prices, rather than quality and features. Arbitrage insures that commodities sell for the same price across locations. This makes primary good prices comparable across locations as the law of one price holds if tariffs and transportation costs are taken into account.

We also include quantity data for 22 individual goods in the data panel. The world production data is taken from *the Food and Agricultural Organization of the United Nation* and *The CRB Commodity Yearbook 2006*.[2] Production data correspond to annual observations and cover at most the years 1960 to 2004. The panel data availability reconciliation is presented in the Data Appendix. Although the quantity data are available for short samples and we have yet to fully involve quantity series into the analysis in this chapter, combining quantity data with price series will be essential to consider supply disturbances and the determination of commodity prices. We will discuss this in Chapter III.

### Summary Statistics

Tables 1 through 3 present the summary statistics of the commodity price series. For most of the analysis, we work with first differences of the logarithms of the nominal prices, but for comparability with existing literature we also report descriptive statistics for relative prices, which are deflated by US CPI-U (CPI for all urban consumers; base period 1982-84).

The most prominent feature documented by Tables 1 through 3 is that individual commodity prices are extremely volatile. The fourth and fifth columns of each table show the standard deviation and coefficient of variation for commodity price series. The volatility of commodity prices varies greatly across commodities, but in general the fluctuations of prices are enormous relative to that of the overall CPI. The cross-sectional averages of coefficient of variation for commodity relative prices (Table 2) and their monthly growth rates (Table

[2] For more information, please visit FAO's website:http://www.fao.org/waicent/portal/statistics_en.asp

Table 1. Summary Statistics of First Differences of Nominal Monthly Commodity Prices

| Commodity | Obs. | Mean | Std. Dev. | cv | a-c 1 | a-c 2 | a-c 3 |
|---|---|---|---|---|---|---|---|
| Aluminum | 1151 | 0.00 | 0.03 | 25.64 | 0.32 | 0.13 | 0.14 |
| Apples | 707 | 0.00 | 0.14 | 57.08 | 0.01 | -0.07 | -0.07 |
| Beef (Meats) | 371 | 0.00 | 0.04 | 17.91 | 0.26 | -0.07 | -0.24 |
| Butter | 923 | 0.00 | 0.06 | 56.18 | 0.22 | -0.07 | -0.06 |
| Cocoa | 947 | 0.00 | 0.08 | 48.73 | 0.21 | 0.00 | 0.02 |
| Coconut Oil | 1004 | 0.00 | 0.08 | 286.27 | 0.30 | 0.05 | 0.06 |
| Coffee | 1089 | 0.00 | 0.07 | 44.80 | 0.29 | 0.14 | 0.07 |
| Copper | 1151 | 0.00 | 0.05 | 19.71 | 0.36 | 0.06 | 0.01 |
| Corn | 1151 | 0.00 | 0.07 | 70.16 | 0.27 | 0.04 | 0.03 |
| Corn Oil | 977 | 0.00 | 0.09 | 92.28 | 0.17 | -0.04 | -0.07 |
| Cotton | 1084 | 0.00 | 0.07 | 41.01 | 0.26 | 0.01 | 0.05 |
| Eggs | 1151 | 0.00 | 0.12 | 228.21 | 0.15 | 0.06 | -0.10 |
| Hides | 1151 | 0.00 | 0.08 | 63.42 | 0.27 | 0.06 | -0.07 |
| Iron (Steel) | 1151 | 0.00 | 0.07 | 32.18 | 0.32 | -0.16 | -0.09 |
| Lead | 1151 | 0.00 | 0.07 | 42.83 | 0.15 | -0.05 | 0.05 |
| Lumber | 563 | 0.00 | 0.08 | 26.94 | 0.18 | -0.09 | -0.10 |
| Milk | 899 | 0.00 | 0.04 | 17.86 | 0.66 | 0.34 | -0.05 |
| Nickel | 76 | 0.01 | 0.08 | 8.34 | 0.07 | 0.00 | -0.06 |
| Oranges | 707 | 0.00 | 0.24 | 384.97 | 0.03 | -0.15 | -0.16 |
| Palm Oil | 338 | 0.00 | 0.08 | 43.81 | 0.15 | -0.15 | -0.01 |
| Peanuts | 903 | 0.00 | 0.07 | 42.07 | 0.01 | 0.08 | 0.01 |
| Pepper | 1031 | 0.00 | 0.09 | 54.55 | 0.21 | -0.02 | -0.06 |
| Petroleum | 719 | 0.01 | 0.06 | 11.50 | 0.18 | 0.00 | -0.01 |
| Potatoes | 1115 | 0.00 | 0.17 | 109.43 | 0.16 | -0.11 | -0.11 |
| Rice, rough | 1093 | 0.00 | 0.07 | 55.26 | 0.10 | 0.06 | 0.02 |
| Rubber | 1151 | 0.00 | 0.07 | 118.25 | 0.32 | 0.09 | 0.06 |
| Rye | 1055 | 0.00 | 0.08 | 50.8 | 0.22 | -0.01 | -0.03 |
| Soybean Meal | 914 | 0.00 | 0.08 | 61.17 | 0.14 | -0.04 | -0.09 |
| Soybean Oil | 1139 | 0.00 | 0.07 | 79.45 | 0.29 | 0.04 | -0.06 |
| Soybeans | 1106 | 0.00 | 0.07 | 70.35 | 0.36 | 0.11 | -0.04 |
| Sugar | 1151 | 0.00 | 0.09 | 80.81 | 0.28 | -0.01 | 0.03 |
| Tallow | 1151 | 0.00 | 0.09 | 121.39 | 0.19 | -0.05 | 0.04 |
| Tin | 1151 | 0.00 | 0.05 | 23.60 | 0.21 | 0.03 | 0.07 |
| Wheat | 1151 | 0.00 | 0.06 | 81.37 | 0.21 | -0.05 | -0.02 |
| Wool | 1151 | 0.00 | 0.05 | 87.65 | 0.49 | 0.22 | 0.14 |
| Zinc | 1151 | 0.00 | 0.05 | 22.28 | 0.41 | 0.10 | 0.03 |
| CPI | 1127 | 0.00 | 0.01 | 2.50 | 0.46 | 0.37 | 0.33 |
| Cross-sectional mean | | | 0.08 | 74.40 | 0.23 | 0.01 | -0.02 |

"cv" denotes the coefficient of variation; "a-c 1", "a-c 2" and "a-c 3" refer to first- , second- and third- order autocorrelations. The statistics are based on first differences of log nominal prices.

Table 2. Summary Statistics of Monthly Commodity Relative Prices

| Commodity | Obs. | Mean | Std. Dev. | cv | a-c 1 | a-c 2 | a-c 3 |
|---|---|---|---|---|---|---|---|
| Aluminum | 1116 | -0.12 | 0.53 | 4.61 | 0.998 | 0.995 | 0.991 |
| Apples | 708 | -1.84 | 0.28 | 0.15 | 0.875 | 0.747 | 0.636 |
| Beef (Meats) | 372 | -0.11 | 0.27 | 2.48 | 0.989 | 0.972 | 0.957 |
| Butter | 924 | 0.43 | 0.49 | 1.13 | 0.992 | 0.979 | 0.969 |
| Cocoa | 948 | 2.79 | 0.60 | 0.21 | 0.991 | 0.980 | 0.968 |
| Coconut Oil | 1005 | -0.97 | 0.53 | 0.55 | 0.989 | 0.971 | 0.953 |
| Coffee | 1055 | -0.01 | 0.57 | 44.87 | 0.993 | 0.981 | 0.967 |
| Copper | 1116 | -0.12 | 0.37 | 2.97 | 0.992 | 0.977 | 0.962 |
| Corn | 1116 | 1.33 | 0.57 | 0.43 | 0.993 | 0.982 | 0.971 |
| Corn Oil | 978 | -1.01 | 0.60 | 0.59 | 0.990 | 0.976 | 0.963 |
| Cotton | 1085 | -0.20 | 0.52 | 2.58 | 0.992 | 0.981 | 0.969 |
| Eggs | 1116 | 0.11 | 0.64 | 5.67 | 0.983 | 0.961 | 0.938 |
| Hides | 1116 | -0.37 | 0.51 | 1.39 | 0.987 | 0.966 | 0.944 |
| Iron (Steel) | 1116 | 0.05 | 0.33 | 7.31 | 0.975 | 0.934 | 0.902 |
| Lead | 1116 | -0.74 | 0.51 | 0.69 | 0.992 | 0.981 | 0.971 |
| Lumber | 564 | 0.72 | 0.30 | 0.41 | 0.968 | 0.923 | 0.884 |
| Milk | 900 | -2.03 | 0.28 | 0.14 | 0.992 | 0.974 | 0.951 |
| Nickel | 77 | 0.89 | 0.32 | 0.36 | 0.969 | 0.933 | 0.897 |
| Oranges | 708 | -2.12 | 1.08 | 0.51 | 0.976 | 0.951 | 0.932 |
| Palm Oil | 340 | -1.65 | 0.45 | 0.27 | 0.985 | 0.965 | 0.950 |
| Peanuts | 904 | -1.30 | 0.43 | 0.33 | 0.987 | 0.974 | 0.958 |
| Pepper | 1032 | 0.03 | 0.70 | 22.49 | 0.991 | 0.979 | 0.968 |
| Petroleum | 720 | -1.99 | 0.46 | 0.23 | 0.991 | 0.979 | 0.966 |
| Potatoes | 1116 | -2.48 | 0.62 | 0.25 | 0.965 | 0.918 | 0.879 |
| Rice, rough | 1094 | -1.41 | 0.55 | 0.39 | 0.992 | 0.983 | 0.973 |
| Rubber | 1116 | -0.16 | 0.82 | 5.25 | 0.996 | 0.990 | 0.983 |
| Rye | 1020 | 1.44 | 0.53 | 0.36 | 0.989 | 0.973 | 0.957 |
| Soybean Meal | 915 | 0.68 | 0.38 | 0.56 | 0.978 | 0.951 | 0.924 |
| Soybean Oil | 1116 | -1.03 | 0.65 | 0.63 | 0.994 | 0.984 | 0.973 |
| Soybeans | 1107 | 2.09 | 0.53 | 0.25 | 0.992 | 0.978 | 0.962 |
| Sugar | 1116 | -1.90 | 0.72 | 0.38 | 0.992 | 0.980 | 0.968 |
| Tallow | 1116 | -1.35 | 0.70 | 0.52 | 0.993 | 0.982 | 0.973 |
| Tin | 1116 | 1.28 | 0.42 | 0.33 | 0.992 | 0.980 | 0.969 |
| Wheat | 1116 | 1.69 | 0.61 | 0.36 | 0.995 | 0.986 | 0.979 |
| Wool | 1116 | 1.32 | 0.71 | 0.54 | 0.998 | 0.993 | 0.988 |
| Zinc | 1116 | -0.87 | 0.32 | 0.37 | 0.987 | 0.963 | 0.936 |
| Cross-sectional mean | | | 0.53 | 3.07 | 0.985 | 0.964 | 0.945 |

"cv" denotes the coefficient of variation; "a-c 1", "a-c 2" and "a-c 3" refer to first- , second- and third- order autocorrelations. The commodity prices are deflated by U.S. CPI.

Table 3. Summary Statistics of First Differences of Commodity Relative Prices

| Commodity | Obs. | Mean | Std. Dev. | cv | a-c 1 | a-c 2 | a-c 3 |
|---|---|---|---|---|---|---|---|
| Aluminum | 1115 | 0.00 | 0.03 | 23.55 | 0.29 | 0.13 | 0.14 |
| Apples | 707 | 0.00 | 0.14 | 197.80 | 0.01 | -0.06 | -0.07 |
| Beef (Meats) | 371 | 0.00 | 0.04 | 30.69 | 0.25 | -0.08 | -0.24 |
| Butter | 923 | 0.00 | 0.06 | 42.94 | 0.21 | -0.08 | -0.07 |
| Cocoa | 947 | 0.00 | 0.08 | 85.55 | 0.20 | -0.01 | 0.01 |
| Coconut Oil | 1004 | 0.00 | 0.08 | 36.59 | 0.29 | 0.04 | 0.05 |
| Coffee | 1053 | 0.00 | 0.07 | 50.36 | 0.28 | 0.15 | 0.07 |
| Copper | 1115 | 0.00 | 0.05 | 120.83 | 0.35 | 0.05 | 0.00 |
| Corn | 1115 | 0.00 | 0.07 | 49.82 | 0.26 | 0.03 | 0.01 |
| Corn Oil | 977 | 0.00 | 0.09 | 54.50 | 0.17 | -0.04 | -0.08 |
| Cotton | 1084 | 0.00 | 0.06 | 56.69 | 0.25 | -0.01 | 0.03 |
| Eggs | 1115 | 0.00 | 0.12 | 68.82 | 0.13 | 0.05 | -0.10 |
| Hides | 1115 | 0.00 | 0.08 | 59.87 | 0.26 | 0.05 | -0.07 |
| Iron (Steel) | 1115 | 0.00 | 0.07 | 402.56 | 0.32 | -0.17 | -0.10 |
| Lead | 1115 | 0.00 | 0.07 | 77.85 | 0.14 | -0.05 | 0.03 |
| Lumber | 563 | 0.00 | 0.08 | 129.59 | 0.19 | -0.09 | -0.10 |
| Milk | 899 | 0.00 | 0.03 | 43.34 | 0.64 | 0.33 | -0.06 |
| Nickel | 76 | 0.01 | 0.08 | 10.78 | 0.08 | 0.01 | -0.06 |
| Oranges | 707 | 0.00 | 0.24 | 63.22 | 0.03 | -0.15 | -0.16 |
| Palm Oil | 338 | 0.00 | 0.08 | 44.06 | 0.16 | -0.15 | -0.01 |
| Peanuts | 903 | 0.00 | 0.07 | 65.89 | 0.00 | 0.07 | 0.01 |
| Pepper | 1031 | 0.00 | 0.09 | 163.28 | 0.20 | -0.03 | -0.07 |
| Petroleum | 719 | 0.00 | 0.06 | 28.84 | 0.16 | -0.01 | -0.02 |
| Potatoes | 1115 | 0.00 | 0.16 | 140.24 | 0.16 | -0.11 | -0.12 |
| Rice, rough | 1093 | 0.00 | 0.07 | 47.93 | 0.09 | 0.05 | 0.01 |
| Rubber | 1115 | 0.00 | 0.07 | 24.26 | 0.31 | 0.11 | 0.08 |
| Rye | 1019 | 0.00 | 0.08 | 91.08 | 0.22 | -0.01 | -0.04 |
| Soybean Meal | 914 | 0.00 | 0.08 | 58.83 | 0.14 | -0.04 | -0.09 |
| Soybean Oil | 1115 | 0.00 | 0.07 | 47.12 | 0.28 | 0.03 | -0.07 |
| Soybeans | 1106 | 0.00 | 0.07 | 39.55 | 0.36 | 0.09 | -0.06 |
| Sugar | 1115 | 0.00 | 0.09 | 66.12 | 0.27 | -0.02 | 0.02 |
| Tallow | 1115 | 0.00 | 0.09 | 45.94 | 0.18 | -0.06 | 0.03 |
| Tin | 1115 | 0.00 | 0.05 | 71.23 | 0.21 | 0.02 | 0.05 |
| Wheat | 1115 | 0.00 | 0.06 | 36.95 | 0.23 | -0.06 | -0.04 |
| Wool | 1115 | 0.00 | 0.05 | 24.31 | 0.47 | 0.20 | 0.13 |
| Zinc | 1115 | 0.00 | 0.05 | 120.01 | 0.41 | 0.09 | 0.02 |
| Cross-sectional mean | | | 0.08 | 75.58 | 0.23 | 0.01 | -0.03 |

"cv" denotes the coefficient of variation; "a-c 1", "a-c 2" and "a-c 3" refer to first- , second- and third- order autocorrelations. The commodity prices are deflated by U.S. CPI.

3) are 3.07 and 75.58, while the corresponding statistics for the monthly growth rates of the nominal prices (Table 1) is 74.40. As one might expect, the price of crude petroleum is among the most volatile with a standard deviation of 46% (Table 2) but at least 5 other commodities have relative prices that are even more volatile.

Figures 1 through 2 give graphical examples. The figures plot the paths of U.S. CPI-U and the nominal price series for corn, and iron during the same period. As anticipated, all these prices exhibit enormous volatility that is comparable to asset price variation. In addition, there are several sharp peaks in the figures, showing the rapid rise and downward movement in commodity prices.

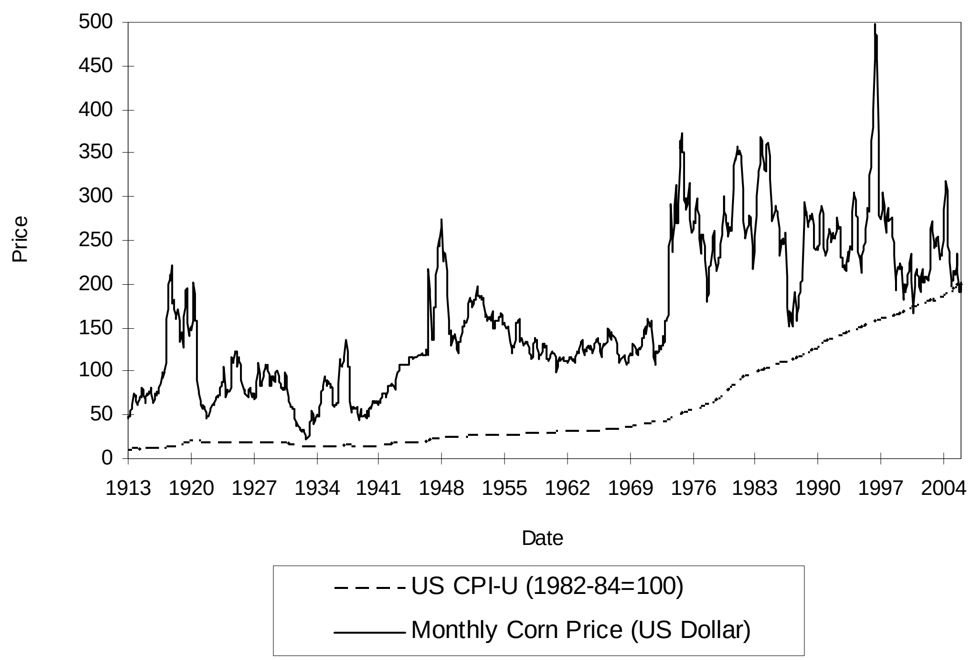



Figure 1. Monthly Corn Prices and US CPI, Jan. 1913 - Dec. 2005

The individual commodity prices are highly persistent. The remaining columns of Tables 1 through 3 report the autocorrelation statistics. The sixth column of Table 2 reports the first-order autocorrelation coefficients of commodity relative prices. Almost all of the first-order coefficients are close to 1. The cross-sectional average of first-order coefficient is 0.985. The second- and third-order coefficients are lower, but they are still substantial. Thirty two out of the thirty six have a third-order coefficient greater than 0.9. These measures show the high persistence of commodity prices.

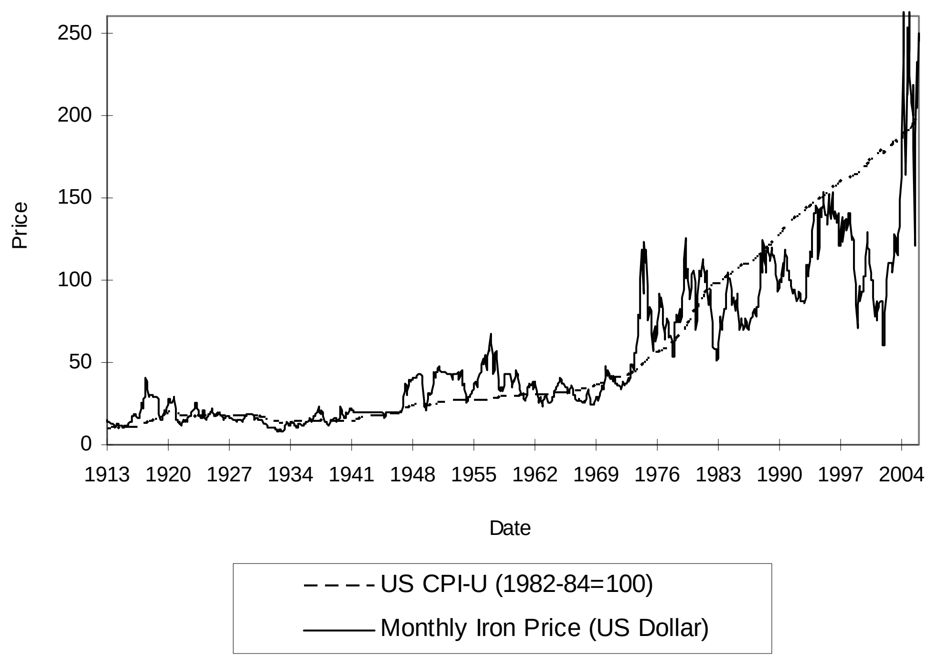



Figure 2. Monthly Iron Prices and US CPI, Jan. 1913 - Dec. 2005

The sixth column of Table 3 presents the first-order autocorrelation coefficients of first difference of commodity relative prices. After taking first difference, the first-order autocorrelation drops and is close to 0.2. In most cases, the first order correlation coefficients are between 0.1 and 0.3, while the cross-sectional mean is 0.23. The second- and third-order coefficients are pretty close to 0; the cross-sectional averages are 0.01 and -0.03, respectively.

In summary, our large cross-sectional panel includes a variety of primary commodities, ranging from agricultural products to industrial goods. It shows that the statistical properties of commodity prices vary greatly across commodities, but in general commodity prices can be summarized as: (i) commodity prices exhibit huge volatility; (ii) commodity prices are subject to dramatic increases or upward spikes; (iii) commodity prices are highly persistent over time. Our findings are consistent with the large literature.

## Estimation Strategy

Since the pioneering work of Dickey and Fuller (1981), there has been a large empirical literature on commodity prices based on unit root tests. Many of these tests fail to reject the unit root null and conclude that commodity prices are random walks. These findings are viewed as puzzling since they are inconsistent with commodity price theory and suggest that relative commodity price changes are all permanent changes. Since most of these studies rely on descriptive univariate time series models such as low order ARMA processes, the results indicate that the lagged commodity price inflation has limited ability to forecast future commodity price inflation.[3]

In this chapter, we employ an approach first advocated and applied by Cochrane (1987) to U.S. output and consumption as well as stock prices and dividends and later employed by Crucini and Shintani (2008) to examine G-7 data. The idea here is to impose

[3]The persistence of commodity prices, however, remains the subject of debate. Although a few argue that commodity price are highly persistent but stationary in levels (Deaton and Laroque 1992), a large amount of literature find it is hard to reject the unit root null hypothesis. For example, Cuddington and Urzua (1989) and Bidarkota and Crucini (2000) conclude that commodity prices are pure random walks and use trend stationary or difference stationary modeling to capture the features of price dynamics.

the hypothesis that CPI and individual commodity prices are cointegrated and employ the bivariate relationship between CPI and commodity price to decompose commodity price movements. This is analogous to the point made by Cochrane (1994) and Crucini and Shintani (2008) regarding trend-cycle decompositions of GNP.

The key is that although commodity prices are near random walks the commodity price to CPI ratio is stationary. As a result, if a commodity price deviates from its customary ratio to CPI, the commodity price must be forecast to be decline until the ratio is restored. Therefore, CPI defines the trend of individual commodity prices and deviations of commodity prices from CPI are cycles. This cointegrating relationship allows a better forecast of commodity price inflation and captures the long-horizon trend-reverting behavior of commodity prices. If a commodity shock hits and induces increases in the commodity price, the commodity price would be expected to decline and come back towards its trend until the long-run relationship is reestablished. The length of time of adjustment depends on the particular commodity market under examination. It may take a few months or several years, rather than never as suggesting by random walks.

### Bivariate Error Correction Model

We employ a bivariate VAR model: CPI and commodity prices inflation are regressed on a constant term, a time trend, their lags and the lagged commodity price to CPI ratio. We do not include the error correction term in the CPI equation, because this restriction can guarantee the Cholesky decomposition will provide an exact decomposition into permanent and transitory shocks (Gonzalo and Ng, 2001). The issue of how many lag terms to retain is important. We start with 12 lag terms in order to ensure that we capture the price dynamics adequately and then choose the numbers of lag terms based on Akaike information criterion (AIC). Our results suggest that the model with 4 lag terms performs best. Our baseline specification is:

$$\begin{aligned}\triangle p_t = &\quad \alpha_1 + \alpha_2 t + \sum_{k=1}^{4} \beta_k \triangle p_{t-k} + \sum_{k=1}^{4} \theta_k \triangle p_{it-k} + \varepsilon_t \qquad \text{(II.1)}\\ \triangle p_{it} = &\quad \tilde{\alpha}_1 + \tilde{\alpha}_2 t + \gamma(p_{it-1} - p_{t-1}) + \sum_{k=1}^{4} \tilde{\beta}_k \triangle p_{t-k} + \sum_{k=1}^{4} \tilde{\theta}_k \triangle p_{it-k} + \tilde{\varepsilon}_t\end{aligned}$$

where $\triangle$ denotes the first difference, $p_t$= *100* $\times \ln CPI_t$, $p_{it} = 100 \times \ln P_{it}$. *CPI* is the U.S. CPI-U and $P_i$ is the nominal price of commodity $i$ in U.S. dollars. The error correction term, $p_{it-1} - p_{t-1}$, is the key in the model. It captures the long-run stationarity in the system, although in the short run, there may be transitory deviations. With the error correction mechanism, a proportion of the deviations in current period can be corrected in the next period. Namely, the error correction term has effect of pulling commodity price back towards its long-run trend.

The sign of the coefficient on the ECT reflects the direction of adjustment in the commodity price inflation to transitory deviations from the stochastic inflation trend. For instance, when the price of oil rises above the CPI index, given that the commodity price to CPI ratio is stable in the long run, one would expect declines in oil price inflation as oil works its way back to a more normal level. Thus, we would expect the sign of coefficient on the ECT should be negative, because a negative sign would imply a negative response of the oil price to fluctuations that expand the value of the stationary ratio. The size of coefficient on the ECT provides information about the speed in which the commodity price inflation adjusts to deviations from the long-run equilibrium relationship.

Since standard OLS estimation is less efficient when a restriction is imposed in one of the equation systems, we employ the generalized least squares method (GLS) to estimate the baseline model. This estimation strategy provides an efficient estimator.

### Identification

To compute the impulse response functions and decompose commodity prices into trend and cyclical components, we need to identify permanent and transitory shocks in our system. To achieve this, we impose an orthogonalization assumption and apply a Choleski transformation to the original error terms. Our Choleski factorization is: the transitory shock (the shock to individual primary commodities) does not affect inflation contemporaneously while commodity price inflation responds to both the transitory shock and permanent shock (the shock to inflation). In this sense, we define the shock in the inflation equation as the "permanent" or "inflation" shock and the shock in the commodity price equation as the "transitory" or "commodity" shock. With this definition, our assumption says that the commodity (transitory) shock has no contemporaneous effect on overall inflation. Using this identification assumption and the zero restriction on the error correction term in the inflation equation, we are able to separate shocks into permanent and transitory disturbances.

Our identification assumption seems plausible given the vast number of commodities entering the CPI basket and the stickiness of consumer good prices. It is well-established that primary goods are homogenous, storable, and traded on competitive markets. If there is an increase in demand for primary goods, it is instantaneously reflected as an increase in their prices. Commodity prices are considered to be flexible. Arbitrage conditions further insure that commodity prices are the same across locations. However, this proposition cannot be applied to consumer goods or services: most of these prices are sticky in the short run. Several possible scenarios have been proposed to explain the stickiness of prices, including menu costs, imperfect information, and contracts. Given this and the fact that the CPI index is a weighted average of consumer basket, it is reasonable to argue that CPI is not free to respond to the transitory shock in the short run. In other words, individual non-oil primary commodity prices have, if any, negligible short-run effects on the overall price level. On the other hand, the changes in inflation are more likely to have a contemporaneous impact on commodity prices, because it changes the real prices of individual commodities and commodity prices are flexible in the short run.

## Empirical Results

### Estimates

Table 4 reports the estimates of the bivariate error correction model (eq. II.1) for 36 individual commodity price series. A prerequisite to our trend-cycle decompositions of commodity prices is the cointegrating relationship between inflation and individual commodity prices. As discussed in previous section, we expect the coefficient on the error correction term to be negative if inflation and commodity price are cointegrated. Our estimation results confirm this. All 36 estimates are negative, and almost all the estimated coefficients are statistically significant at 10% level. This finding provides strong evidence to support the cointegrating relationship between commodity price and CPI, and thus the validity of our methodology. Moreover, the estimates also verify that the error correction term, together with lagged overall inflation, have good predictive power for future commodity price inflation which is poorly predicted by the conventional univariate model. To see this, we take aluminum as an example. For aluminum price inflation, the estimated coefficients or $p_{it-1} - p_{t-1}$, $\triangle\, p_{t-1}$ ,$\triangle\, p_{t-2}$ , $\triangle\, p_{t-3}$ and $\triangle\, p_{t-4}$ are -0.01, 0.49, -0.42, -0.01 and 0.05. Particularly, among them $p_{it-1} - p_{t-1}$, $\triangle\, p_{t-1}$ and $\triangle\, p_{t-2}$ are statistically significant at the 5% level. This suggests that combining commodity prices with the inflation trends better captures the commodity price dynamics. With regard to overall inflation, we find that it is also predictable in the bivariate model. However, the lagged commodity price inflation plays a less important role in the inflation movements, as evident in the insignificant estimated coefficients on lagged $\triangle\, p_i$. A commodity price index might do better.

Table 4. CPI and Commodity Price Regression: Cointegrated VAR Estimates

| | | *const.* | *trend* | $p_{i,t-1} - p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Aluminum (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.31 | 0.12 | 0.08 | 0.20 | 0.01 | 0.00 | 0.00 | -0.01 |
| | $\Delta p_{i,t}$ | 0.65 | 0.00 | -0.01 | 0.49 | -0.42 | -0.01 | 0.05 | 0.30 | 0.00 | 0.10 | 0.05 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 |
| | $\Delta p_{i,t}$ | 0.32 | 0.00 | 0.00 | 0.17 | 0.18 | 0.18 | 0.17 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.78 | 0.62 | . | 10.56 | 3.81 | 2.45 | 6.71 | 2.63 | -0.31 | 0.14 | -1.24 |
| | $\Delta p_{i,t}$ | 2.04 | -2.10 | -2.89 | 2.95 | -2.39 | -0.08 | 0.29 | 10.02 | -0.03 | 3.11 | 1.71 |
| **Apples (T=708)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.09 | 0.00 | 0.00 | 0.34 | 0.12 | 0.11 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -34.61 | -0.02 | -0.22 | 3.39 | -2.07 | -0.09 | -1.32 | 0.12 | 0.04 | 0.04 | 0.00 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.04 | 0.04 | 0.04 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 4.38 | 0.00 | 0.03 | 1.54 | 1.63 | 1.59 | 1.53 | 0.04 | 0.04 | 0.04 | 0.04 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 3.28 | 0.34 | . | 9.02 | 2.97 | 2.87 | 3.13 | 1.48 | -0.31 | -1.90 | -1.08 |
| | $\Delta p_{i,t}$ | -7.90 | -5.30 | -8.27 | 2.20 | -1.27 | -0.06 | -0.86 | 3.07 | 1.06 | 1.07 | 0.02 |
| **Beef (T=372)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.27 | 0.00 | 0.00 | 0.54 | -0.10 | -0.02 | 0.15 | 0.01 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 1.11 | -0.01 | -0.04 | 0.42 | 2.19 | -0.16 | -1.83 | 0.23 | -0.05 | -0.17 | -0.06 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.05 | 0.00 | 0.00 | 0.05 | 0.06 | 0.06 | 0.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.75 | 0.00 | 0.02 | 0.78 | 0.89 | 0.90 | 0.83 | 0.05 | 0.05 | 0.05 | 0.05 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 5.70 | -4.23 | . | 10.59 | -1.68 | -0.42 | 2.82 | 2.37 | -0.52 | 0.68 | 1.25 |
| | $\Delta p_{i,t}$ | 1.48 | -1.97 | -2.10 | 0.53 | 2.46 | -0.18 | -2.22 | 4.33 | -1.02 | -3.16 | -1.23 |
| **Butter (T=924)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.31 | 0.13 | 0.11 | 0.15 | 0.01 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 3.55 | -0.01 | -0.03 | -0.07 | 1.38 | 0.39 | 0.27 | 0.25 | -0.13 | 0.00 | -0.08 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.93 | 0.00 | 0.01 | 0.47 | 0.49 | 0.49 | 0.47 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.13 | 1.72 | . | 9.39 | 3.78 | 3.21 | 4.39 | 3.34 | -1.62 | -1.37 | -1.35 |
| | $\Delta p_{i,t}$ | 3.81 | -3.76 | -4.31 | -0.14 | 2.81 | 0.78 | 0.57 | 7.43 | -3.78 | -0.09 | -2.41 |

*P=100*lnCPI, Pi=100*lnPi* ; △ denotes first differences.

Table 4. (Continued)

| | | const. | trend | $p_{i,t-1} - p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Cocoa (T=948)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.11 | 0.00 | 0.00 | -0.59 | -0.37 | -0.10 | -0.04 | -0.09 | 0.50 | 0.04 | -0.11 |
| | $\Delta p_{i,t}$ | 2.58 | 0.00 | -0.02 | 0.46 | 0.13 | -0.08 | 0.07 | -0.73 | -0.54 | -0.19 | -0.02 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 4.14 | 0.01 | 0.00 | 0.03 | 0.04 | 0.04 | 0.03 | 0.03 | 0.04 | 0.04 | 0.03 |
| | $\Delta p_{i,t}$ | 4.89 | 0.01 | 0.01 | 0.04 | 0.04 | 0.04 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.27 | -0.23 | . | -18.15 | -9.32 | -2.87 | -1.18 | -2.73 | 12.90 | 0.91 | -3.29 |
| | $\Delta p_{i,t}$ | 0.53 | -0.52 | -1.90 | 13.06 | 3.16 | -2.20 | 2.12 | -21.58 | -13.03 | -4.19 | -0.67 |
| **Coconut Oil (T=1005)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.00 | 0.00 | 0.00 | 0.33 | 0.09 | 0.10 | 0.16 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -1.54 | 0.00 | -0.04 | 0.81 | 0.19 | -0.06 | 1.40 | 0.32 | -0.05 | 0.07 | 0.02 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.55 | 0.00 | 0.01 | 0.45 | 0.48 | 0.47 | 0.45 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.09 | 2.49 | . | 10.52 | 2.81 | 2.91 | 5.03 | 1.32 | 0.51 | 0.46 | 0.83 |
| | $\Delta p_{i,t}$ | -2.80 | -4.04 | -5.43 | 1.79 | 0.40 | -0.13 | 3.09 | 10.11 | -1.50 | 2.26 | 0.56 |
| **Coffee (T=1055)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.14 | 0.00 | 0.00 | 0.17 | 0.06 | 0.08 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.27 | 0.00 | -0.01 | -0.23 | -0.15 | 0.23 | -0.08 | 0.26 | 0.09 | 0.02 | -0.01 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.07 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 |
| | $\Delta p_{i,t}$ | 0.45 | 0.00 | 0.00 | 0.20 | 0.20 | 0.20 | 0.20 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.91 | 0.58 | . | 5.20 | 1.79 | 2.42 | 2.02 | 0.06 | 0.29 | 0.13 | 0.36 |
| | $\Delta p_{i,t}$ | 0.60 | -0.21 | -2.89 | -1.19 | -0.77 | 1.15 | -0.39 | 7.95 | 2.55 | 0.60 | -0.18 |
| **Copper (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.07 | 0.00 | 0.00 | 0.30 | 0.12 | 0.07 | 0.20 | 0.01 | 0.01 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -0.07 | 0.00 | -0.01 | 0.33 | 0.10 | 0.08 | -0.08 | 0.39 | -0.09 | 0.04 | -0.04 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.27 | 0.00 | 0.00 | 0.23 | 0.24 | 0.24 | 0.23 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.89 | 0.55 | . | 10.20 | 3.85 | 2.20 | 6.85 | 2.26 | 1.56 | 0.44 | 0.66 |
| | $\Delta p_{i,t}$ | -0.25 | -0.06 | -2.48 | 1.43 | 0.41 | 0.31 | -0.34 | 13.08 | -2.64 | 1.12 | -1.46 |

*P=100*lnCPI, Pi=100*lnPi* ; △ denotes first differences.

Table 4. (Continued)

| | | *const.* | *trend* | $p_{i,t-1} - p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Corn (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.27 | 0.11 | 0.04 | 0.23 | 0.01 | 0.00 | 0.02 | 0.00 |
| | $\Delta p_{i,t}$ | 5.58 | 0.00 | -0.03 | -0.25 | 0.77 | 0.37 | -0.20 | 0.29 | -0.03 | 0.05 | -0.04 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 1.37 | 0.00 | 0.01 | 0.36 | 0.37 | 0.37 | 0.36 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.84 | 1.03 | . | 8.99 | 3.70 | 1.32 | 7.72 | 3.56 | 0.92 | 5.87 | -0.44 |
| | $\Delta p_{i,t}$ | 4.08 | -3.52 | -4.08 | -0.67 | 2.06 | 0.99 | -0.55 | 9.44 | -1.04 | 1.50 | -1.39 |
| **Corn Oil (T=978)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.02 | 0.00 | 0.00 | 0.31 | 0.10 | 0.09 | 0.14 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -1.13 | -0.01 | -0.04 | -0.25 | -0.42 | 2.25 | 1.99 | 0.20 | -0.03 | -0.04 | -0.02 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.57 | 0.00 | 0.01 | 0.58 | 0.60 | 0.60 | 0.59 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.76 | 2.41 | . | 9.72 | 2.96 | 2.75 | 4.48 | 1.52 | 1.26 | 0.38 | 1.59 |
| | $\Delta p_{i,t}$ | -1.98 | -4.84 | -5.53 | -0.43 | -0.69 | 3.73 | 3.39 | 6.34 | -0.82 | -1.15 | -0.59 |
| **Cotton (T=1085)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.05 | 0.00 | 0.00 | 0.31 | 0.10 | 0.06 | 0.21 | 0.01 | 0.00 | 0.01 | 0.00 |
| | $\Delta p_{i,t}$ | 0.97 | 0.00 | -0.02 | 0.64 | 0.96 | -0.21 | -0.23 | 0.28 | -0.08 | 0.07 | -0.02 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.45 | 0.00 | 0.01 | 0.34 | 0.36 | 0.36 | 0.34 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.59 | 0.98 | . | 10.29 | 3.38 | 1.84 | 7.28 | 2.86 | 1.32 | 3.01 | 0.54 |
| | $\Delta p_{i,t}$ | 2.17 | -3.19 | -3.81 | 1.87 | 2.69 | -0.58 | -0.68 | 9.28 | -2.37 | 2.20 | -0.69 |
| **Eggs (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.30 | 0.13 | 0.09 | 0.22 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 14.45 | -0.02 | -0.13 | 0.55 | 1.80 | 0.91 | 0.87 | 0.17 | 0.10 | -0.05 | -0.03 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 1.70 | 0.00 | 0.01 | 0.60 | 0.63 | 0.63 | 0.61 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.66 | 0.50 | . | 10.06 | 4.17 | 2.87 | 7.36 | -1.24 | -1.55 | -3.22 | -3.30 |
| | $\Delta p_{i,t}$ | 8.49 | -8.90 | -9.45 | 0.91 | 2.87 | 1.44 | 1.42 | 5.58 | 3.25 | -1.51 | -0.82 |

*P=100*lnCPI, Pi=100*lnPi* ; △ denotes first differences.

Table 4. (Continued)

| | | *const.* | *trend* | $p_{i,t-1}-p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Hides (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.29 | 0.12 | 0.08 | 0.20 | 0.01 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.47 | 0.00 | -0.03 | 0.85 | -0.02 | -0.06 | 0.49 | 0.28 | 0.02 | -0.06 | -0.04 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.51 | 0.00 | 0.01 | 0.43 | 0.45 | 0.45 | 0.43 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.83 | 0.65 | . | 9.78 | 3.91 | 2.50 | 6.92 | 3.71 | 0.94 | -1.21 | 0.38 |
| | $\Delta p_{i,t}$ | 0.92 | -3.20 | -4.77 | 1.97 | -0.04 | -0.14 | 1.15 | 9.09 | 0.67 | -1.82 | -1.27 |
| **Iron (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.30 | 0.12 | 0.07 | 0.20 | 0.01 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.93 | 0.00 | -0.04 | 0.74 | 0.43 | -0.03 | 0.59 | 0.46 | -0.33 | 0.13 | -0.05 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.45 | 0.00 | 0.01 | 0.35 | 0.36 | 0.36 | 0.35 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.79 | 0.65 | . | 10.39 | 3.99 | 2.25 | 6.82 | 2.32 | 0.07 | 0.95 | -1.39 |
| | $\Delta p_{i,t}$ | 2.05 | -2.48 | -5.15 | 2.13 | 1.17 | -0.08 | 1.70 | 15.45 | -10.03 | 3.83 | -1.63 |
| **Lead (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.07 | 0.00 | 0.00 | 0.28 | 0.11 | 0.08 | 0.20 | 0.01 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -0.55 | -0.01 | -0.05 | 0.56 | -0.87 | 1.49 | 0.85 | 0.19 | -0.04 | 0.07 | 0.01 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.41 | 0.00 | 0.01 | 0.36 | 0.37 | 0.37 | 0.36 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.93 | 0.65 | . | 9.20 | 3.64 | 2.54 | 6.76 | 3.34 | 1.44 | 1.15 | -0.73 |
| | $\Delta p_{i,t}$ | -1.35 | -4.94 | -5.99 | 1.57 | -2.36 | 4.03 | 2.36 | 5.97 | -1.24 | 2.12 | 0.30 |
| **Lumber (T=564)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.11 | 0.00 | 0.00 | 0.40 | 0.14 | 0.01 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 4.10 | 0.00 | -0.03 | -0.96 | -0.62 | -0.30 | -0.04 | 0.20 | -0.12 | -0.02 | -0.12 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.04 | 0.05 | 0.05 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 1.44 | 0.00 | 0.01 | 1.17 | 1.27 | 1.26 | 1.19 | 0.04 | 0.04 | 0.04 | 0.04 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 3.81 | -1.03 | . | 9.72 | 3.02 | 0.19 | 4.58 | 1.07 | 0.65 | 0.14 | -0.75 |
| | $\Delta p_{i,t}$ | 2.85 | -1.41 | -2.20 | -0.83 | -0.49 | -0.24 | -0.04 | 4.68 | -2.66 | -0.50 | -2.83 |

*P=100*lnCPI, Pi=100*lnPi* ; △ denotes first differences.

Table 4. (Continued)

| | | const. | trend | $p_{i,t-1}-p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Milk (T=900)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.30 | 0.12 | 0.13 | 0.13 | 0.02 | -0.02 | -0.02 | 0.01 |
| | $\Delta p_{i,t}$ | -3.79 | 0.00 | -0.02 | 0.11 | 0.30 | 0.51 | 0.56 | 0.61 | 0.12 | -0.20 | -0.20 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 |
| | $\Delta p_{i,t}$ | 0.84 | 0.00 | 0.00 | 0.19 | 0.19 | 0.19 | 0.19 | 0.03 | 0.04 | 0.04 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 2.16 | 1.02 | . | 9.06 | 3.56 | 3.89 | 4.00 | 3.55 | -2.65 | -2.89 | 2.31 |
| | $\Delta p_{i,t}$ | -4.51 | -4.32 | -4.66 | 0.57 | 1.55 | 2.65 | 2.97 | 18.68 | 3.14 | -5.22 | -6.18 |
| **Nickel (T=77)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.25 | 0.00 | 0.00 | 0.39 | -0.40 | -0.14 | -0.02 | 0.00 | 0.00 | 0.00 | 0.01 |
| | $\Delta p_{i,t}$ | 2.59 | 0.10 | -0.06 | -2.22 | -0.85 | -3.01 | 3.17 | 0.08 | 0.02 | -0.05 | 0.02 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.09 | 0.00 | 0.00 | 0.12 | 0.13 | 0.13 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 3.02 | 0.07 | 0.05 | 3.58 | 3.83 | 3.95 | 3.97 | 0.13 | 0.13 | 0.13 | 0.13 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 2.90 | -0.13 | . | 3.32 | -3.08 | -1.04 | -0.18 | 0.34 | -0.21 | 0.89 | 2.59 |
| | $\Delta p_{i,t}$ | 0.86 | 1.44 | -1.23 | -0.62 | -0.22 | -0.76 | 0.80 | 0.61 | 0.19 | -0.37 | 0.15 |
| **Oranges (T=708)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.09 | 0.00 | 0.00 | 0.35 | 0.12 | 0.10 | 0.12 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -8.35 | -0.09 | -0.17 | 4.73 | 0.37 | -1.00 | 3.74 | 0.09 | -0.07 | -0.08 | -0.09 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.04 | 0.04 | 0.04 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 2.19 | 0.01 | 0.03 | 2.61 | 2.77 | 2.70 | 2.60 | 0.04 | 0.04 | 0.04 | 0.04 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 3.28 | 0.33 | . | 9.17 | 2.96 | 2.69 | 3.12 | -0.23 | -0.96 | -0.23 | -1.14 |
| | $\Delta p_{i,t}$ | -3.82 | -6.43 | -6.69 | 1.81 | 0.13 | -0.37 | 1.44 | 2.22 | -1.92 | -2.07 | -2.45 |
| **Palm Oil (T=340)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.26 | 0.00 | 0.00 | 0.55 | -0.08 | 0.07 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -2.26 | -0.01 | -0.03 | -1.58 | 0.78 | -0.71 | -0.04 | 0.21 | -0.14 | 0.05 | 0.08 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.05 | 0.00 | 0.00 | 0.06 | 0.06 | 0.06 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 2.45 | 0.01 | 0.01 | 1.64 | 1.85 | 1.86 | 1.64 | 0.06 | 0.06 | 0.06 | 0.06 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 5.10 | -3.91 | . | 9.89 | -1.31 | 1.11 | 1.44 | -0.39 | 0.58 | -0.24 | 2.01 |
| | $\Delta p_{i,t}$ | -0.92 | -2.07 | -2.22 | -0.96 | 0.42 | -0.38 | -0.02 | 3.68 | -2.52 | 0.85 | 1.49 |

*P=100*lnCPI, Pi=100*lnPi* ; △ denotes first differences.

Table 4. (Continued)

| | | *const.* | *trend* | $p_{i,t-1} - p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Peanuts (T=904)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.32 | 0.10 | 0.12 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -2.00 | 0.00 | -0.03 | 0.64 | -0.16 | 0.54 | 0.16 | 0.01 | 0.09 | 0.02 | 0.07 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.82 | 0.00 | 0.01 | 0.53 | 0.55 | 0.55 | 0.53 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.88 | 1.40 | . | 9.58 | 2.79 | 3.51 | 3.97 | 1.35 | 1.98 | -0.28 | 2.15 |
| | $\Delta p_{i,t}$ | -2.44 | -2.83 | -3.63 | 1.20 | -0.29 | 0.98 | 0.30 | 0.35 | 2.56 | 0.60 | 2.21 |
| **Pepper (T=1032)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | -0.02 | 0.00 | 0.00 | 0.32 | 0.10 | 0.06 | 0.14 | 0.00 | 0.00 | 0.01 | 0.00 |
| | $\Delta p_{i,t}$ | 0.28 | 0.00 | -0.01 | 0.44 | 0.98 | 0.17 | -0.29 | 0.22 | -0.06 | -0.05 | 0.05 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.57 | 0.00 | 0.00 | 0.57 | 0.59 | 0.60 | 0.56 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | -0.77 | 3.62 | . | 10.34 | 3.10 | 1.79 | 4.53 | 2.30 | -0.80 | 2.85 | -0.59 |
| | $\Delta p_{i,t}$ | 0.48 | -0.79 | -2.39 | 0.77 | 1.66 | 0.29 | -0.52 | 6.84 | -1.90 | -1.54 | 1.42 |
| **Petroleum (T=720)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.11 | 0.00 | 0.00 | 0.32 | 0.05 | 0.13 | 0.18 | 0.01 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -4.78 | 0.00 | -0.02 | 1.01 | 0.27 | 0.50 | 0.62 | 0.18 | -0.04 | 0.00 | -0.05 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.04 | 0.04 | 0.04 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 1.64 | 0.00 | 0.01 | 0.61 | 0.64 | 0.64 | 0.61 | 0.04 | 0.04 | 0.04 | 0.04 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 3.36 | -0.37 | . | 8.61 | 1.26 | 3.42 | 4.83 | 3.13 | -0.11 | 0.01 | -0.96 |
| | $\Delta p_{i,t}$ | -2.92 | 1.65 | -3.03 | 1.65 | 0.41 | 0.78 | 1.01 | 4.67 | -1.05 | -0.08 | -1.36 |
| **Potatoes (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.31 | 0.13 | 0.06 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -17.35 | -0.02 | -0.11 | 0.88 | 0.35 | -1.52 | 2.25 | 0.22 | -0.07 | -0.02 | 0.00 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 2.48 | 0.00 | 0.01 | 0.84 | 0.87 | 0.87 | 0.84 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.75 | 0.67 | . | 10.41 | 4.13 | 1.85 | 6.68 | 0.14 | -0.98 | 1.82 | -0.89 |
| | $\Delta p_{i,t}$ | -6.99 | -6.29 | -7.64 | 1.05 | 0.40 | -1.74 | 2.69 | 7.12 | -2.26 | -0.50 | -0.08 |

*P=100*lnCPI, Pi=100*lnPi* ; △ denotes first differences.

Table 4. (Continued)

| | | *const.* | *trend* | $p_{i,t-1} - p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Rice (T=1094)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.31 | 0.11 | 0.06 | 0.20 | 0.01 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -1.79 | 0.00 | -0.02 | -0.19 | 1.03 | 0.30 | -0.13 | 0.11 | 0.05 | 0.01 | 0.01 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.64 | 0.00 | 0.01 | 0.38 | 0.40 | 0.40 | 0.38 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.85 | 0.74 | . | 10.12 | 3.42 | 2.01 | 6.79 | 2.79 | 0.46 | 0.97 | 1.26 |
| | $\Delta p_{i,t}$ | -2.82 | -2.86 | -3.90 | -0.49 | 2.57 | 0.74 | -0.33 | 3.53 | 1.64 | 0.31 | 0.35 |
| **Rubber (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.07 | 0.00 | 0.00 | 0.30 | 0.12 | 0.07 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 1.55 | 0.00 | -0.02 | 0.68 | 0.26 | -0.57 | 0.76 | 0.32 | 0.01 | 0.05 | 0.01 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.60 | 0.00 | 0.00 | 0.36 | 0.38 | 0.38 | 0.36 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.96 | 0.55 | . | 10.28 | 3.89 | 2.22 | 6.82 | 1.95 | 0.91 | -0.09 | 0.49 |
| | $\Delta p_{i,t}$ | 2.58 | -3.27 | -4.42 | 1.88 | 0.69 | -1.51 | 2.10 | 10.49 | 0.20 | 1.61 | 0.37 |
| **Rye (T=1020)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.05 | 0.00 | 0.00 | 0.30 | 0.13 | 0.07 | 0.20 | 0.00 | 0.00 | 0.01 | 0.00 |
| | $\Delta p_{i,t}$ | 7.29 | 0.00 | -0.04 | 0.26 | 0.35 | 0.94 | 0.07 | 0.24 | -0.04 | -0.01 | 0.03 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.04 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 1.61 | 0.00 | 0.01 | 0.41 | 0.43 | 0.43 | 0.41 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.39 | 0.98 | . | 9.76 | 4.18 | 2.11 | 6.36 | 0.63 | -0.51 | 2.17 | 0.13 |
| | $\Delta p_{i,t}$ | 4.54 | -3.69 | -4.75 | 0.63 | 0.82 | 2.20 | 0.18 | 7.76 | -1.25 | -0.27 | 0.92 |
| **Soybean Meal (T=915)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.04 | 0.00 | 0.00 | 0.31 | 0.11 | 0.11 | 0.15 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 5.49 | 0.00 | -0.05 | -0.60 | 0.02 | 1.33 | 0.59 | 0.18 | 0.00 | -0.06 | 0.05 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.04 | 0.04 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 1.22 | 0.00 | 0.01 | 0.61 | 0.63 | 0.63 | 0.61 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.39 | 1.65 | . | 9.21 | 3.05 | 3.14 | 4.57 | 2.36 | 1.00 | 1.74 | -0.05 |
| | $\Delta p_{i,t}$ | 4.51 | -3.34 | -4.86 | -1.00 | 0.04 | 2.11 | 0.98 | 5.22 | -0.10 | -1.83 | 1.39 |

*P=100*lnCPI, Pi=100*lnPi* ; △ denotes first differences.

Table 4. (Continued)

| | | *const.* | *trend* | $p_{i,t-1}-p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Soybean Oil (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.29 | 0.12 | 0.07 | 0.20 | 0.01 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -0.44 | -0.01 | -0.04 | 0.69 | -0.07 | 0.64 | 0.55 | 0.32 | -0.02 | -0.06 | 0.03 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.44 | 0.00 | 0.01 | 0.37 | 0.39 | 0.39 | 0.38 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.82 | 0.77 | . | 9.86 | 3.78 | 2.28 | 6.81 | 2.77 | 1.15 | 0.76 | 0.23 |
| | $\Delta p_{i,t}$ | -1.00 | -5.10 | -5.58 | 1.83 | -0.17 | 1.65 | 1.47 | 10.44 | -0.49 | -1.83 | 1.09 |
| **Soybeans 1 (T=408)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.10 | 0.00 | 0.00 | 0.29 | 0.09 | 0.07 | 0.21 | 0.00 | 0.02 | 0.00 | 0.01 |
| | $\Delta p_{i,t}$ | 9.52 | -0.01 | -0.04 | 0.11 | 0.30 | 0.52 | 0.65 | 0.41 | 0.12 | -0.10 | -0.04 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.08 | 0.00 | 0.00 | 0.05 | 0.05 | 0.05 | 0.05 | 0.01 | 0.01 | 0.01 | 0.01 |
| | $\Delta p_{i,t}$ | 3.17 | 0.00 | 0.01 | 0.42 | 0.43 | 0.43 | 0.41 | 0.05 | 0.05 | 0.05 | 0.05 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.12 | -0.30 | . | 5.89 | 1.87 | 1.30 | 4.49 | 0.66 | 2.65 | 0.37 | 1.58 |
| | $\Delta p_{i,t}$ | 3.01 | -1.70 | -3.20 | 0.27 | 0.69 | 1.22 | 1.58 | 8.29 | 2.22 | -1.89 | -0.83 |
| **Soybeans 2 (T=699)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.20 | 0.00 | 0.00 | 0.46 | -0.04 | -0.05 | 0.02 | -0.12 | -0.33 | -0.04 | 0.01 |
| | $\Delta p_{i,t}$ | 3.27 | -0.01 | -0.02 | -0.08 | -0.32 | 0.32 | -0.06 | -0.59 | -0.35 | -0.28 | -0.23 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.35 | 0.00 | 0.00 | 0.04 | 0.04 | 0.03 | 0.02 | 0.01 | 0.01 | 0.02 | 0.01 |
| | $\Delta p_{i,t}$ | 3.00 | 0.01 | 0.01 | 0.22 | 0.23 | 0.16 | 0.11 | 0.04 | 0.05 | 0.09 | 0.08 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.57 | 0.10 | . | 12.02 | -0.99 | -1.66 | 1.17 | -17.26 | -36.43 | -2.47 | 1.04 |
| | $\Delta p_{i,t}$ | 1.09 | -1.21 | -1.98 | -0.38 | -1.36 | 1.97 | -0.57 | -15.50 | -6.96 | -3.14 | -3.02 |
| **Sugar (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.31 | 0.12 | 0.06 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -3.47 | -0.01 | -0.03 | 0.67 | 0.64 | 0.35 | 0.22 | 0.32 | -0.11 | 0.07 | 0.02 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.83 | 0.00 | 0.01 | 0.46 | 0.48 | 0.48 | 0.46 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.79 | 0.69 | . | 10.34 | 3.97 | 2.09 | 6.76 | 1.59 | -0.21 | 1.54 | -1.10 |
| | $\Delta p_{i,t}$ | -4.20 | -4.34 | -5.29 | 1.47 | 1.35 | 0.74 | 0.47 | 10.52 | -3.35 | 2.25 | 0.59 |

*P=100*lnCPI, Pi=100*lnPi* ; △ denotes first differences.

Table 4. (Continued)

| | | *const.* | *trend* | $p_{i,t-1} - p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Tallow (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.30 | 0.12 | 0.07 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -2.72 | -0.01 | -0.07 | 1.69 | 0.01 | 1.39 | 1.12 | 0.23 | -0.09 | 0.10 | -0.08 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.60 | 0.00 | 0.01 | 0.44 | 0.46 | 0.46 | 0.45 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.81 | 0.69 | . | 10.32 | 3.92 | 2.21 | 6.71 | 1.44 | 0.18 | 0.96 | -0.82 |
| | $\Delta p_{i,t}$ | -4.52 | -7.29 | -7.79 | 3.84 | 0.02 | 3.02 | 2.49 | 7.83 | -2.87 | 3.37 | -2.64 |
| **Tin (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.30 | 0.12 | 0.07 | 0.20 | 0.01 | 0.00 | 0.01 | -0.01 |
| | $\Delta p_{i,t}$ | 1.38 | 0.00 | -0.01 | -0.30 | 0.38 | 0.74 | -0.31 | 0.23 | -0.02 | 0.07 | 0.00 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.59 | 0.00 | 0.00 | 0.28 | 0.29 | 0.29 | 0.28 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.76 | 0.70 | . | 10.23 | 4.04 | 2.19 | 6.98 | 3.03 | 0.35 | 2.66 | -2.84 |
| | $\Delta p_{i,t}$ | 2.34 | 0.19 | -2.62 | -1.07 | 1.33 | 2.58 | -1.11 | 7.65 | -0.63 | 2.11 | 0.03 |
| **Wheat (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.31 | 0.13 | 0.06 | 0.20 | 0.00 | 0.00 | 0.01 | 0.00 |
| | $\Delta p_{i,t}$ | 7.18 | 0.00 | -0.03 | 0.47 | 0.59 | -0.09 | 0.61 | 0.26 | -0.10 | 0.01 | 0.02 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 1.64 | 0.00 | 0.01 | 0.33 | 0.34 | 0.34 | 0.33 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.76 | 0.71 | . | 10.63 | 4.07 | 1.92 | 6.81 | 0.67 | -0.93 | 3.06 | -1.63 |
| | $\Delta p_{i,t}$ | 4.38 | -4.12 | -4.50 | 1.44 | 1.74 | -0.25 | 1.84 | 8.74 | -3.30 | 0.47 | 0.63 |
| **Wool (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.30 | 0.12 | 0.07 | 0.20 | 0.00 | 0.01 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 3.87 | 0.00 | -0.02 | 0.54 | -0.14 | 0.11 | -0.09 | 0.50 | -0.05 | 0.04 | 0.05 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.95 | 0.00 | 0.00 | 0.22 | 0.23 | 0.23 | 0.22 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.74 | 0.79 | . | 10.29 | 3.77 | 2.15 | 6.80 | 0.92 | 2.27 | -0.42 | 0.06 |
| | $\Delta p_{i,t}$ | 4.09 | -3.91 | -4.06 | 2.38 | -0.60 | 0.47 | -0.39 | 16.49 | -1.35 | 1.20 | 1.66 |

*P=100*lnCPI, Pi=100*lnPi* ; △ denotes first differences.

Table 4. (Continued)

| | | *const.* | *trend* | $p_{i,t-1} - p_{t-1}$ | $\Delta p_{t-1}$ | $\Delta p_{t-2}$ | $\Delta p_{t-3}$ | $\Delta p_{t-4}$ | $\Delta p_{i,t-1}$ | $\Delta p_{i,t-2}$ | $\Delta p_{i,t-3}$ | $\Delta p_{i,t-4}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Zinc (T=1116)** | | | | | | | | | | | | |
| Estimate: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.06 | 0.00 | 0.00 | 0.31 | 0.12 | 0.07 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | -1.70 | 0.00 | -0.02 | 0.39 | 0.08 | -0.16 | 0.26 | 0.46 | -0.09 | 0.04 | 0.01 |
| Standard Error: | | | | | | | | | | | | |
| | $\Delta p_t$ | 0.03 | 0.00 | 0.00 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 |
| | $\Delta p_{i,t}$ | 0.52 | 0.00 | 0.01 | 0.25 | 0.26 | 0.26 | 0.25 | 0.03 | 0.03 | 0.03 | 0.03 |
| t-statistic: | | | | | | | | | | | | |
| | $\Delta p_t$ | 1.78 | 0.66 | . | 10.36 | 3.94 | 2.20 | 6.82 | 1.25 | 0.42 | 0.37 | -0.35 |
| | $\Delta p_{i,t}$ | -3.29 | -0.68 | -4.09 | 1.57 | 0.31 | -0.64 | 1.06 | 15.03 | -2.63 | 1.09 | 0.22 |

Note: 1. Coffee: some missing data is deleted, (Jan. 1913-Dec. 2005). 2. Soybeans 1: U.S. Farm Price, (Jan. 1913 - Sept. 1947). 3. Soybeans 2: No. 2 Yellow, Chicago (Oct. 1947 - Dec. 1956); No. 1 Yellow,Chicago (Jan. 1957 - Mar. 1982); No. 1 Yellow, Central Illinois (Apr. 1982 - Dec. 2005).

## Impulse Response Functions

Figures 3 through 7 display the impulse response functions to a unit shock based on the estimated baseline model. It contains the impulse response functions for 36 individual commodities (Figures 3 through 6) and 25th percentile, median and 75th percentile responses among these commodities (Figure 7). Not surprisingly, we see that in all 36 cases the impulse response functions of CPI and commodity price converge to a common level following a unit shock. This reflects the cointegrating relationship between CPI and commodity price. The length of time of convergence, however, varies largely across commodities, ranging from twenty months to over ten years.

Turning to the details of individual shocks now, we look at the responses to a permanent (inflation) shock. In general, CPI rises monotonically to the new equilibrium level following a permanent shock. The pattern of transition is relatively flat. The impulse response functions of commodity prices have quite heterogeneous paths. Most commodities overshoot the new level: rising more than CPI initially and then declining to the long-run level along the transition path. A few commodity price series move closely with CPI or converge to CPI from below at all horizons.

Also of interest is how commodity prices respond to a temporary (commodity) shock. It can be seen from Figure 3 that almost all commodity prices have hump-shaped responses to the transitory shock. That is, in response to a transitory shock, commodity prices rise sharply, reach their peaks and then drop back monotonically to the long-run level. In most cases, the response functions to a transitory shock lie above the functions for a permanent shock for many months. This result illustrates that temporary shock plays a relatively important role in commodity price movements. With regard to CPI, we find that CPI does not contemporaneously respond to the temporary shock, reflecting the orthogonalization assumption imposed in the model. However, after the first month, we do observe very slight hump-shaped response functions of CPI. Generally, the rise in CPI is not statistically significant and in some cases the responses are even negative in the first several months.

Among the 36 commodity price series, one anomaly is found. In Figure 6, we see that there exist dramatic oscillations in the impulse response function of cocoa. The price fluctuations last a very long period and then die out gradually. The oscillations are probably due to the seasonal effect in the monthly observations. To verify this argument, we re-estimate the baseline model by employing annual observations. We find that dramatic oscillations disappear after the seasonal effect is controlled; this can be seen in the third panel of Figure 10. The resulting impulse response function still displays slight fluctuations in the first 3 years, but it becomes smooth later.

### Half Life

Figure 8 presents the half-lives of commodity prices to a transitory shock. The half-life is the length of time until the impulse response of a unit shock is half of its initial magnitude. It provides a scalar measure of the persistence of a shock. Figure 8 indicates that the range of half-lives is very wide, ranging from a low of 4.19 (apples) to 78.1 (pepper) months. Typically, tranisory shocks to commodity prices are short-lived; 20 of the 37 commodity price shocks have half-lives of less than 24 months and 31 out of 37 have half-life less than 48 months (see Table 5). The 25th percentile, median and 75th percentile are 18.62, 23.90, and 35.89 months, respectively.

Figure 3: Impulse Response Functions (I)

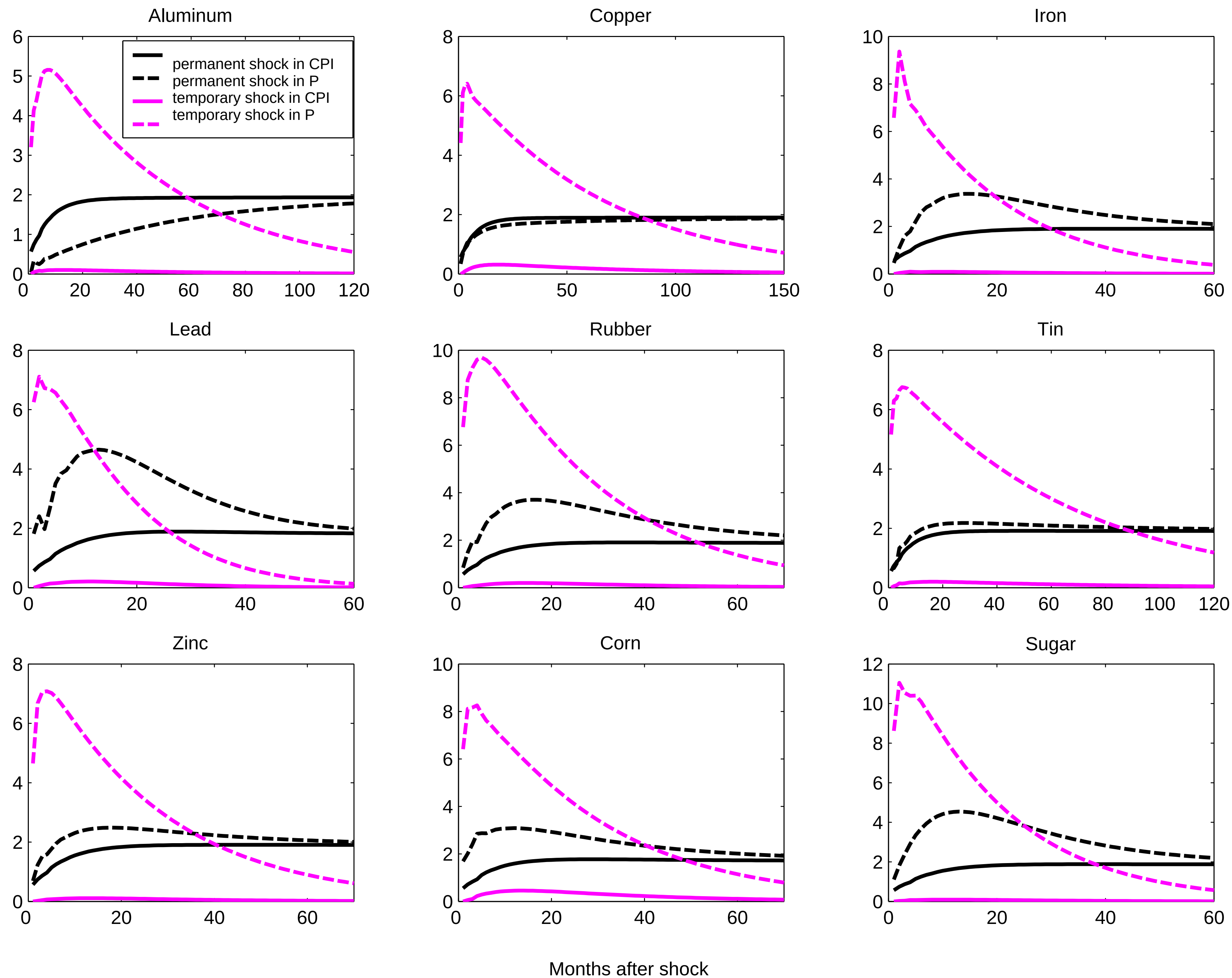


Figure 4: Impulse Response Functions (II)

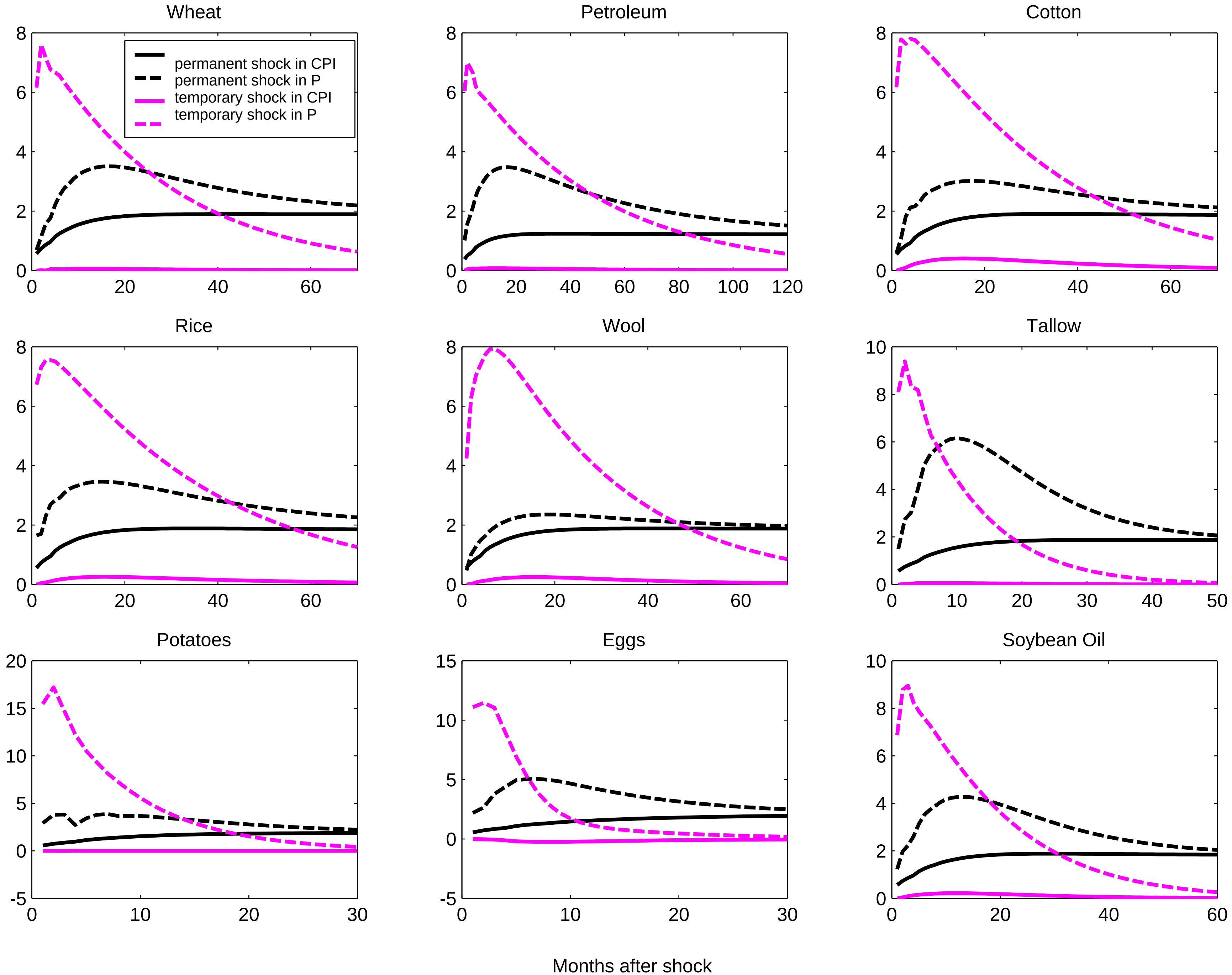


Figure 5: Impulse Response Functions (III)

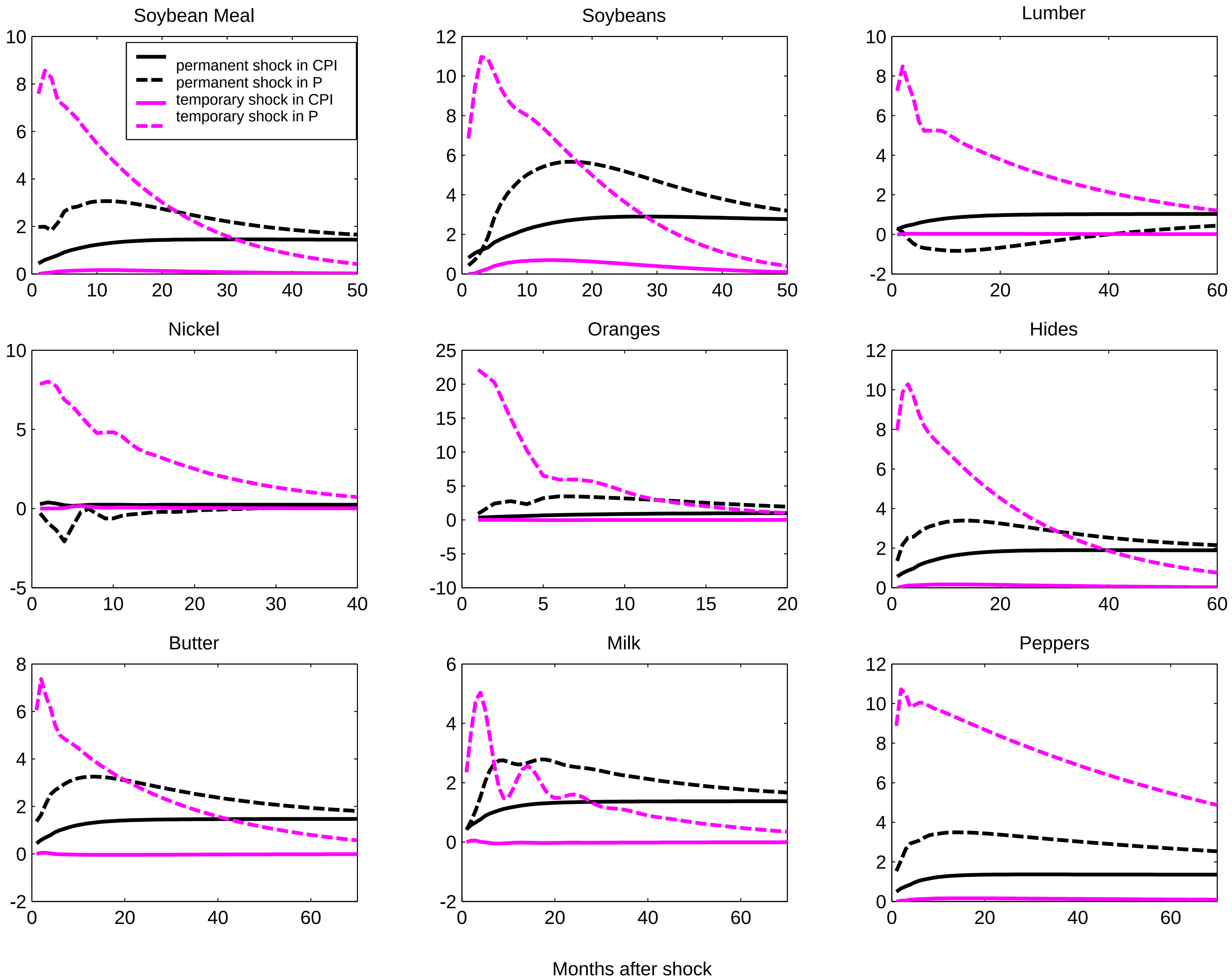


Figure 6: Impulse Response Functions (IV)

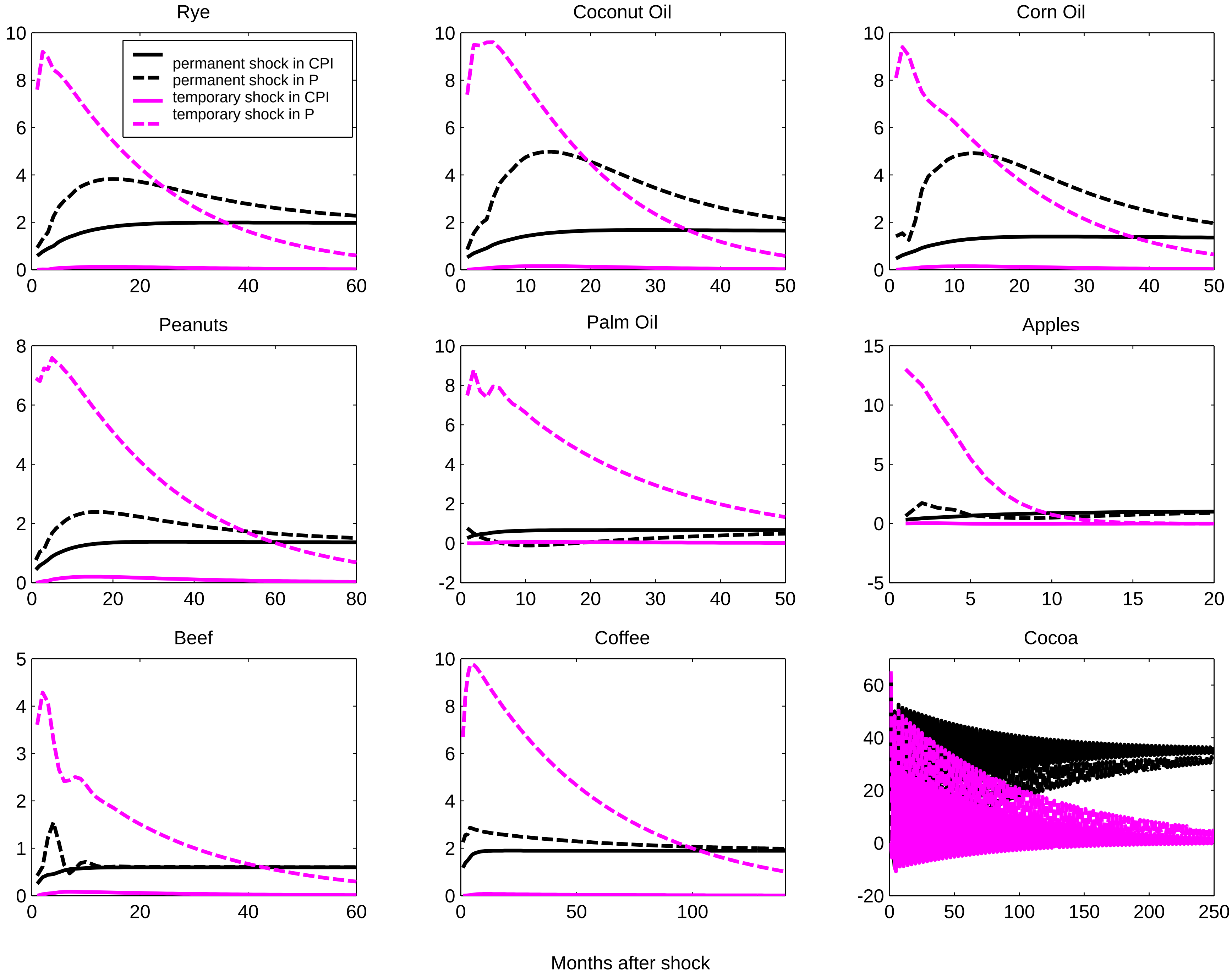


Figure 7: Impulse Response Functions (V)

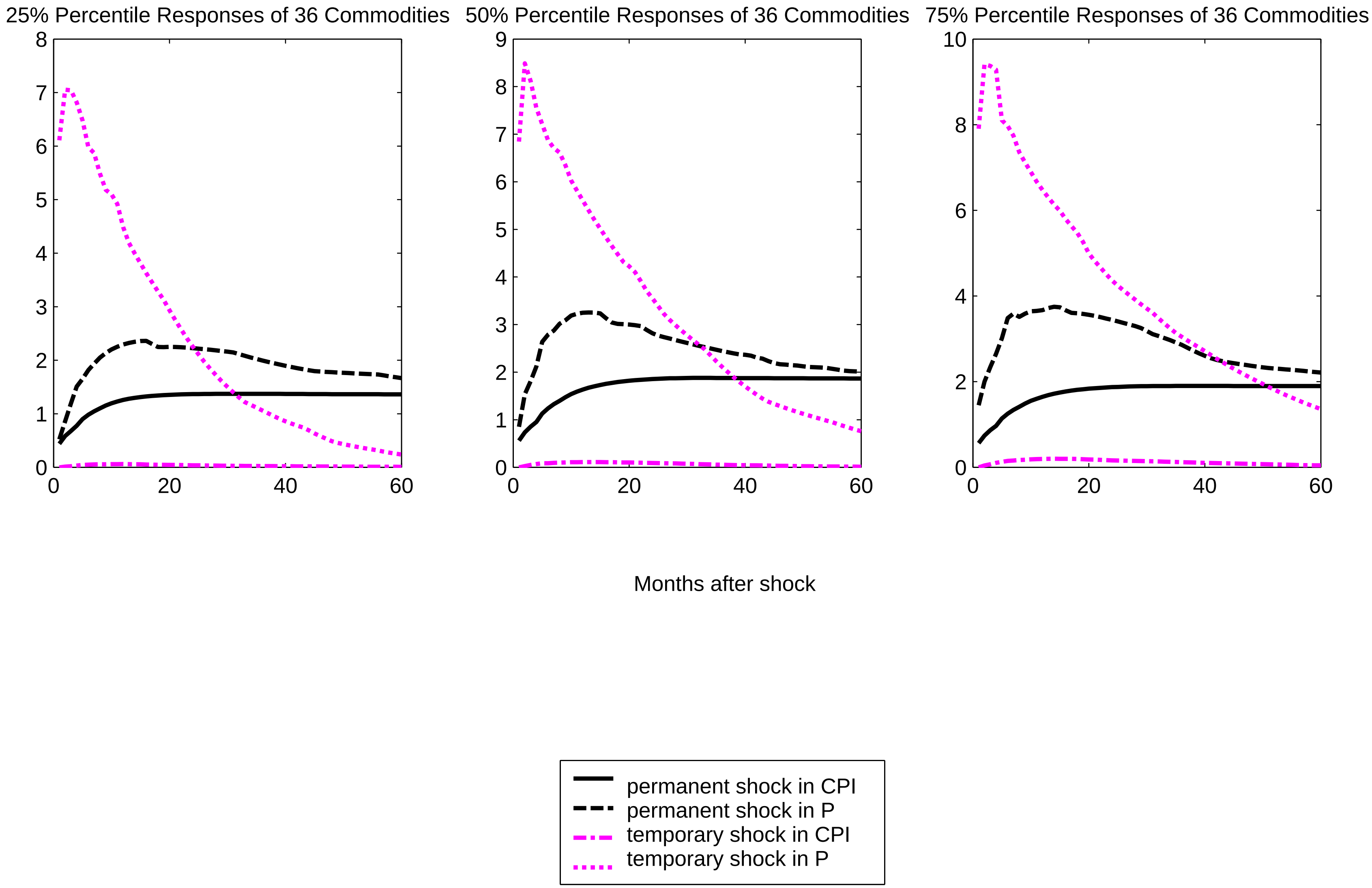
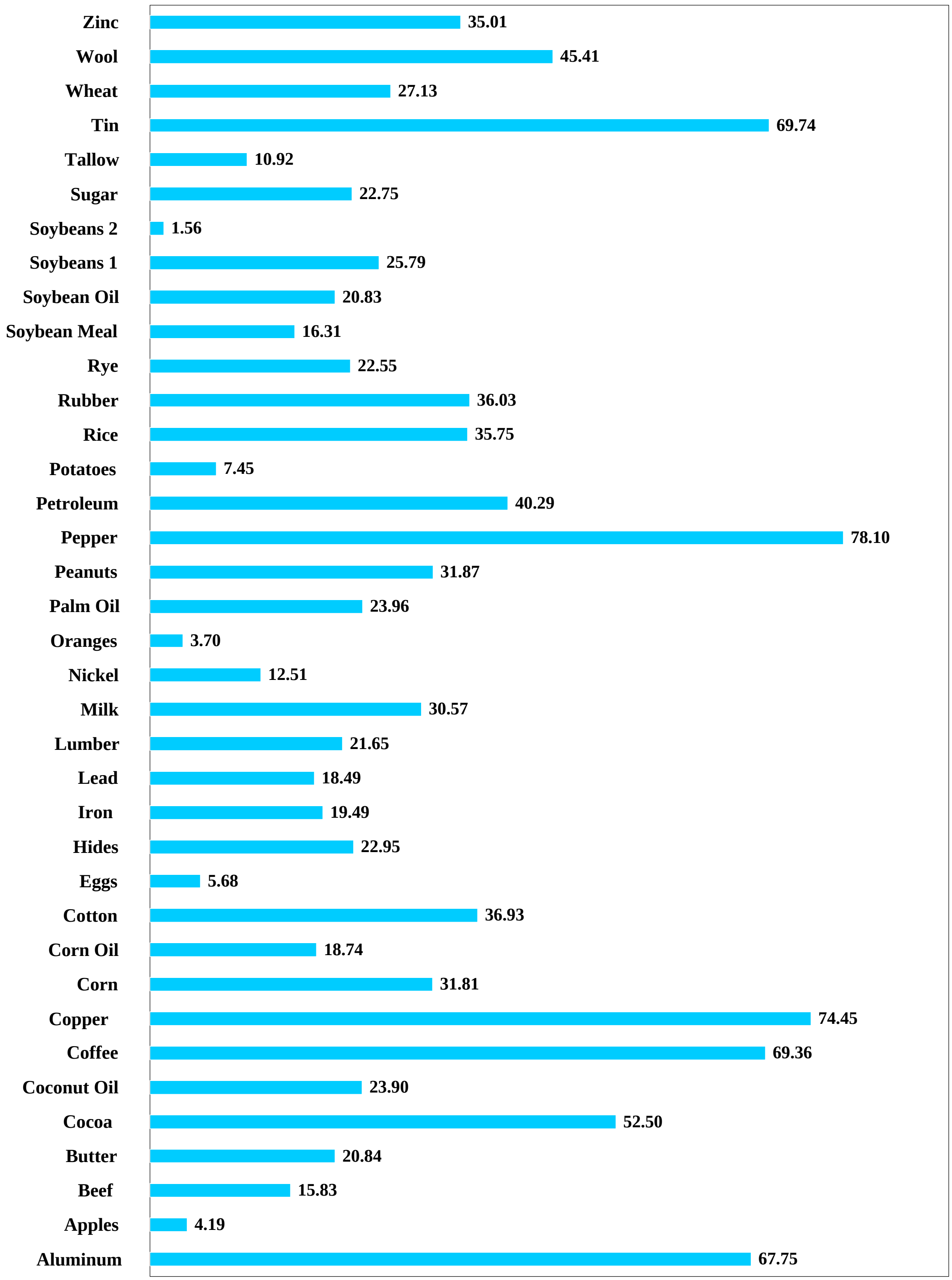


Figure 8.  Half-Life of a Unit Temporary Shock in Commodity Prices (Months)



## Decomposition of Variance

To provide a formal measure of the relative importance of the permanent and transitory disturbances, we turn to the variance decomposition of price level inflation and commodity price inflation. We employ a strategy similar to Cochrane (1994) to orthogonalize the error terms. Namely, Choleski decompose the variance-covariance matrix of the residual in the estimated equations and transform the original error terms to new error terms. The new errors $v_t$ can be expressed as: $v_t = R^{-1}\epsilon_t$ and $E(v_t v_t^{'}) = I$ where $R$ is the triangular matrix from the Choleski decomposition and $\epsilon_t$ is the original errors.

Table 6 shows the results of the variance decomposition. The transitory shocks have no impact on inflation at horizon 1; this reflects our orthogonalization assumption. Inflation is affected by transitory shocks after horizon 1, but the influence is tiny. Only about 1 percent of the variation of the inflation can be attributed to transitory commodity price disturbances.

Our main interest in this paper concerns the importance of permanent and transitory shocks for individual commodity price movements. From Table 6, we find that temporary disturbances play a dominant role in commodity price variation: they account for an estimated 90-99 percent of the variance of commodity price inflation. Almost all of the variance of commodity price inflation in our panel is due to transitory shocks. One exception is cocoa; only about 60 percent of the cocoa price variation are accounted for by temporary shocks. These results, again, emphasize the importance of transitory components in commodity price, in contrast to the large literature suggesting near unit root behavior of commodity prices.

Table 5. Persistence of Transitory Shocks in Commodity Prices: Half- Life

| Less Than 1 Year | 1- 2 Years | 2- 3 Years | 3- 4 Years | 4- 6 Years | More Than 6 Years |
|---|---|---|---|---|---|
| Apples | Beef | Corn | Cotton | Aluminum | Copper |
| Eggs | Butter | Milk | Petroleum | Cocoa | Pepper |
| Oranges | Coconut Oil | Peanuts | Rubber | Coffee | |
| Potatoes | Corn Oil | Rice | Wool | Tin | |
| Soybeans 2 | Hides | Soybeans 1 | | | |
| Tallow | Iron | Wheat | | | |
| | Lead | Zinc | | | |
| | Lumber | | | | |
| | Nickel | | | | |
| | Palm Oil | | | | |
| | Rye | | | | |
| | Soybean Meal | | | | |
| | Soybean Oil | | | | |
| | Sugar | | | | |
| 6 goods | 14 goods | 7 goods | 4 goods | 4 goods | 2 goods |

Table 6. CPI and Commodity Price Variance Decompositions

| Variance of | | $\triangle P$ | | $\triangle Pi$ | |
|---|---|---|---|---|---|
| | | | *Due to* | | |
| | Horizon | Permanent shock | Temporary shock | Permanent shock | Temporary shock |
| Aluminum | | | | | |
| | 1 | 100.00 | 0.00 | 0.01 | 99.99 |
| | 12 | 99.36 | 0.64 | 0.93 | 99.07 |
| | 24 | 99.36 | 0.64 | 0.99 | 99.01 |
| | 300 | 99.34 | 0.66 | 1.08 | 98.92 |
| Apples | | | | | |
| | 1 | 100.00 | 0.00 | 0.24 | 99.76 |
| | 12 | 99.22 | 0.79 | 1.06 | 98.94 |
| | 24 | 99.20 | 0.80 | 1.07 | 98.93 |
| | 300 | 99.20 | 0.80 | 1.07 | 98.93 |
| Beef | | | | | |
| | 1 | 100.00 | 0.00 | 1.34 | 98.66 |
| | 12 | 98.24 | 1.76 | 7.33 | 92.67 |
| | 24 | 98.18 | 1.82 | 7.31 | 92.69 |
| | 300 | 98.13 | 1.87 | 7.29 | 92.71 |
| Butter | | | | | |
| | 1 | 100.00 | 0.00 | 4.85 | 95.15 |
| | 12 | 98.62 | 1.38 | 5.67 | 94.33 |
| | 24 | 98.63 | 1.37 | 5.67 | 94.33 |
| | 300 | 98.62 | 1.38 | 5.73 | 94.27 |
| Cocoa | | | | | |
| | 1 | 100.00 | 0.00 | 0.59 | 99.41 |
| | 12 | 52.67 | 47.33 | 37.38 | 62.62 |
| | 24 | 49.29 | 50.71 | 39.80 | 60.20 |
| | 300 | 46.54 | 53.46 | 41.85 | 58.15 |
| Coconut Oil | | | | | |
| | 1 | 100.00 | 0.00 | 1.31 | 98.69 |
| | 12 | 99.25 | 0.75 | 4.62 | 95.38 |
| | 24 | 99.21 | 0.79 | 4.67 | 95.33 |
| | 300 | 99.12 | 0.88 | 4.90 | 95.10 |
| Coffee | | | | | |
| | 1 | 100.00 | 0.00 | 10.19 | 89.81 |
| | 12 | 99.95 | 0.05 | 9.75 | 90.25 |
| | 24 | 99.95 | 0.05 | 9.71 | 90.29 |
| | 300 | 99.95 | 0.05 | 9.64 | 90.36 |
| Copper | | | | | |
| | 1 | 100.00 | 0.00 | 0.59 | 99.41 |
| | 12 | 97.76 | 2.24 | 1.40 | 98.60 |
| | 24 | 97.76 | 2.24 | 1.41 | 98.59 |
| | 300 | 97.62 | 2.38 | 1.40 | 98.60 |
| Corn | | | | | |
| | 1 | 100.00 | 0.00 | 6.48 | 93.52 |
| | 12 | 93.55 | 6.45 | 6.95 | 93.05 |
| | 24 | 93.47 | 6.53 | 6.91 | 93.09 |
| | 300 | 92.98 | 7.02 | 6.90 | 93.10 |
| Corn Oil | | | | | |
| | 1 | 100.00 | 0.00 | 2.95 | 97.05 |
| | 12 | 98.93 | 1.07 | 6.68 | 93.32 |
| | 24 | 98.88 | 1.12 | 6.75 | 93.25 |
| | 300 | 98.79 | 1.21 | 6.95 | 93.05 |

Table 6. (Continued)

| Variance of | | $\triangle P$ | | $\triangle Pi$ | |
|---|---|---|---|---|---|
| | | *Due to* | | | |
| | Horizon | Permanent shock | Temporary shock | Permanent shock | Temporary shock |
| Cotton | | | | | |
| | 1 | 100.00 | 0.00 | 0.85 | 99.15 |
| | 12 | 95.94 | 4.06 | 3.13 | 96.87 |
| | 24 | 95.93 | 4.07 | 3.11 | 96.89 |
| | 300 | 95.52 | 4.48 | 3.13 | 96.87 |
| Eggs | | | | | |
| | 1 | 100.00 | 0.00 | 3.77 | 96.23 |
| | 12 | 97.00 | 3.00 | 4.90 | 95.10 |
| | 24 | 96.75 | 3.25 | 5.02 | 94.98 |
| | 300 | 96.71 | 3.29 | 5.04 | 94.96 |
| Hides | | | | | |
| | 1 | 100.00 | 0.00 | 2.82 | 97.18 |
| | 12 | 98.50 | 1.50 | 3.83 | 96.17 |
| | 24 | 98.49 | 1.51 | 3.81 | 96.19 |
| | 300 | 98.42 | 1.58 | 3.83 | 96.17 |
| Iron | | | | | |
| | 1 | 100.00 | 0.00 | 0.50 | 99.50 |
| | 12 | 99.30 | 0.70 | 2.39 | 97.61 |
| | 24 | 99.29 | 0.71 | 2.39 | 97.61 |
| | 300 | 99.28 | 0.72 | 2.44 | 97.56 |
| Lead | | | | | |
| | 1 | 100.00 | 0.00 | 7.78 | 92.22 |
| | 12 | 98.32 | 1.68 | 11.52 | 88.48 |
| | 24 | 98.25 | 1.75 | 11.52 | 88.48 |
| | 300 | 98.12 | 1.88 | 11.71 | 88.29 |
| Lumber | | | | | |
| | 1 | 100.00 | 0.00 | 0.18 | 99.82 |
| | 12 | 99.60 | 0.40 | 0.59 | 99.41 |
| | 24 | 99.60 | 0.40 | 0.61 | 99.39 |
| | 300 | 99.60 | 0.40 | 0.66 | 99.34 |
| Milk | | | | | |
| | 1 | 100.00 | 0.00 | 2.97 | 97.03 |
| | 12 | 97.91 | 2.09 | 8.39 | 91.61 |
| | 24 | 97.89 | 2.11 | 8.30 | 91.70 |
| | 300 | 97.89 | 2.11 | 8.41 | 91.59 |
| Nickel | | | | | |
| | 1 | 100.00 | 0.00 | 0.15 | 99.85 |
| | 12 | 87.81 | 12.19 | 4.66 | 95.34 |
| | 24 | 87.72 | 12.28 | 4.65 | 95.35 |
| | 300 | 87.70 | 12.30 | 4.64 | 95.36 |
| Oranges | | | | | |
| | 1 | 100.00 | 0.00 | 0.17 | 99.83 |
| | 12 | 99.73 | 0.27 | 0.77 | 99.23 |
| | 24 | 99.71 | 0.29 | 0.79 | 99.21 |
| | 300 | 99.71 | 0.29 | 0.80 | 99.21 |
| Palm Oil | | | | | |
| | 1 | 100.00 | 0.00 | 1.03 | 98.97 |
| | 12 | 98.73 | 1.27 | 1.20 | 98.80 |
| | 24 | 98.70 | 1.30 | 1.20 | 98.80 |
| | 300 | 98.65 | 1.35 | 1.20 | 98.80 |

Table 6. (Continued)

| Variance of | | $\triangle P$ | | $\triangle Pi$ | |
|---|---|---|---|---|---|
| | | *Due to* | | | |
| | Horizon | Permanent shock | Temporary shock | Permanent shock | Temporary shock |
| Peanuts | | | | | |
| | 1 | 100.00 | 0.00 | 1.22 | 98.78 |
| | 12 | 98.19 | 1.81 | 1.83 | 98.17 |
| | 24 | 98.17 | 1.83 | 1.82 | 98.18 |
| | 300 | 98.00 | 2.00 | 1.83 | 98.17 |
| Pepper | | | | | |
| | 1 | 100.00 | 0.00 | 2.90 | 97.10 |
| | 12 | 98.70 | 1.30 | 3.61 | 96.39 |
| | 24 | 98.70 | 1.30 | 3.60 | 96.40 |
| | 300 | 98.66 | 1.34 | 3.61 | 96.39 |
| Petroleum | | | | | |
| | 1 | 100.00 | 0.00 | 2.75 | 97.25 |
| | 12 | 98.78 | 1.22 | 4.44 | 95.56 |
| | 24 | 98.79 | 1.21 | 4.44 | 95.56 |
| | 300 | 98.76 | 1.24 | 4.52 | 95.48 |
| Potatoes | | | | | |
| | 1 | 100.00 | 0.00 | 3.43 | 96.57 |
| | 12 | 99.81 | 0.19 | 4.07 | 95.93 |
| | 24 | 99.81 | 0.19 | 4.09 | 95.91 |
| | 300 | 99.81 | 0.19 | 4.09 | 95.91 |
| Rice | | | | | |
| | 1 | 100.00 | 0.00 | 5.68 | 94.32 |
| | 12 | 98.36 | 1.64 | 6.77 | 93.23 |
| | 24 | 98.36 | 1.64 | 6.74 | 93.26 |
| | 300 | 98.20 | 1.80 | 6.75 | 93.25 |
| Rubber | | | | | |
| | 1 | 100.00 | 0.00 | 1.52 | 98.48 |
| | 12 | 99.01 | 0.99 | 3.44 | 96.56 |
| | 24 | 99.00 | 1.00 | 3.42 | 96.58 |
| | 300 | 98.89 | 1.11 | 3.47 | 96.53 |
| Rye | | | | | |
| | 1 | 100.00 | 0.00 | 1.46 | 98.54 |
| | 12 | 99.47 | 0.53 | 3.00 | 97.00 |
| | 24 | 99.46 | 0.54 | 2.99 | 97.01 |
| | 300 | 99.42 | 0.58 | 3.06 | 96.94 |
| Soybean Meal | | | | | |
| | 1 | 100.00 | 0.00 | 6.36 | 93.64 |
| | 12 | 98.50 | 1.50 | 6.68 | 93.32 |
| | 24 | 98.42 | 1.58 | 6.66 | 93.34 |
| | 300 | 98.31 | 1.69 | 6.69 | 93.31 |
| Soybeans 1 | | | | | |
| | 1 | 100.00 | 0.00 | 0.39 | 99.61 |
| | 12 | 93.52 | 6.48 | 5.03 | 94.97 |
| | 24 | 93.38 | 6.62 | 5.02 | 94.98 |
| | 300 | 92.61 | 7.39 | 5.26 | 94.74 |
| Soybeans 2 | | | | | |
| | 1 | 100.00 | 0.00 | 0.00 | 100.00 |
| | 12 | 25.47 | 74.53 | 0.56 | 99.44 |
| | 24 | 25.46 | 74.54 | 0.56 | 99.44 |
| | 300 | 25.43 | 74.57 | 0.57 | 99.43 |

Table 6. (Continued)

| Variance of | | $\triangle P$ | | $\triangle Pi$ | |
|---|---|---|---|---|---|
| | | | *Due to* | | |
| | Horizon | Permanent shock | Temporary shock | Permanent shock | Temporary shock |
| Soybean Oil | | | | | |
| | 1 | 100.00 | 0.00 | 3.09 | 96.91 |
| | 12 | 98.41 | 1.60 | 5.11 | 94.89 |
| | 24 | 98.33 | 1.67 | 5.12 | 94.88 |
| | 300 | 98.19 | 1.81 | 5.25 | 94.75 |
| Sugar | | | | | |
| | 1 | 100.00 | 0.00 | 1.62 | 98.38 |
| | 12 | 99.56 | 0.44 | 3.30 | 96.70 |
| | 24 | 99.55 | 0.45 | 3.30 | 96.70 |
| | 300 | 99.53 | 0.47 | 3.40 | 96.60 |
| Tallow | | | | | |
| | 1 | 100.00 | 0.00 | 3.27 | 96.73 |
| | 12 | 99.74 | 0.26 | 7.99 | 92.01 |
| | 24 | 99.72 | 0.28 | 8.34 | 91.66 |
| | 300 | 99.72 | 0.28 | 8.56 | 91.44 |
| Tin | | | | | |
| | 1 | 100.00 | 0.00 | 1.66 | 98.34 |
| | 12 | 98.14 | 1.86 | 2.79 | 97.21 |
| | 24 | 98.16 | 1.84 | 2.80 | 97.20 |
| | 300 | 98.11 | 1.89 | 2.79 | 97.22 |
| Wheat | | | | | |
| | 1 | 100.00 | 0.00 | 1.23 | 98.77 |
| | 12 | 99.44 | 0.56 | 3.22 | 96.78 |
| | 24 | 99.45 | 0.55 | 3.21 | 96.79 |
| | 300 | 99.44 | 0.56 | 3.28 | 96.72 |
| Wool | | | | | |
| | 1 | 100.00 | 0.00 | 1.23 | 98.77 |
| | 12 | 98.43 | 1.57 | 3.01 | 96.99 |
| | 24 | 98.41 | 1.59 | 2.96 | 97.04 |
| | 300 | 98.24 | 1.76 | 2.92 | 97.08 |
| Zinc | | | | | |
| | 1 | 100.00 | 0.00 | 2.17 | 97.83 |
| | 12 | 99.61 | 0.39 | 3.55 | 96.45 |
| | 24 | 99.60 | 0.40 | 3.51 | 96.49 |
| | 300 | 99.57 | 0.43 | 3.49 | 96.51 |

Note: 1. Coffee: some missing data is deleted, (Jan. 1913-Dec. 2005). 2. Soybeans 1: U.S. Farm Price, (Jan. 1913 - Sept. 1947). 3. Soybeans 2: No. 2 Yellow, Chicago (Oct. 1947 - Dec. 1956); No. 1 Yellow, Chicago (Jan. 1957 - Mar. 1982);No. 1 Yellow, Central Illinois (Apr. 1982 - Dec. 2005).

### Robustness

To check the robustness of the results, a variety of specifications are examined. We include or exclude some lagged terms of overall inflation and commodity price in the alternative models. We find that the estimates, impulse response functions and variance decomposition are not sensitive to these variations. Longer lags just add wiggles to the short end of the impulse response functions and the basic shape of the response functions remain the same. In the specifications where seasonal dummies are added, we also find similar results, suggesting the findings are robust.[4] Moreover, even if annual observations are used, the impulse response functions still capture the main features of the model. Figures 9 through 10 present the impulse response functions for the annual commodity price. The cointegrating relationship is still sound, although the hump-shaped responses disappear in most cases. This is because the low-frequency data is less able to capture the detail of short-run dynamics.

## Conclusion

This chapter employs a bivariate cointegration model of commodity price and CPI inflation to examine price dynamics. By combining commodity prices with inflation trends, we decompose commodity prices into permanent and transitory shocks to gauge their relative importance. We find that much of the movement in commodity prices are transitory, in contrast to the large literature suggesting near unit root behavior. Specifically, our variance decomposition results show that the temporary commodity disturbances play a dominant role in their price volatility. Almost all 36 commodities in our panel have a

[4] These results are available upon request.

Figure 9: Impulse Response Functions (VI)

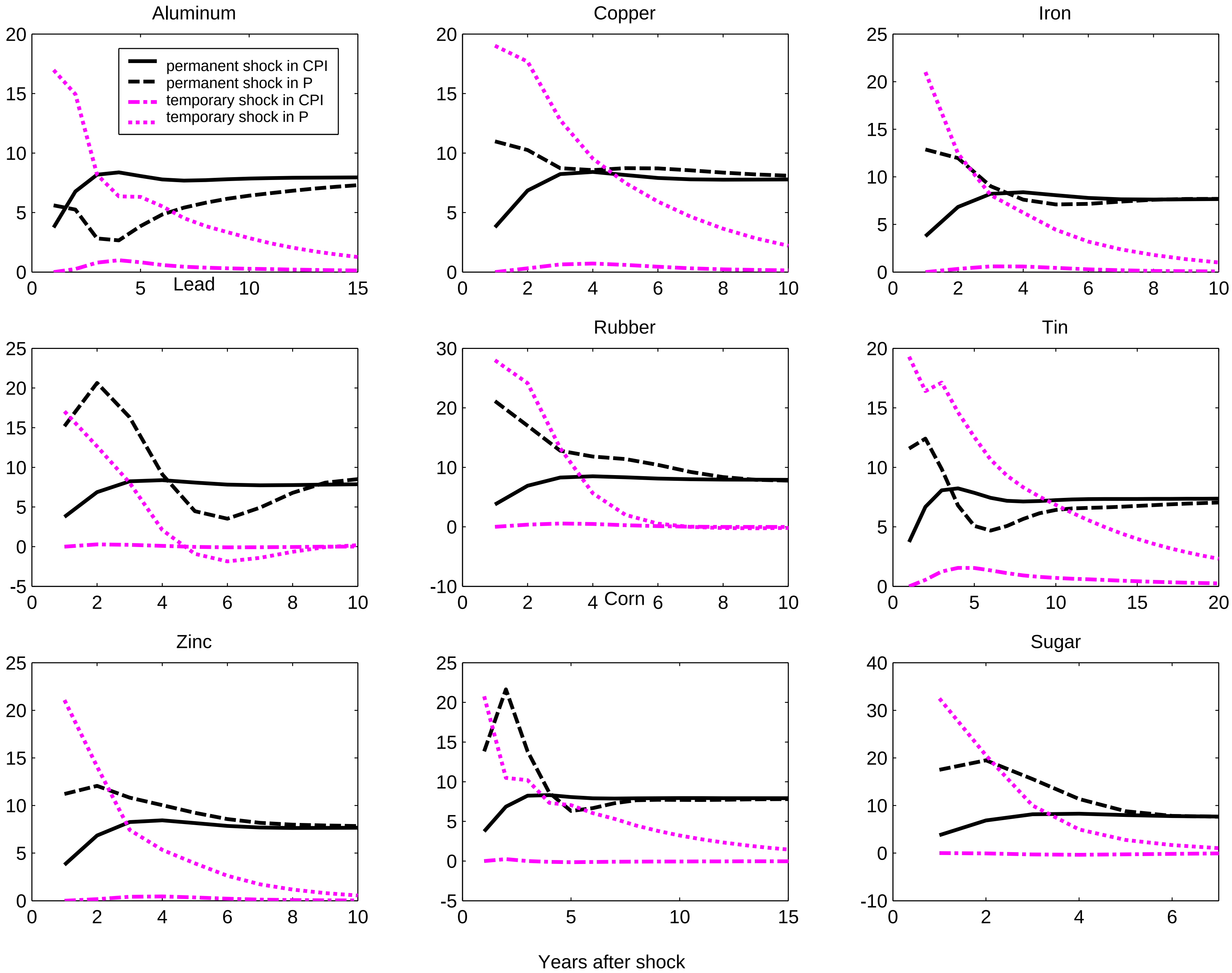
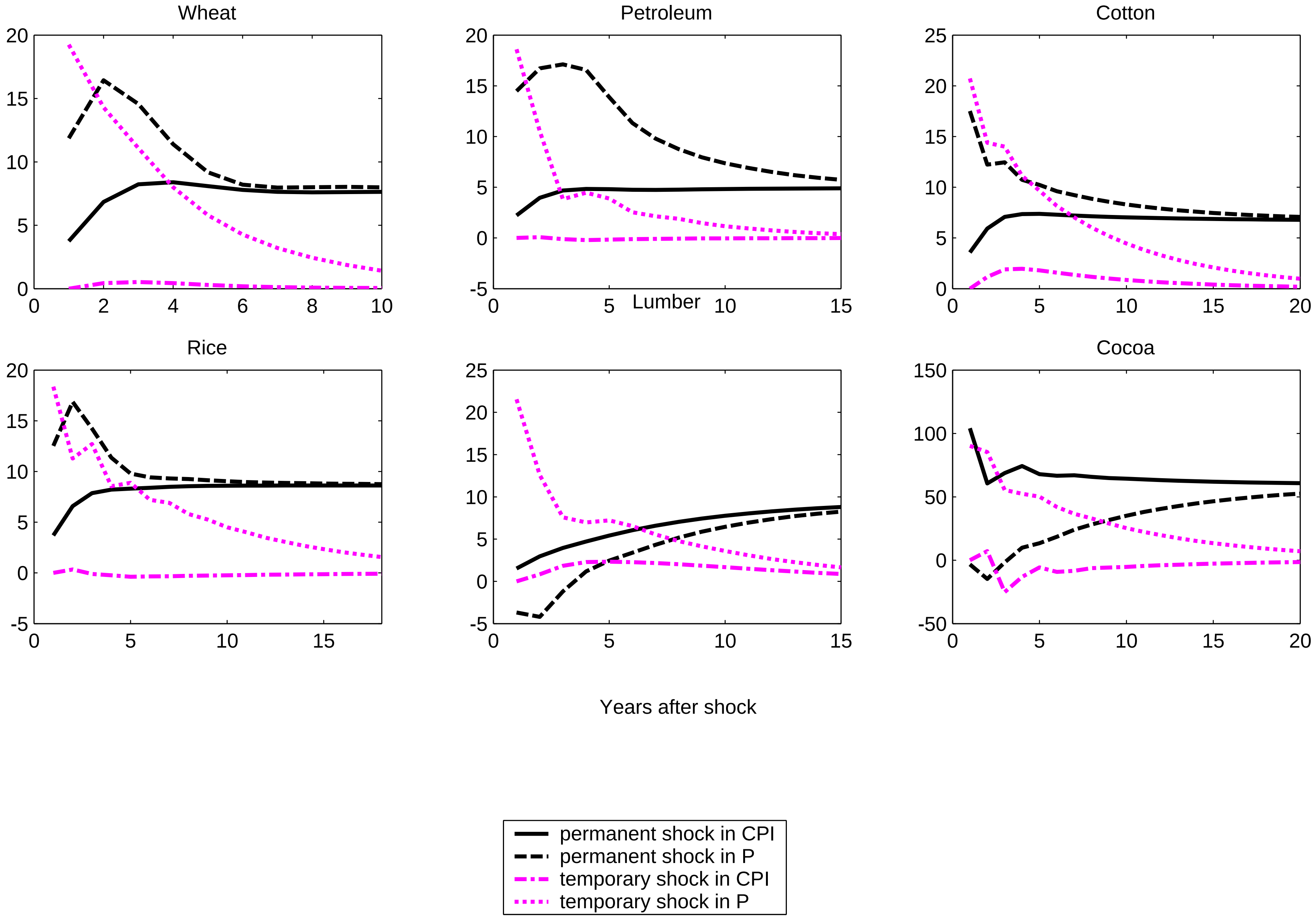


Figure 10: Impulse Response Functions (VII)



transitory component accounting for 90-99 percent of the price variance. On the other hand, the permanent components play the dominant role in the variation of inflation; only about 2% of the variation of the inflation can be attributed to transitory disturbances. In addition, we find that the persistence of transitory shocks varies greatly across commodities but most of them are short-lived.

A large literature has studied the role of commodity prices as leading indicators of inflation (Cody and Mills 1991, Garner 1995, Kugler 1991). These studies show that commodity prices were relatively good leading indicators of overall inflation during the 1970s and early 1980s. However, the performance of commodity prices as indicators was poor after the early 1980s. The results of this paper might also provide some insights for this issue, though we study commodity price in a much more disaggregated level. Commodity prices respond quickly to both permanent and transitory shocks. Most variation in commodity price, however, is due to transitory (commodity) shocks. Although transitory shocks are subsequently passed through to CPI, we find that the effects on overall price level are not statistically significant in many goods. Therefore, the observed link between commodity price and inflation would be quite different, depending on the type of shocks. Changes in commodity prices are not very informative in forecasting inflation, unless one can identify the underlying disturbances.

Primary goods are well known to be important inputs used in the manufacturing industry and their prices therefore affect production costs and general price level in industrial countries. Developing countries produce a large fraction of these primary commodities; thus, the commodity price dynamics might have implications for North-South business cycles. The current study documents the stylized facts of commodity prices. Future extension, which we are beginning to pursue, is to build a structural model of commodity markets and capture these features in commodity data.

CHAPTER III

# COMMODITY PRICE DYNAMICS: A THREE-COUNTRY STOCHASTIC DYNAMIC GENERAL EQUILIBRIUM ANALYSIS

## Introduction

Because the frequent and wide fluctuations of commodity markets not only cause commodity exporting developing countries to face a substantial impact on their national income but also cause wild swings in production costs in developed economies, commodity price dynamics have received considerable attention among policymakers and in the popular press. Due to the importance of commodity prices, their time series properties have been extensively examined in the literature. The most thoroughly documented features are that commodity relative prices are extremely volatile and highly persistent (for example, Bidarkota and Crucini 2000).

While these features are widely agreed upon, they are viewed as puzzling from the viewpoint of most existing themes. Some macroeconomists view the exogenous changes in the demand for primary goods as the major source of fluctuations in relative commodity prices (for example, Chu and Morrison 1984, Borensztein and Reinhart 1994).[1] Others emphasize the role of commodity inventories in intertemporal price dependence and attribute the fluctuations of commodity prices to supply shocks (Newbery and Stiglitz 1982, Williams and Wright 1991, Deaton and Laroque 1992, 1996). Although focusing on different aspects, none of them can fully explain the high volatility and persistence observed in the data.

[1] They emphasize that commodity price fluctuations are driven by derived demand for primary commodity inputs from industrialized countries. The presumption in this literature is that common changes in derived demand for primary inputs increase the prices of all commodity prices as world demand slides along a fixed inelastic commodity supply curve.

This chapter focuses specifically on the analysis of the determination of commodity price dynamics through the lens of a stochastic dynamic general equilibrium model. We share with both branches of the literature an interest in how dynamic behavior on the part of rational maximizing agents shapes the time series properties of commodity prices. We argue that the time series correlations of commodity relative prices and production levels are consistent with an important quantitative role for both demand and supply shifts in international commodity markets. Once this is recognized it becomes obvious that a general equilibrium framework is needed to develop a more complete understanding of these markets.

The primary goal of this chapter is threefold. First, we integrate both supply and (derived) demand channels into an international framework and examine the determination of commodity price movements in an international real business cycle model. An attractive feature of the general equilibrium setup is that commodity prices and quantities are determined endogenously, providing a structural setting in which to investigate supply and (derived) demand channels and their relative importance. With the aid of impulse response functions, we show that both supply and demand shocks play important roles in price movements. Yet, demand shocks can generate larger price responses than do supply shocks.

The second goal of this chapter is to evaluate whether an otherwise standard international real business cycle model incorporating commodity markets can account for the observed volatility and persistence of commodity prices when calibrated to the international covariance of productivity shocks. We investigate the extent to which shocks can account for the dynamics of commodity prices and find that our model can generate volatile and highly persistent commodity relative prices. The third goal of this chapter, which can be viewed as an additional check of the model's performance, is to confront the model with macro-data. Since our model belongs to the class of dynamic stochastic general equilibrium models advanced by Kydland and Prescott (1982), one important criterion for assessing the model performance is to compare the model predictions for the business cycle behavior of a set of macroeconomic aggregates. We find that the model is capable of explaining certain key qualitative features of international business cycles between industrial and developing countries while missing others.

The structure of our model follows the international business cycle literature closely. Backus and Crucini (2000) model two manufacturing regions and an oil-producing sector and focus on oil prices and the terms of trade. Kouparitsas (1997) studies the business cycle propagation between developed Northern economies and developing Southern economies in a two-country model. For the purpose of this chapter, we do not intend to explain all of the business cycle facts, the focus here is on the mechanisms affecting commodity price dynamics. Our model is motivated by the central features of international commodity markets: a very large fraction of world commodity exports are produced by a group of small developing countries and a few developed countries import a considerable fraction of primary goods.[2] In terms of these features, we model commodity price dynamics in an environment in which the developing South exports primary commodities to the industrial North in exchange for imports of manufactured products. More specifically, we introduce two primary exporting Southern countries: one produces a non-oil primary good and the other produces oil. These two raw materials are then used as intermediate inputs in both Northern and Southern economies.[3] Under this asymmetric trade structure, the North uses a sizable fraction of Southern primary goods as inputs in its manufactured production and

[2]As a group, developing countries account for more than 50% of world commodity exports.

[3]The production side of the model follows Kim and Loungani (1992) and Rotemberg and Woodford (1996), who have oil entering in firm's production function.

the South consumes manufactured/capital goods from the North.

Low elasticities of commodity demand, together with low short-run elasticities of supply for primary goods result in large short-run movements in world market prices. To account for the observed commodity price volatility, we need large variability in total primary commodity output because quantities and prices are linked by efficiency considerations in input choices by agents. To accomplish this we allow little opportunity to substitute oil and non-oil primary commodities technologically.[4] Otherwise, a change in the quantity of non-oil primary inputs would be compensated for by a change in oil inputs with little in the way of a relative commodity price change or aggregate primary commodity quantity fluctuation. Persistence of commodity prices in our setting can be naturally attributed to the features of basic neoclassical model: the persistence of derived demand for commodities and the role of capital accumulation.

The model explicitly examines the price movements of two primary goods (one commodity oil and the rest). A problem with the international real business cycle literature is that the details of commodity price dynamics are often left buried in some aggregate index. The aggregate price index such as terms of trade is usually unable to fully capture individual relative commodity price dynamics.[5] The micro-data and more careful presentation of the properties of individual prices and trade patterns may provide a more compelling story. The model, to some extent, moves in this direction.

In terms of the commodity price literature, there are a number of papers that have emphasized different channels through which shocks might affect commodity prices. One that merits special mention here is the competitive storage model of Deaton and Laroque

[4] We estimate the elasticity of substitution in production of oil and non-oil primary goods in the latter section. The finding indicates that the average elasticity of substitution is about 0.25 which is quite low.

[5] Empirical evidence shows that individual commodity prices exhibit quite different cyclical dynamics (see, for example, Chapter II of this dissertation). Trade patterns of individual developing economies are also known to be very heterogeneous.

(1992). In their paper, they model the harvest as an exogenous supply shock and model the behavior of rational profit-maximizing speculators who alter inventory levels to arbitrage prices changes across time. They show that supply shocks can explain the variability of commodity prices and arbitrage can generate some persistence, but less so than in the data.[6] In contrast to this literature, our paper focuses on an open economy setting and studies how dynamic behavior of rational maximizing agents influences commodity price determination. We examine the effects of productivity shocks in each of the model's three sectors: the manufacturing sector, the non-oil primary goods sector and the crude petroleum sector.

The organization of the chapter is as follows. We first review the stylized facts about commodity price dynamics and describe the characteristics of international commodity markets that motivate the structure of the model. In particular, a set of empirical features concerning North-South business cycles are documented. We then present the benchmark model and discuss the procedure of calibrating the key parameters. The section following presents the main results, including impulse responses and the business cycle moment predictions of the model. The last section concludes.

[6] Even introducing serially correlated supply shocks, they still under-estimate relative price persistence (see, Deaton and Laroque 1996, Chambers and Bailey 1996).

## Facts about International Commodity Markets

### Data

In contrast to Chapter II, we study commodity market dynamics using annual price and production data of 36 individual commodities. We use annual data primarily because most commodity quantity data is not available at higher frequencies. Most commodity prices have been collected for the period 1913 to 2005, while commodity production data is mainly from 1970 to 2005. The principal source of the commodity price data (in U.S. dollar per physical unit) is Commodity Research Bureau's "The CRB Commodity Yearbook 2006". Quantity data (world total production) is taken from three different sources: "The CRB Commodity Yearbook 2006", the Food and Agricultural Organization of the United Nations, and "Commodity Trade and Price Trends" (World Bank publication). We study North-South business cycles for a broad set of countries using annual national income and product account data from 1970 to 2005. Our measure of output is real gross domestic product, consumption is real private consumption expenditure and investment is real gross private capital formation. These series are from the World Development Indicators (WDI) database. More detailed data description is given in the Data Appendix.

### Commodity Market Dynamics

Previous research has extensively studied the dynamics of primary commodity markets. Four prominent facts have been highlighted in the literature (see, for example, Bidarkota and Crucini 2000, Bleaney and Greenaway 1993, Cuddington and Urzua 1989, Deaton and Miller 1996, Reinhart and Wickham 1994 and others). First, commodity relative prices exhibit enormous volatility, comparable to asset price variation. Second, commodity relative prices are highly persistent.[7] Third, commodity relative prices are subject to dramatic increases or price spikes. Fourth, commodity production variability is higher than manufacturing output variability, but lower than relative commodity price variability. The statistical evidence from our dataset is also consistent with these facts.

Figure 11 is typical of the behavior of commodity price series. It plots the U.S. dollar price of wheat along with the U.S. CPI monthly index from 1913 to 2005. Nominal wheat price swings are enormous relative to the movement in the CPI measure of the price level. Wheat prices are highly persistent. In addition, there are several sharp peaks in Figure 11. For example, the real price of wheat was about twice as high in 1973 as it was in 1972.

In Table 7, we report the volatility and persistence of price and quantity series for 35 individual commodities. For comparability with some of the existing literature (for example, Deaton and Laroque 1992), we report the descriptive statistics using log-levels.

The second and sixth columns of Table 7 shows the coefficient of variation for commodity relative prices and commodity relative quantities (relative quantities defined as the physical level of commodity production divided by U.S. real GDP). We see, first of all, large differences in volatility of relative commodity prices across goods, ranging from 1.18 for rubber to 0.21 for apples. In general, most commodity price series exhibit great volatility; the cross-sectional average of coefficient of variation for relative commodity prices is 0.53. Comparing column 6 and column 2, we see that the coefficient of variation for relative quantities is consistently much lower than that of relative prices; their respective cross-sectional average coefficients of variation are 0.18 and 0.53. Thus, models which

[7] There is an ongoing debate about the stationarity of commodity prices. For example, Cuddington and Urzua (1989) argue that the relative commodity prices are difference stationary. Yet, Deaton and Laroque (1992) claim that the prices are stationary in levels but highly persistent. Chapter II reports some evidence supporting the cointegrating relationship between commodity prices and CPI consistent with DL view.

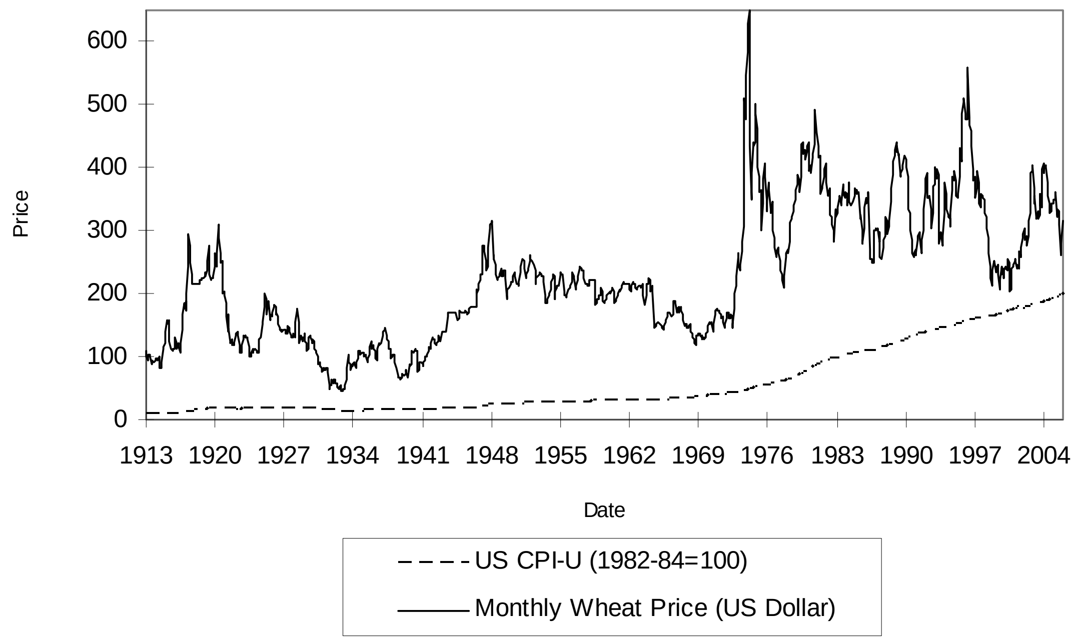



Figure 11. Monthly Wheat Prices and US CPI, Jan. 1913 - Dec. 2005

Table 7. Facts about Commodity Relative Prices and Quantities

| | Price | | | | Quantity | | | |
|---|---|---|---|---|---|---|---|---|
| | cv | a-c 1 | a-c 2 | a-c 4 | cv | a-c 1 | a-c 2 | a-c 4 |
| Aluminum | 0.73 | 0.87 | 0.67 | 0.61 | 0.06 | 0.73 | 0.47 | 0.29 |
| Apples | 0.21 | 0.58 | 0.47 | 0.48 | 0.19 | 0.74 | 0.61 | 0.45 |
| Beef | 0.28 | 0.93 | 0.93 | 0.83 | 0.07 | 0.81 | 0.66 | 0.55 |
| Butter | 0.39 | 0.96 | 0.90 | 0.85 | 0.29 | 0.99 | 0.97 | 0.93 |
| Cocoa | 0.68 | 0.82 | 0.64 | 0.47 | 0.11 | 0.81 | 0.54 | 0.17 |
| Coconut Oil | 0.46 | 0.70 | 0.46 | 0.44 | 0.15 | 0.63 | 0.47 | 0.61 |
| Coffee | 0.56 | 0.84 | 0.71 | 0.48 | 0.45 | 0.85 | 0.91 | 0.81 |
| Copper | 0.39 | 0.85 | 0.64 | 0.42 | 0.10 | 0.93 | 0.85 | 0.74 |
| Corn | 0.51 | 0.88 | 0.73 | 0.53 | 0.11 | 0.60 | 0.59 | 0.48 |
| Corn Oil | 0.51 | 0.86 | 0.71 | 0.67 | 0.25 | 0.97 | 0.94 | 0.89 |
| Cotton | 0.45 | 0.89 | 0.76 | 0.71 | 0.15 | 0.79 | 0.69 | 0.66 |
| Eggs | 0.55 | 0.96 | 0.93 | 0.88 | 0.25 | 0.63 | 0.02 | -0.06 |
| Hides | 0.62 | 0.92 | 0.82 | 0.64 | 0.19 | 0.98 | 0.95 | 0.92 |
| Iron | 0.32 | 0.72 | 0.50 | 0.36 | 0.22 | 0.98 | 0.97 | 0.95 |
| Lead | 0.56 | 0.89 | 0.70 | 0.49 | 0.18 | 0.93 | 0.84 | 0.68 |
| Lumber | 0.29 | 0.77 | 0.54 | 0.44 | 0.21 | 0.98 | 0.96 | 0.93 |
| Milk | 0.25 | 0.95 | 0.90 | 0.80 | 0.26 | 0.99 | 0.98 | 0.97 |
| Oranges | 0.81 | 0.95 | 0.92 | 0.90 | 0.07 | 0.40 | 0.25 | 0.01 |
| Palm Oil | 0.46 | 0.86 | 0.67 | 0.61 | 0.47 | 1.00 | 0.99 | 0.99 |
| Peanuts | 0.35 | 0.92 | 0.88 | 0.79 | 0.12 | 0.66 | 0.49 | 0.64 |
| Pepper | 0.91 | 0.91 | 0.71 | 0.24 | 0.11 | 0.12 | 0.10 | 0.00 |
| Crude Oil | 0.55 | 0.90 | 0.76 | 0.55 | 0.23 | 0.99 | 0.98 | 0.94 |
| Potatoes | 0.54 | 0.79 | 0.68 | 0.70 | 0.17 | 0.89 | 0.82 | 0.79 |
| Rice | 0.47 | 0.88 | 0.73 | 0.60 | 0.10 | 0.92 | 0.88 | 0.77 |
| Rubber | 1.18 | 0.94 | 0.87 | 0.66 | 0.04 | 0.67 | 0.51 | 0.40 |
| Rye | 0.56 | 0.87 | 0.69 | 0.43 | 0.39 | 0.89 | 0.90 | 0.82 |
| Soybean Meal | 0.35 | 0.73 | 0.57 | 0.55 | 0.14 | 0.89 | 0.84 | 0.66 |
| Soybean Oil | 0.59 | 0.89 | 0.74 | 0.63 | 0.14 | 0.90 | 0.87 | 0.70 |
| Soybeans | 0.50 | 0.91 | 0.84 | 0.73 | 0.12 | 0.69 | 0.72 | 0.56 |
| Sugar | 0.69 | 0.79 | 0.66 | 0.60 | 0.11 | 0.91 | 0.80 | 0.81 |
| Tallow | 0.72 | 0.90 | 0.76 | 0.63 | 0.15 | 0.94 | 0.89 | 0.83 |
| Tin | 0.46 | 0.91 | 0.79 | 0.60 | 0.31 | 0.98 | 0.96 | 0.91 |
| Wheat | 0.53 | 0.93 | 0.84 | 0.68 | 0.14 | 0.88 | 0.88 | 0.79 |
| Wool | 0.57 | 0.90 | 0.80 | 0.70 | 0.30 | 0.99 | 0.98 | 0.97 |
| Zinc | 0.39 | 0.71 | 0.39 | 0.12 | 0.12 | 0.95 | 0.96 | 0.92 |
| Cross-good Average | 0.53 | 0.86 | 0.72 | 0.60 | 0.18 | 0.83 | 0.75 | 0.67 |

"cv" denotes the coefficient of variation; "a-c 1", "a-c 2" and "a-c 4" refer to first- , second- and fourth- order autocorrelations. Price statistics are based on annual relative commodity prices which are defined as nominal prices divided by U.S. CPI. Quantity statistics are based on annual relative commodity outputs which are defined as commodity outputs divided by U.S. real GDP.

predict comparable variability of quantities and prices of primary commodities relative to manufactured output are doomed to failure.

Figure 12 plots empirical distributions of commodity price and quantity variations using the coefficients of variation reported in Table 7. The density estimates are generated using a Gaussian kernel and the bandwidth is selected based on the method suggested by Silverman (1986). The density of commodity quantity variation is situated to the left of commodity price variation, indicating that commodity prices are systematically more volatile than commodity quantities. The density distribution of commodity price variation also exhibits large dispersion.

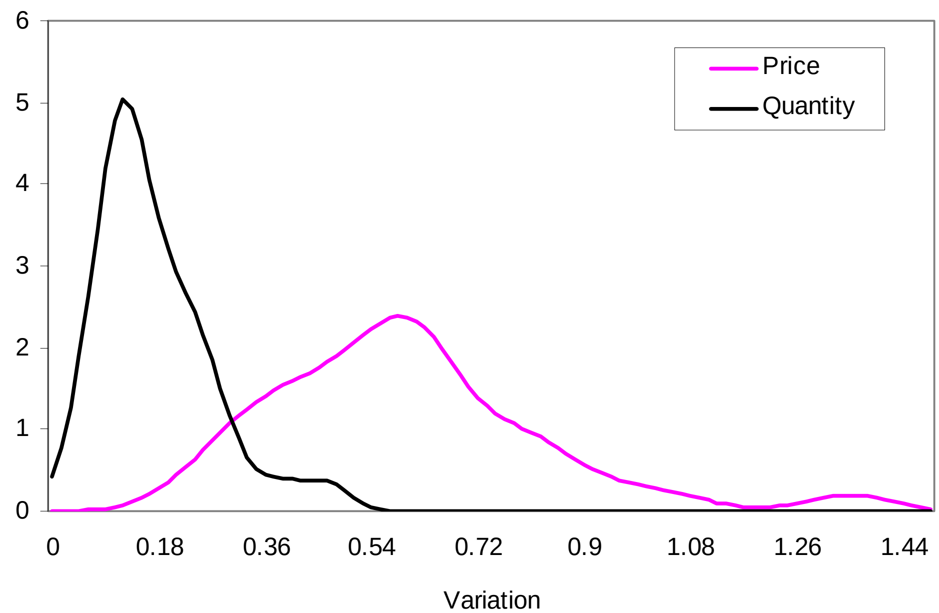



Figure 12. Empirical Distributions of Commodity Price and Quantity Variations

The remaining columns of Table 7 report the autocorrelation coefficients. Most of the first-order autocorrelation coefficients of relative commodity prices are close to 0.9;

the cross-sectional average is 0.86. The second- and fourth-order coefficients are lower, yet substantial. These statistics demonstrate the high persistence of commodity relative prices. The persistence of relative quantities is also very high; the cross-good average of fourth-order autocorrelation is still close to 0.7.

To anticipate some of the structure the equilibrium model will put on the data, we relate relative price and relative quantity variations of commodities by an Euler equation similar to that used in Backus, Kehoe, and Kydland (1995):

$$p_{it}/p_t = \varpi + \sigma_i(q_{it}/q_t) \tag{III.1}$$

where $p_{it}$ and $q_{it}$ are the price and quantity of commodity $i$, $p_t$ and $q_t$ are the CPI and real GDP, $\varpi$ is a constant, and $1/\sigma_i$ gives the elasticity of substitution between commodity $i$ and the final consumption basket. Thus $\sigma_i$ can be approximated by the volatility of the price ratio relative to the quantity ratio:

$$\hat{\sigma}_i \simeq \frac{\sigma_{p_i/p}}{\sigma_{q_i/q}} \tag{III.2}$$

$\sigma_{p_i/p}$ and $\sigma_{q_i/q}$ represent the standard deviations of relative price and relative quantity ratios, respectively. The results are presented in Table 8. All statistics here are based on the first difference of the log-levels.

Columns 2 through 3 present the standard deviations of commodity relative prices and quantities. Again, we see that commodity relative prices are more volatile than relative quantities. In addition, the cross-sectional correlation of the standard deviations of relative price and relative quantity is only 0.05 indicating a weak positive relation between a commodity's price and quantity variation. The fourth column of Table 8 reports the estimated elasticities of substitution between primary goods and consumer goods. The elasticities range from a low of 0.11 (crude oil) to a high of 2.30 (eggs). The cross-sectional average is 0.37 which is within the range of elasticities of 1 and 0.2 employed by Deaton and Laroque (1992) to simulate commodity price disturbances. These numbers suggest the demand for primary commodities is generally quite inelastic.

Since oil plays a particularly important role in the world economy and above estimates show the very low substitutability between oil and consumer goods, it is also instructive to examine the elasticity of substitution between oil and non-oil primary goods. Using the same method, we estimate the elasticity of substitution of oil and non-oil primary goods and report the results in the fifth column of Table 8. The elasticities of substitution are very low; most of these numbers are less than 0.3. On average, the elasticity of substitution between oil and individual non-oil primary goods is 0.26 compared to 0.37 for the elasticity of substitution between consumer goods and non-oil commodities. This suggests that firms have limited ability to substitute oil and non-oil primary commodities as relative price changes.

The last column of Table 8 presents the correlation between relative price growth rate and relative quantity growth rate. The correlations vary considerably across commodities; however, most commodities exhibit weak correlation between price and quantity changes. Some exceptions are cocoa and iron which have strong relations between the two. The cross-good average of correlation is only 0.04. These results suggest that it is hard to argue that either supply or demand shocks dominate as driving forces of commodity market fluctuations.

Another way to shed light on the relative importance of supply and demand shocks is to examine the common and idiosyncratic movements in relative prices. The presumption

Table 8. Facts about Growth Rates of Commodity Relative Prices and Quantities

| | Std. Dev. of | | Elasticity of Substitution between | | Correlation of |
|---|---|---|---|---|---|
| | $\Delta p$ | $\Delta q$ | Commodity and Consumer good | Commodity and Oil | $\Delta p$ and $\Delta q$ |
| Aluminum | 0.14 | 0.04 | 0.31 | 0.15 | 0.13 |
| Apples | 0.18 | 0.15 | 0.81 | 0.45 | 0.24 |
| Beef | 0.09 | 0.04 | 0.47 | 0.23 | -0.07 |
| Butter | 0.19 | 0.04 | 0.23 | 0.15 | 0.08 |
| Cocoa | 0.27 | 0.07 | 0.25 | 0.21 | -0.48 |
| Coconut Oil | 0.43 | 0.15 | 0.35 | 0.37 | 0.04 |
| Coffee | 0.32 | 0.12 | 0.38 | 0.30 | -0.40 |
| Copper | 0.18 | 0.03 | 0.19 | 0.15 | 0.09 |
| Corn | 0.18 | 0.10 | 0.52 | 0.37 | -0.10 |
| Corn Oil | 0.22 | 0.07 | 0.32 | 0.26 | -0.36 |
| Cotton | 0.20 | 0.09 | 0.46 | 0.31 | 0.21 |
| Eggs | 0.17 | 0.40 | 2.30 | 1.23 | -0.06 |
| Hides | 0.21 | 0.03 | 0.14 | 0.11 | -0.48 |
| Iron | 0.23 | 0.04 | 0.16 | 0.14 | 0.74 |
| Lead | 0.19 | 0.06 | 0.33 | 0.27 | -0.01 |
| Lumber | 0.20 | 0.04 | 0.20 | 0.12 | 0.38 |
| Milk | 0.09 | 0.03 | 0.31 | 0.15 | -0.04 |
| Oranges | 0.41 | 0.08 | 0.20 | 0.16 | 0.20 |
| Palm Oil | 0.26 | 0.04 | 0.17 | 0.16 | 0.13 |
| Peanuts | 0.22 | 0.08 | 0.38 | 0.27 | 0.39 |
| Pepper | 0.27 | 0.14 | 0.54 | 0.38 | -0.09 |
| Crude Oil | 0.26 | 0.03 | 0.11 | * | 0.18 |
| Potatoes | 0.22 | 0.08 | 0.35 | 0.27 | 0.12 |
| Rice | 0.22 | 0.04 | 0.17 | 0.16 | 0.12 |
| Rubber | 0.22 | 0.04 | 0.16 | 0.13 | 0.51 |
| Rye | 0.19 | 0.17 | 0.90 | 0.61 | 0.04 |
| Soybean Meal | 0.25 | 0.06 | 0.26 | 0.18 | 0.10 |
| Soybean Oil | 0.25 | 0.07 | 0.26 | 0.22 | -0.13 |
| Soybeans | 0.19 | 0.10 | 0.50 | 0.31 | 0.06 |
| Sugar | 0.38 | 0.05 | 0.13 | 0.16 | -0.20 |
| Tallow | 0.22 | 0.05 | 0.23 | 0.18 | -0.11 |
| Tin | 0.19 | 0.07 | 0.35 | 0.32 | 0.03 |
| Wheat | 0.20 | 0.06 | 0.30 | 0.22 | 0.07 |
| Wool | 0.31 | 0.05 | 0.16 | 0.13 | -0.20 |
| Zinc | 0.17 | 0.03 | 0.20 | 0.15 | 0.07 |
| Cross-good Average | 0.23 | 0.08 | 0.37 | 0.26 | 0.04 |

Relative commodity prices are defined as nominal commodity prices divided by U.S. CPI. Relative commodity productions are defined as commodity outputs divided by U.S. real GDP. All series are annual frequency and transformed to growth rates taking the first difference of log-levels.

in much of the literature is that common shocks are due to shifts in derived demand for primary inputs as world commodity demand slides along each of the fixed inelastic commodity supply curves. Supplies are arguably idiosyncratic, particularly for agriculture where yields depend on weather conditions. Under these assumptions, we identify the common shock as a world derived demand shock and the idiosyncratic shocks as commodity supply shocks.

Our first estimation strategy is to model each commodity price as a random walk with a common component:

$$\begin{aligned} \triangle\tilde{p}_{it} &= \alpha_i + \beta_i \triangle\tilde{p}_t + \xi_{it} \\ \triangle\tilde{p}_t &= \frac{1}{n}\sum_{i=1}^{n} \triangle\tilde{p}_{it} \end{aligned} \tag{III.3}$$

where $\triangle\tilde{p}_{it}$ is the first difference of the logarithm of the relative price for commodity $i$, $\triangle\tilde{p}_t$ is a common innovation affecting all commodity prices (defined in the second equation), and $\xi_{it}$ is the idiosyncratic shock to the relative price change. Here, we use cross-commodity average to capture the common stochastic trend in commodity prices. The variance of the price change of commodity $i$ can be expressed as:

$$\sigma^2_{\Delta\tilde{p}_i} = \beta_i^2 \sigma^2_{\Delta\tilde{p}} + \sigma^2_{\xi_i} \tag{III.4}$$

Second, we employ the Bayesian dynamic factor model advanced by Otrok and Whiteman (1998). Here, each commodity relative price is modeled as the sum of two unobserved factors: a common factor $f_t$ which accounts for all comovement among the commodity price changes, and an idiosyncratic factor $\varepsilon_{it}$ which captures commodity specific movements. The model can be written as:

$$\triangle\tilde{p}_{it} = a_i + b_i f_t + \varepsilon_{it} \tag{III.5}$$

where the coefficient $b_i$ is the factor loading reflecting the degree to which variation in $\triangle\tilde{p}_{it}$ can be explained by the common factor and $a_i$ is a constant term. We model idiosyncratic errors $\varepsilon_{it}$ as second-order autoregressions:

$$\begin{aligned} \varepsilon_{it} &= \phi_{i,1}\varepsilon_{it-1} + \phi_{i,2}\varepsilon_{it-2} + u_{it} \\ Eu_{it}u_{jt-s} &= \sigma_i^2 \; for \; i = j, s = 0; 0 \; otherwise. \end{aligned} \tag{III.6}$$

Following Otrok and Whiteman (1998), we estimate this model by Markov Chain Monte Carlo methods and compute variance decompositions for each commodity price.

Table 9 reports our findings. The results are almost identical across the two methods. In both cases, the commodity-specific component plays the dominant role, accounting for two-thirds of the variation for the typical commodity relative price. There are some differences across goods, with the idiosyncratic component ranging from a low of 37% (rubber) to a high of 93% (cocoa). The common factor is particularly important for iron and rubber, accounting for about 60% of the variance.

It is interesting to compare these results with the findings of Chapter II. Chapter II focuses on the permanent-transitory decomposition in the bivariate error correction model, while current section tends to evaluate the relative importance of common and commodity-specific components using two different methods. Chapter II shows that temporary disturbances play a dominant role in commodity price variability, accounting for an estimated 90-99 percent of the variance of commodity price inflation, independent of the forecast horizon. This section shows that the commodity-specific component tends to be larger than the common component. However, there is lots of heterogeneity across commodities, with copper, iron, rubber and wheat sharing a large common component and the relative price variations of cocoa, crude oil and zinc being mostly driven by commodity-specific factors.

Table 9. Variance Decomposition of Commodity Relative Price

| | Common Trend Model | | Dynamic Factor Model | | |
|---|---|---|---|---|---|
| | Common Component | Idyosyncratic Component | Common Component | Idyosyncratic Component | Standard Deviation |
| Aluminum | 0.28 | 0.72 | 0.28 | 0.72 | 0.05 |
| Cocoa | 0.07 | 0.93 | 0.20 | 0.80 | 0.05 |
| Coconut Oil | 0.41 | 0.59 | 0.33 | 0.67 | 0.06 |
| Copper | 0.53 | 0.47 | 0.45 | 0.55 | 0.08 |
| Corn | 0.37 | 0.63 | 0.38 | 0.62 | 0.06 |
| Cotton | 0.27 | 0.73 | 0.29 | 0.71 | 0.06 |
| Iron | 0.59 | 0.41 | 0.53 | 0.47 | 0.07 |
| Lead | 0.32 | 0.68 | 0.23 | 0.77 | 0.05 |
| PalmOil | 0.34 | 0.66 | 0.34 | 0.66 | 0.07 |
| Crude Oil | 0.11 | 0.89 | 0.06 | 0.94 | 0.03 |
| Rice | 0.26 | 0.74 | 0.24 | 0.76 | 0.05 |
| Rubber | 0.63 | 0.37 | 0.61 | 0.39 | 0.08 |
| Soybeans | 0.43 | 0.57 | 0.53 | 0.47 | 0.07 |
| Sugar | 0.26 | 0.74 | 0.21 | 0.79 | 0.06 |
| Tin | 0.44 | 0.56 | 0.44 | 0.56 | 0.07 |
| Wheat | 0.49 | 0.51 | 0.47 | 0.53 | 0.08 |
| Zinc | 0.18 | 0.82 | 0.15 | 0.85 | 0.04 |
| Average | 0.35 | 0.65 | 0.34 | 0.66 | 0.06 |

Sample period: 1977-2001.

## Some Characteristics of International Commodity Markets

Primary commodities are important traded goods in international markets; about 25% of world merchandise trade consists of primary commodities. Developing countries are the major suppliers of most such exports. Averaging over all goods within each category, lower and middle income economies account for more than 50% of world commodity exports.[8] Although the export compositions in individual developing countries vary greatly, many of these countries rely heavily on a few primary goods for the bulk of their export earnings. More than 70% of developing country exports come from primary commodities. In some developing economies, primary commodities are the most important exported products and one or two primary goods constitute almost all of exports. Bidarkota and Crucini

[8] The statistics are based on data from World Bank database.

(2000) provide a comprehensive study of the export concentration of developing countries at the commodity level and implications of export concentration for terms of trade volatility. They show that approximately one-sixth of developing countries in their dataset depend on one particular commodity for more than 50% of their export earnings.[9]

On the demand side of the international commodity market, industrial countries import a large amount of primary commodities; primary products account for about 25% of total imports of G7 countries.[10] Although developed countries are the major buyers of primary goods in international market, developing countries also demand a sizable fraction of world primary goods. About 18% of total imports of developing countries are raw materials.[11]

Raw materials are important for developed countries because they are key intermediate inputs used in manufactured production. To get a measure of this, we report the average factor shares for 18 major manufacturing industries, nondurable goods manufacturing, durable goods manufacturing and aggregate manufacturing of the U.S. economy in Table 10.[12] Factor shares are defined as factor costs divided by the value of production. All figures are averages for the years 1987-2005 and the data source is Bureau of Labor Statistics (BLS). There are five factor inputs in the BLS factor tables: capital (K), labor (L), energy (E), materials (M) and purchased business services (S), collectively the KLEMS inputs.[13] The data for intermediate inputs (energy, materials, and purchased business services) are obtained from Bureau of Economic Analysis's (BEA) annual input-output use tables.

[9]They investigate 66 lower or middle income economies and report the export share of the three most important primary good exports for these countries. In general, Coffee, petroleum and sugar are the most important goods exported.

[10]See Kose (2002) table 1 for detailed statistics.

[11]Again, see Kose (2002).

[12]These 18 industries are roughly corresponding to the 3-digit North American Industry Classification System (NAICS) level.

[13]Material input includes all commodity inputs exclusive of fuels but inclusive of fuel-type inputs used as raw materials in manufacturing.

Table 10. Average Factor Shares for U.S. Aggregate Manufacturing and Major Manufacturing Industries: 1987-2005

| Industry | 3-digit NAICS | (1) Capital | (2) Labor | (3) Energy | (4) Materials | (5) Purchased Services | (3)+(4)+(5) Intermediate |
|---|---|---|---|---|---|---|---|
| Food and Beverage and Tobacco Products | 311,312 | 0.14 | 0.15 | 0.02 | 0.48 | 0.21 | 0.71 |
| Textile Mills and Textile Product Mills | 313,314 | 0.08 | 0.27 | 0.03 | 0.51 | 0.11 | 0.65 |
| Apparel and Leather and Applied Products | 315,316 | 0.12 | 0.34 | 0.01 | 0.37 | 0.15 | 0.54 |
| Wood Products | 321 | 0.12 | 0.26 | 0.02 | 0.52 | 0.08 | 0.63 |
| Paper Products | 322 | 0.13 | 0.24 | 0.06 | 0.45 | 0.12 | 0.63 |
| Printing and Related Support Activities | 323 | 0.12 | 0.38 | 0.01 | 0.37 | 0.12 | 0.51 |
| Petroleum and Coal Products | 324 | 0.11 | 0.06 | 0.02 | 0.75 | 0.07 | 0.83 |
| Chemical Products | 325 | 0.23 | 0.20 | 0.03 | 0.32 | 0.23 | 0.58 |
| Plastics and Rubber Products | 326 | 0.15 | 0.26 | 0.02 | 0.43 | 0.13 | 0.59 |
| Nonmetallic Mineral Products | 327 | 0.19 | 0.33 | 0.06 | 0.27 | 0.15 | 0.48 |
| Primary Metal Products | 331 | 0.11 | 0.27 | 0.05 | 0.46 | 0.11 | 0.62 |
| Fabricated Metal Products | 332 | 0.15 | 0.35 | 0.02 | 0.34 | 0.14 | 0.50 |
| Machinery | 333 | 0.11 | 0.34 | 0.01 | 0.36 | 0.17 | 0.54 |
| Computer and Electronic Products | 334 | 0.07 | 0.35 | 0.01 | 0.26 | 0.30 | 0.58 |
| Electrical Equipment, Appliances, and Components | 335 | 0.20 | 0.31 | 0.01 | 0.35 | 0.14 | 0.50 |
| Transportation Equipment | 336 | 0.08 | 0.31 | 0.01 | 0.45 | 0.16 | 0.61 |
| Furniture and Related Products | 337 | 0.10 | 0.36 | 0.01 | 0.38 | 0.14 | 0.54 |
| Miscellaneous Manufacturing | 339 | 0.14 | 0.37 | 0.01 | 0.29 | 0.19 | 0.49 |
| NonDurables | 311-316, 322-326 | 0.18 | 0.23 | 0.03 | 0.36 | 0.20 | 0.59 |
| Durables | 321,327, 331-337,339 | 0.13 | 0.38 | 0.02 | 0.27 | 0.21 | 0.50 |
| Manufacturing Sector | 31-33 | 0.16 | 0.33 | 0.03 | 0.27 | 0.21 | 0.51 |

Source: Bureau of Labor Statistics. Factor share is defined as factor cost divided by the value of production.

Beginning with material inputs, we see that materials are crucial in manufactured production. At the disaggregate level, the raw materials get a big share in production cost; 13 out of 18 industries have material shares that are the largest among their cost shares. There are differences though: the material shares range from a low of 29% (the material share of Miscellaneous Manufacturing) to a high of 75% (the material share of Petroleum and Coal Products). The shares of purchased business service are also large, comparable to the capital shares in most industries. Approximately half of all 18 industries have service shares larger than 15%; specifically, the share ranges from 8% for wood products to 30% for computer and electronic products. Summing over material, energy and service shares, intermediate inputs account for more than 50% of total input cost in most industries. Furthermore, at a more aggregated level, raw materials remain important. Both nondurable and durable goods industries have substantial material shares. For manufacturing as a whole, materials, together with energy, account for 30% of total cost, which is just a little bit less than the labor share (33%). These large shares of intermediate inputs suggest that raw materials may have important implications for business cycles.

### North-South Business Cycles

The study of international real business cycles is a mature field; however, most existing literature focuses on analyzing business cycle transmission between industrial countries.[14] Only a few studies focus on the general equilibrium propagation of aggregate fluctuations between developed and developing nations, mainly because the data of developing countries is limited. Kouparitsas (1997) documents some empirical regularities about the North-South business cycle where the South is described as an aggregate of non-oil commod-

[14] See, for example, the survey by Crucini (2008).

ity exporting countries. For the purpose of current study, we consider the entire Southern region as two aggregates: one is an aggregate of non-oil primary good exporting developing countries and the other is an aggregate of oil exporting developing countries.

These distinctions allow us to study a richer set of business cycle transmission patterns as well as heterogeneity in the cross-section of commodity price and quantity behavior documented earlier. We select 57 lower or middle income primary good exporting countries for the first aggregate (hereafter, the non-oil South) from the World Bank WDI database.[15] Based on the data from Energy Information Administration, we choose 10 oil exporting developing countries for the second aggregate (hereafter, the oil South).[16] The North is an aggregate of 8 major industrial countries. A complete country list and the detail of aggregation is reported in the Data Appendix.

Tables 11 through 12 present the features of North-South business cycles. All statistics are based on Hodrick-Prescott filtered data.[17] Starting with the volatility, Table 11 shows that investment is uniformly much more volatile than aggregate output while consumption is uniformly smoother than output in both Northern and Southern regions. This ranking of variability of macroeconomic variables is consistent with the existing business cycle literature. Table 11 also shows that there is a clear ranking in volatility of macroeconomic aggregates across regions: the variables of the Northern countries are least volatile; that of oil exporting countries are most volatile; non-oil primary good exporting countries falls between these extremes.[18] The standard deviation of output for the North averages

[15] Since the data for developing countries is less reliable and the data coverage is often limited, we mainly focus on the market-based economies for the study.

[16] The top 15 world oil net exporters in 2006 (from the number 1 to the number 15) are: Saudi Arabia, Russia, Norway, Iran, United Arab Emirates, Venezuela, Kuwait, Nigeria, Algeria, Mexico, Libya, Iraq, Angola, Kazakhstan and Canada.

[17] For comparison purpose, we set the smooth coefficient 10 which is equal to that used by Kouparitsas (1997).

[18] One reason for this is that developing countries are small and more vulnerable to a variety of shocks.

1.53, lower than 2.00 for non-oil primary good exporting countries and 3.31 for oil exporting countries. Consumption volatility is also lower in the Northern countries, averaging 1.28 compared with 1.85 for non-oil and 3.4 for oil countries. The largest difference in variability can be seen in investment; the standard deviation of investment for the North, non-oil South and oil South are 4.41, 6.86 and 10.04, respectively. The difference in the volatility of the net export to GDP ratios is also substantial, averaging 0.42 for the North and 2.41 for the oil countries.

Table 11. Business Cycle Properties: Volatility

| | North | | South (non-oil) | | South (oil) | |
|---|---|---|---|---|---|---|
| | Std | Rel. Std | Std. | Rel. Std | Std. | Rel. Std |
| GDP | 1.53 | 1.00 | 2.00 | 1.00 | 3.31 | 1.00 |
| Consumption | 1.28 | 0.84 | 1.85 | 0.93 | 3.40 | 1.03 |
| Investment | 4.41 | 2.88 | 6.86 | 3.44 | 10.04 | 3.03 |
| Net Export/GDP | 0.42 | | 1.18 | | 2.41 | |

The statistics are based on H-P filtered data. Std denotes the percentage Standard Deviation from H-P Trend. Rel. Std denotes the standard deviation of variable relative to that of GDP. The sample period is 1980-2004. Except for the net export to GDP all variables are transformed to logarithms before filtering. Source: World Bank WDI.

Table 12 reports correlation statistics of aggregate variables across countries. The contemporaneous correlations of output across regions is not particularly strong, so we focus on the correlation of GDP in one region at period t with the other region at period t-1. We see that current GDP in the North is positively correlated with lagged GDP growth in the non-oil South, with a correlation coefficient 0.42. Lagged output growth in the oil region is associated with expansions in the North and non-oil South in the following period, with correlations of -0.55 and -0.39, respectively. The second panel of Table 12 presents the correlation between the North and non-oil South for three key aggregates: consumption, investment, and net export.[19] We see that the one-period lag correlations of all variables

[19]For the North and oil exporting pair and non-oil and oil exporting pair, we only report the correlation

are positive. The correlation of consumption is 0.12 and the correlation of investment is 0.3. This indicates that there exists an international comovement between industrial and non-oil primary good exporting developing countries. The contemporaneous correlations are less consistent; some are marginally negatively correlated. This suggests there may be a lag in propagation of business cycles across these three regions.[20]

Table 12. Business Cycle Properties: International Comovement

| Panel 1<br>GDP | (t, t-1) | (t, t) | (t, t+1) |
|---|---|---|---|
| (North, Nonoil) | 0.42 | 0.33 | -0.24 |
| (North, Oil) | -0.55 | 0.13 | 0.24 |
| (Nonoil, Oil) | -0.39 | -0.20 | -0.27 |
| **Panel 2**<br>**(North, Nonoil)** | **(t, t-1)** | **(t, t)** | **(t, t+1)** |
| Consumption | 0.12 | -0.12 | -0.39 |
| Investment | 0.30 | 0.45 | -0.02 |
| NE/GDP | 0.08 | -0.14 | -0.11 |

All statistics are based on logged and H-P filtered data. The sample period is 1980-2004. Comovement is measured by cross-region correlations.
Source: World Bank WDI.

In summary, empirical evidence shows that business cycles are more severe in the South than in the North and oil exporting countries have the most volatile statistics among them. The data also suggests that there exists asymmetric dynamic correlations across pairs of regions, the correlation is not maximized within the period. These central features shape our model structure.

## The Model

We develop a quantitative dynamic model of North-South trade which is similar, in terms of basic structure, to Long and Plosser (1983) and Kouparitsas (1997). Because the

coefficients for GDP because the data for other macroeconomic variables is limited.

[20]This also motivates the timing issue of production with primary goods in our model presented in the next section.

goal of this paper is not to seek to explain all quantitative features of North-South business cycles but to confront the observations in commodity markets, we adapt the traditional assumption in North-South trade literature that the North is completely specialized in the production of manufactured goods and the South is completely specialized in the production of primary goods. The main source of novelty here is that the South is classified into two groups: one exports non-oil primary commodity and the other sells oil. Both non-oil primary goods and oil are used in the production of manufactured goods. This feature allows us to investigate the price dynamics of both non-oil primary goods and oil.

## The Economic Environment

The world economy consists of three groups of countries. One group of developing countries specializes in the production of non-oil primary commodity. One group of developing countries specializes in the production of oil. The third group specializes in manufactured goods which serves as the consumption/investment good.

### Preferences

In each country $i$, there is a representative household who derives utility from consumption and leisure. Each household chooses consumption and leisure to maximize his expected lifetime utility, given by:

$$\begin{aligned} E_0 \sum_{t=0}^{\infty} \beta^t U(C_{i,t}, Z_{i,t}) &= E_0 \sum_{t=0}^{\infty} \beta^t \frac{(C_{i,t}^{\theta} Z_{i,t}^{1-\theta})^{1-\gamma}}{1-\gamma} \\ 0 &< \beta < 1, 0 < \theta < 1, \textit{for i=1,2,3} \end{aligned} \tag{III.7}$$

where $C$ is consumption of the final good, $Z$ is leisure, and $\beta$ denotes the subjective discount factor. $\gamma$ is the relative risk aversion parameter, $1/\gamma$ controls intertemporal substitution of consumption and leisure, and $\theta$ governs the fraction of time spent in work. The preferences over consumption and leisure are nonseparable.[21]

Technology

Every country specializes in the production of one good using three factor inputs: labor services $N$, physical capital $K$, and intermediate goods $M$. Country 1 and country 2 produce the non-oil primary good and oil, respectively. These two raw materials are generally used as inputs in producing intermediate goods which do not contribute to utility directly. The only final consumption or investment goods are manufactured goods produced by country 3. The production structure here is designed to capture the feature that both developed and developing countries import a sizeable fraction of primary goods and that raw materials, together with energy, are important in manufactured production. The production function is:

$$\begin{aligned} Y_{i,t+1} &= A_{i,t+1} N_{i,t+1}^{\alpha} [\omega K_{i,t+1}{}^{1-\frac{1}{\sigma}} + (1-\omega) M_{i,t}{}^{1-\frac{1}{\sigma}}]^{\frac{1-\alpha}{1-\frac{1}{\sigma}}} \qquad \text{(III.8)} \\ 0 &< \alpha < 1, \omega > 0, \textit{for i=1,2,3} \end{aligned}$$

The $i$ subscript indicates the country or good, $A$ is productivity and $\omega$ influences the relative importance of capital and materials as factor inputs. Capital and intermediate input are represented in CES form ($\sigma$ governs the elasticity of substitution between these two factors) and labor enters in Cobb-Douglas unitary-elasticity form with a labor income share $\alpha$.

As the time indices suggest, it takes one period to place materials into use; therefore, intermediate goods produced in the current period can only be used as inputs in the next period. Materials are also assumed to be perishable; therefore, any materials produced this period get fully used up in the production process next period.

[21] Separable preference over consumption and leisure may help generate more volatile relative prices (see, for example, Chari, Kehoe and McGrattan 2002), but for now we focus on the standard preference specification frequently employed in the business cycle literature.

Intermediate goods, $M$, are produced from non-oil and oil raw materials (primary good $Y_1$ and oil $Y_2$) according to an Armington aggregator:

$$M_t = (\omega_1 Y_{1,t}^{1-\frac{1}{\varepsilon}} + \omega_2 Y_{2,t}^{1-\frac{1}{\varepsilon}})^{\frac{1}{1-\frac{1}{\varepsilon}}} \tag{III.9}$$

In other words, the intermediate goods are an aggregate of two imperfectly substitutable raw materials with an elasticity of substitution $\varepsilon$.

### Investment

Capital is accumulated in the standard way:

$$K_{i,t+1} = (1-\delta)K_{i,t} + \phi(\frac{I_{i,t}}{K_{i,t}})K_{i,t}, \textit{for i=1,2,3} \tag{III.10}$$

where $\delta$ is the rate of depreciation and $\phi(\cdot)$ represents the adjustment cost function, with $\phi > 0, \phi^{'} > 0, \phi^{''} < 0$. $1/\phi^{'}$ is Tobin's Q, giving the number of units of current investment good that must be foregone to increase the capital stock by one unit. Physical capital formation is subject to adjustment costs which prevent excessive volatility of investment.

### Resource Constraints

Asset markets are assumed to be complete, therefore the model will be closed with the following constraints:

$$N_{i,t} = 1 - Z_{i,t}, \textit{for i=1,2,3} \tag{III.11}$$

$$Y_{3,t} = \pi_1(C_{1t} + I_{1t}) + \pi_2(C_{2t} + I_{2t}) + \pi_3(C_{3t} + I_{3t}) \tag{III.12}$$

$$M_t = \pi_1 M_{1,t} + \pi_2 M_{2,t} + \pi_3 M_{3,t}$$

where $\pi_i$ denotes the fraction of the world population residing in country $i$ and $M_i$ refers to the amount of intermediate goods $M$ used in country $i$ for production purposes. The total hours are normalized to unity and divided between leisure and work.

### Equilibrium and Numerical Solution Method

Since the baseline model is a complete markets model, we solve it by exploiting the equivalence between a competitive equilibrium and Pareto optima. The optimization problem we solve is:

$$E_0 \sum_{t=0}^{\infty} \beta^t \{\pi_1 U(C_{1t}, Z_{1t}) + \pi_2 U(C_{2t}, Z_{2t}) + \pi_3 U(C_{3t}, Z_{3t})\}$$

subject to the constraints (8)-(13). Because this problem has no analytical solution, we approximate the solution by log-linearizing the first-order necessary conditions around the deterministic steady state. The linearized dynamic equation system is then solved using the method advanced by King, Plosser and Rebelo (1988). This method is widely used in solving international real business cycle models with complete or incomplete markets and is shown to be quite accurate for these models. Details of the model solution are presented in the Technical Appendix.

## Calibration

Calibrating the model poses some challenges because the availability of developing countries data is limited. Generally, we select the parameter values roughly consistent with the long-run features of economic environments of representative developed and developing countries. We also stay as close as possible to published estimates of key parameters when available. The benchmark parameters are reported in Table 13.

### Preferences and Technology

We parameterize tastes symmetrically across the North and the South but allow production parameters to be different. We assume that the model period corresponds to a

Table 13. Benchmark Parameters

| | | | |
|---|---|---|---|
| Preferences | | | |
| $r$ | real interest rate | 0.04 | |
| $\beta = 1/(1+r)$ | discount factor | 0.96 | |
| $1/\gamma$ | intertemporal elasticity of substitution | 0.5 | |
| $\theta$ | Cobb-Douglas parameter | 0.8 | |
| Technology | | | |
| $\alpha$ | labor share | 0.41 (the North) | 0.32 (the South) |
| $\sigma$ | elasticity of substitution b/t capital and material | 0.09 | |
| $\varepsilon$ | elasticity of substitution b/t commodity and oil | 0.25 | |
| $\omega$ | relative weight of capital | 0.55 | |
| $\omega_1$ | relative weight of commodity | 0.5 | |
| Investment | | | |
| $\delta$ | depreciation rate | 0.1 | |
| $\eta$ | cost function parameter | 30 | |
| Country Size | | | |
| $\pi_1$ | non-oil primary | 0.1 | |
| $\pi_2$ | oil | 0.1 | |
| $\pi_3$ | manufactured | 0.8 | |

Exogenous Driving Variables

$$\rho = \begin{bmatrix} 0.54 & 0 & 0 \\ 0 & 0.69 & 0 \\ 0 & 0 & 0.73 \end{bmatrix} \qquad \Omega = \begin{bmatrix} 0.12 & 0 & 0 \\ 0 & 0.41 & 0 \\ 0 & 0 & 0.69 \end{bmatrix}$$

year in the data. Under this assumption, we set subjective discount factor $\beta = 0.96$ such that the annual real interest rate is about equal to 4%, as in the existing business cycle literature. The preference specification has a general functional form with two parameters $\gamma$ and $\theta$. We set the elasticity of intertemporal substitution equal to 1/2, which is in the range of many empirical estimates (see, for example, Backus , Kehoe and Kydland 1995). The value of $\theta$ is selected so that the fraction of time spent in the workplace in the steady state is 0.2, which is roughly consistent with earlier studies (Kose 2002, Mendoza 1995).

The annual capital depreciation rate $\delta$ is set at 0.1 which is frequently used in the literature. The labor share $\alpha$ is found to be 0.41 for the manufacturing sector using BLS's U.S. manufacturing factor shares averaged across years 1987-2005.[22] We set the labor share for the primary sectors at 0.32 that is close to the average value of prior empirical estimates (see, Kouparitsas 1997, Kose 2002). Following Kose (2002), the relative weight of capital in the CES composite $\omega$ is set at 0.55. The substitution between capital and intermediate inputs has been extensively studies in the literature. Most studies suggest that the relationship between capital and intermediate inputs is close to Leontief (Berndt and Wood 1975, Kim and Loungani 1992, Kose 2002, Backus and Crucini 2000). We vary the elasticity of substitution between capital and intermediate inputs $\sigma$ so that the standard deviation of consumption relative to GDP predicted by the model is close to the data. The resulting value of $\sigma$ is 0.09. We have seen that the elasticity of substitution between primary goods and oil is pretty low in Section 2. In our model, commodity prices are related to quantities by the first-order condition:

$$\log(\frac{P_1}{P_2}) = \log(\frac{\omega_1}{\omega_2}) - \frac{1}{\varepsilon}\log(\frac{Y_1}{Y_2}) \tag{III.13}$$

[22]The factor share data from BLS includes purchased business service. For the purpose of the paper, we do not take this into account when estimating the labor share.

To assign value for $\varepsilon$, we estimate above equation using aggregate commodity price and quantity.[23] The estimate of $\varepsilon$ is 0.25. Following Baxter and Crucini (1993), we set capital adjustment cost function $\phi$ so that at the steady state $\phi = I/K = \delta$ and $\phi^{'}(I/K) = 1$. The elasticity of the investment-capital ratio with respect to Tobin's q, $\eta$, is selected so that the investment volatility generated by the model is consistent with that of the data. This turns out to involve a very low adjustment cost parameter.

The remaining parameters to be calibrated are the steady state share of intermediate inputs and the country size $\pi_i$. According to the BLS's 2006 factor shares Tables, the average share of intermediate goods in manufacturing output is around 0.5. We measure country size as real GDP divided by total real GDP of all countries in the dataset. The country weights are then averaged across the time. The North, an aggregate of eight major industrial countries, accounts for about 80% of world output, while 67 developing countries together produce 20% of the total. For symmetry, we set the size of non-oil developing country equal to that of the oil country.

## Productivity

We assume that the log of the productivity shock follows a multivariate autoregressive process:

$$\ln A_t = \rho \ln A_{t-1} + \varepsilon_t$$

where $A_t = [A_{1t}\ A_{2t}\ A_{3t}]^{'}$, and $\varepsilon_t$ is a normally distributed mean zero shock with a covariance matrix $\Omega$. Since the model world economy is driven by productivity shocks, it is important to measure their persistence, volatility and comovement across the manufacturing and primary goods sectors. One way to calibrate the process for productivity shocks

[23] See Data Appendix for the detail of aggregation.

is to estimate a vector autoregressive (VAR) model based on observed properties of Solow residuals. However, in the absence of quality data of Southern countries, we are unable to use this approach. We follow Kydland and Prescott (1982) and calibrate the covariance of productivity shocks such that the estimates of the variance of cyclical output for the model equal that of cyclical output for the industrial countries, non-oil primary country and oil country in our data during the sample period. Since we tend to focus on the features of the benchmark model, we assume diagonal matrices for persistence and covariance. The correlations of innovations across the North and the South are set to zero. If we allow positive spillovers, it allows productivity shocks to exhibit other sources of positive correlation across countries and may enhance the North-South business cycles. The specification of the innovations for the benchmark model is:

$$\rho = \begin{bmatrix} 0.54 & 0 & 0 \\ 0 & 0.69 & 0 \\ 0 & 0 & 0.73 \end{bmatrix} \text{ and } \Omega = \begin{bmatrix} 0.12 & 0 & 0 \\ 0 & 0.41 & 0 \\ 0 & 0 & 0.69 \end{bmatrix}.$$

## Results

### Impulse Responses

Our model is driven by shocks to Northern and Southern productivity. To emphasize the roles played by productivity disturbances originated from different regions, we trace out the dynamic responses of key macroeconomic aggregates to two different shocks: a positive innovation to non-oil primary productivity (supply shock to regions specialized in the non-oil material input); and a positive innovation to manufacturing productivity (derived demand shock to both non-oil and oil sectors).[24] Figures 13 through 16 graph the percent deviations of the relevant variables from their steady state values in response to a unit shock.

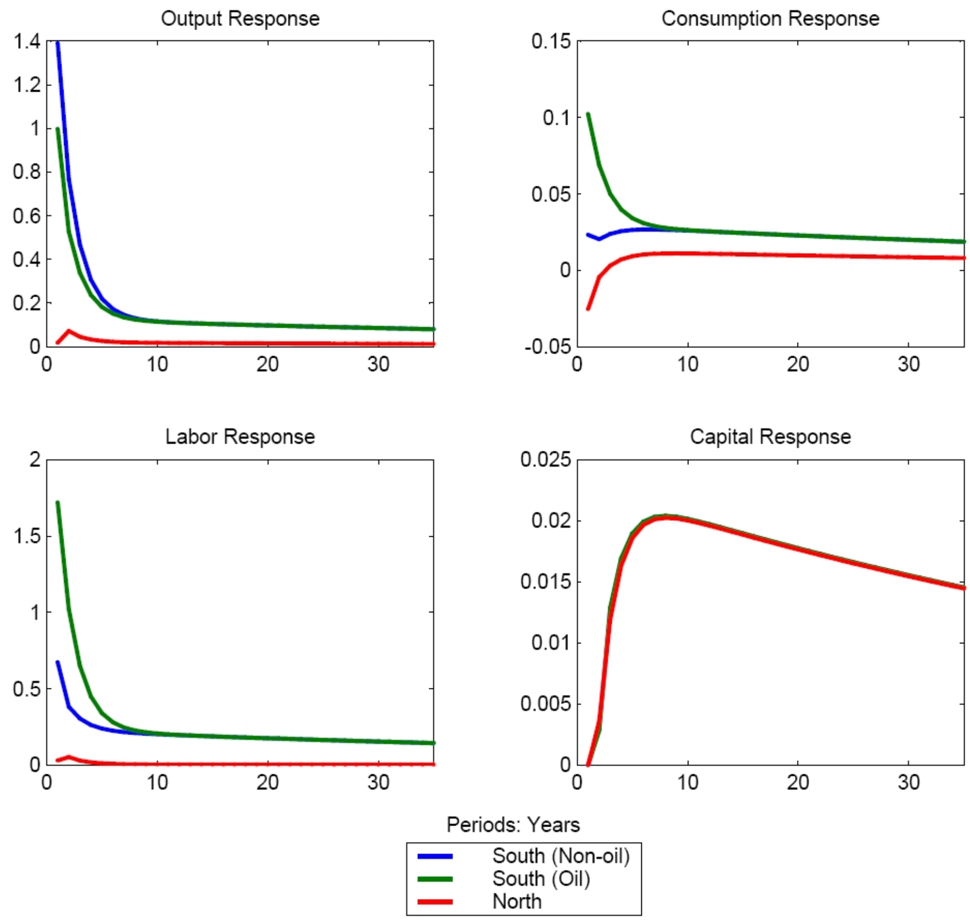



Figure 13. The effect of a 1% shock to non-oil Southern country (I)

*(A) Non-oil primary productivity shock*

Figures 13 through 14 present the response of output, consumption, labor hours, capital, investment, intermediate input usage, and commodity prices to a temporary 1% innovation to non-oil primary productivity. We see that the increase in non-oil primary

[24]We do not present the oil productivity shock here, because under symmetry the transmission mechanism of oil productivity shock is very similar to that of non-oil primary productivity shock.

productivity results in a world-wide boom. The supply of non-oil primary goods increases because the primary sector becomes more productive; output of non-oil primary goods rises by about 1.4%. Thus it causes the non-oil primary price to immediately fall by about 0.4%. The lower non-oil primary input price induces expansion in manufacturing sector but with a one-period lag because intermediate inputs require one period to put into place. The increase in manufacturing output is tiny; only about 0.1% increase is observed in the second period after the shock.[25] In the meantime, the boom in the manufacturing sector increases the derived demand for oil and raises the oil price by about 1.6%. Consumption increases in all regions as manufacturing output rises, but the rise of consumption is smaller than that of manufacturing output since representative agents tend to smooth their consumption.

The increase in production also affects the factor markets. It raises the demand for capital input and labor in all sectors. This results in a rise in investment and labor hours. However, labor input increases are different across sectors, ranging from a high of 1.7% (oil sector) to a low of 0.1% (manufacturing sector). The increase in non-oil primary productivity causes two opposite effects on the demand for intermediate inputs as production increases: non-oil primary and manufacturing sectors increase their demand for intermediate inputs while the oil exporting country decrease their usage of intermediates as intermediate inputs are allocated to more productive regions.

Turning to commodity price dynamics, we see that in response to the non-oil primary productivity shock commodity prices behave quite differently. Following the shock, non-oil primary good prices drop and oil prices rise simultaneously. These two prices then gradually converge to the steady state in a pretty close pace as the non-oil primary com-

[25] Another alternative is to consider one standard deviation shocks rather than unit shocks. That way, the larger commodity shocks would play a more significant role in the impulse response in terms of the manufacturing sector impact.

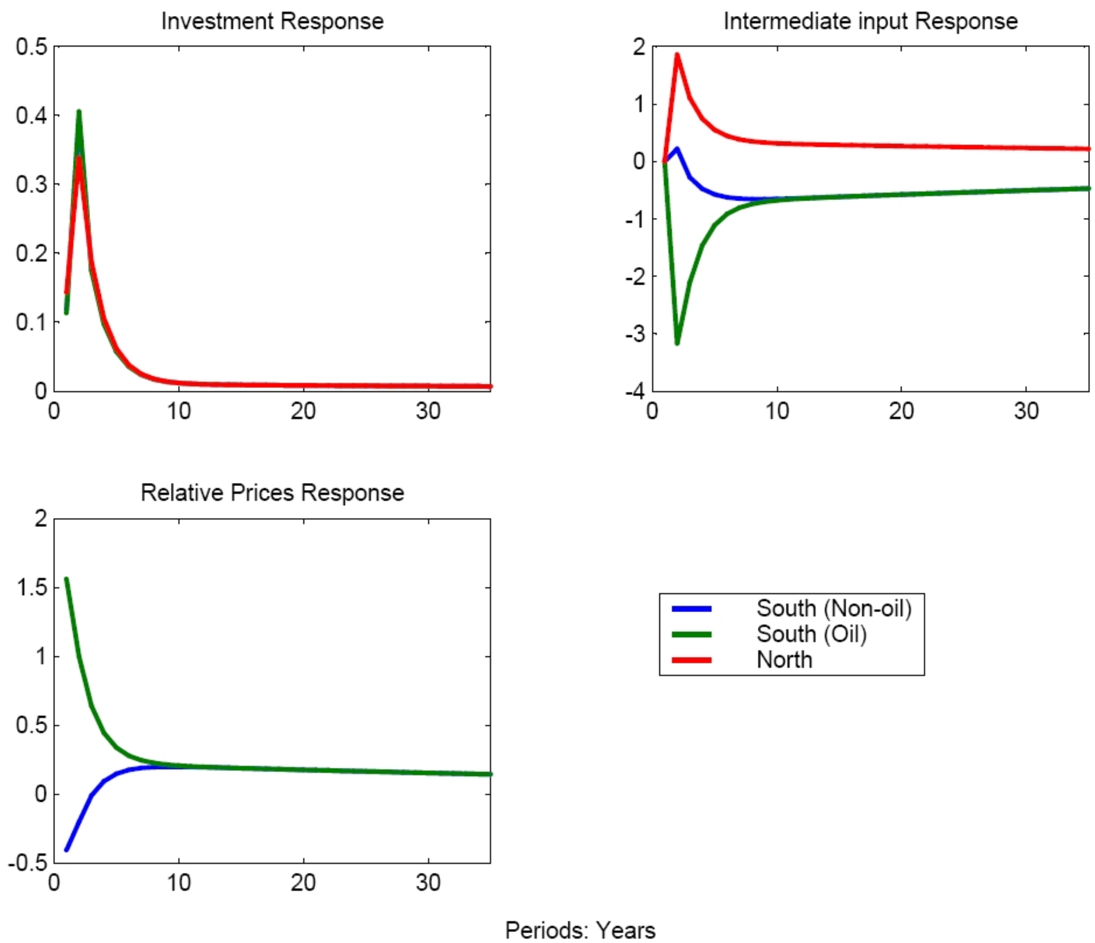



Figure 14. The effect of a 1% shock to non-oil Southern country (II)

modity and oil are less substitutable. Contrary to commodity prices, the manufactured price changes very little reflecting the fact that manufacturing output only increases a little in response to the shock originating in the non-oil South. This experiment rationalizes the fact that primary commodity prices are more volatile than the manufacturing good price. Since manufacturing good price remains the same, the time paths of commodity relative prices (commodity prices relative to manufacturing good price) are very similar to that of commodity prices. The largest relative price movement is found in the oil sector because oil production is rather more than that limited in the short-run.

*(B) Manufacturing productivity shock*

Figures 15 through 16 show the time paths of relevant variables in response to a temporary 1% innovation to manufacturing productivity. An increase in manufacturing productivity raises manufacturing production and therefore causes higher demand for capital, labor and intermediate inputs. This is reflected in greater output, investment, labor hours and intermediate inputs in the manufacturing sector. Since the income level in the manufacturing sector increases, so does consumption.

The boom in the manufacturing sector increases derived demand for all primary commodity inputs. Notice that there is a strong spillover from the manufacturing sector to commodity markets for quantity and particularly for price. This is the derived demand channel that we discuss in previous section. In response to increased demand, non-oil primary and oil sectors both tend to raise their production. Nevertheless, in the short-run they have rather limited abilities to increase their outputs since capital and intermediate inputs are predetermined and cannot be adjusted immediately. The only way to increase their production is to raise labor inputs resulting in about 3% increase in labor hours and 1% rise in real wage.[26] This is still not enough to equilibrate the markets and therefore drives up non-oil primary prices and oil prices substantially. Both non-oil and oil prices increase by about 2.5% immediately. The movement of relative prices is even bigger; relative non-oil primary price and relative oil price rise more than 3% initially and reach a peak of 4.5% eight years after the shock. Higher production also leads to a boom in Southern countries so that their consumption and investment move above the steady state levels for an extended period of time.

Focusing on commodity price dynamics, we see that in response to a unit manufacturing productivity shock, non-oil primary good prices and oil prices exhibit the same

[26] If the model featured incomplete market, a larger wealth effect in the region where the shock originates would tend to reduce the response of labor. We plan to investigate the role of financial market structure in future research.

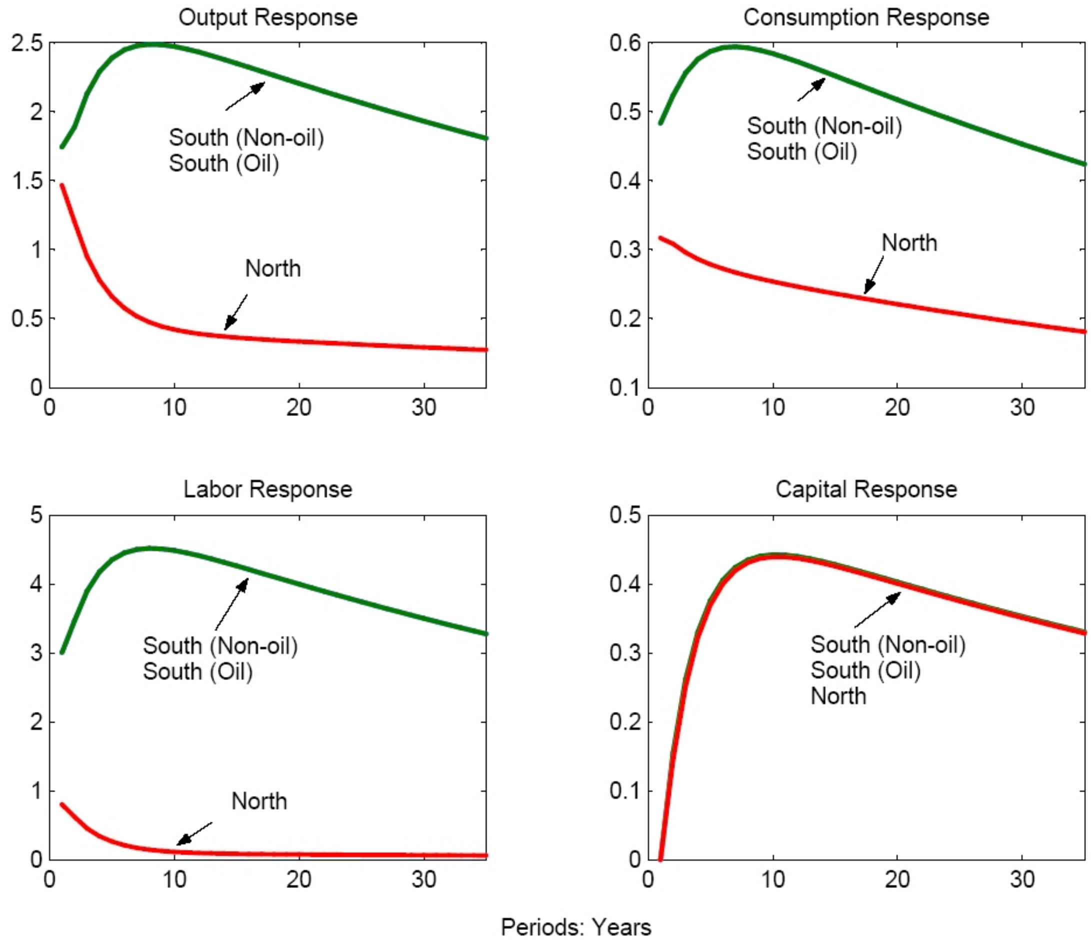



Figure 15. The effect of a 1% shock to the Northern country (I)

pattern due to the symmetric structure. They start with rising above the steady state and then gradually converge back to the long-run equilibrium. The derived demand drives the price movement and its magnitude is bigger than that driven by a unit primary productivity shock (supply shock). In contrast, manufactured prices decline by about 0.5% in response to a unit supply shock in the manufacturing sector.

In summary, we have examined how two different productivity shocks affect commodity markets. The first one is a supply shock, that is, the productivity shock originated from the South; the other one is a derived demand shock, the productivity shock in the North. The impulse responses plots show that both shocks play important roles in the

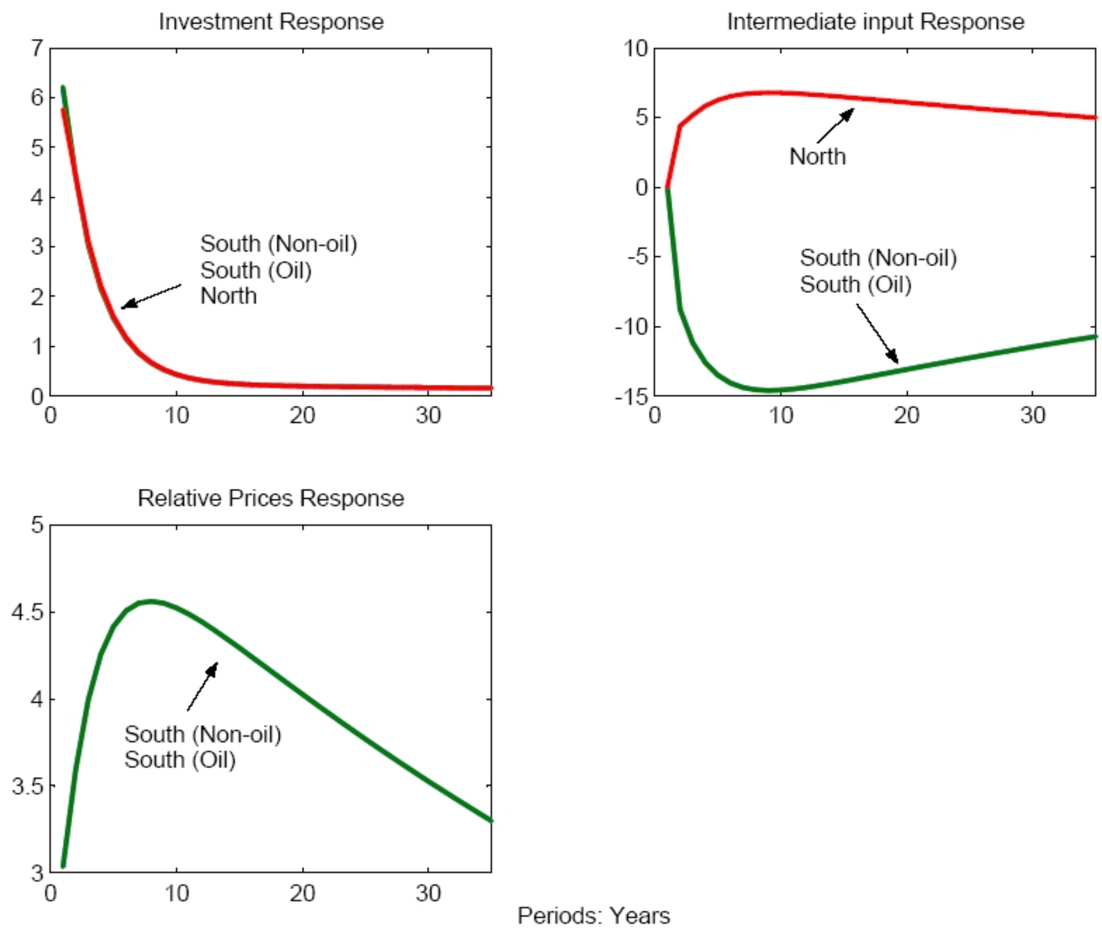



Figure 16. The effect of a 1% shock to the Northern country (II)

determination of commodity market dynamics, but the transmission mechanisms through which productivity shocks influence commodity price movements are different. The derived demand shock can generate larger price responses than can commodity supply shocks (of the same magnitude). Furthermore, commodity prices are more volatile than commodity outputs consistent with the data observations presented in previous section. The production and price of manufacturing goods are much less volatile than that of primary commodities. There are two reasons for this: First, Northern country has a larger country size such that the productivity shock from the South has little effect on it. Second, there is no derived demand shock in the manufacturing sector; the major shock to the North is supply shocks generating small fluctuations in manufacturing market. Another possible reason could be the issue of shocks averaging out more in the manufacturing sector than commodity sectors. These results are consistent with the view that small developing economies exhibit more volatility.

### Moment Implications

We evaluate the quantitative performance of the benchmark model by confronting its predictions against two sets of stylized facts observed in the data. The first set of facts is about the features of international business cycle including volatility and comovement of macroeconomic aggregates. The second set of facts concerns the commodity price dynamics. To achieve this, we use Monte Carlo methods to simulate the model. The time series properties of the model can be summarized by two systems of linear equations. The first system of equations describes the dynamic evolution of the state vector:

$$\hat{S}_{t+1} = M\hat{S}_t + e_{t+1} \tag{III.14}$$

The second system of equations relates the vector of choice variables, $\hat{H}_t$, to the current state vector, $\hat{S}_t$:

$$\begin{aligned} \hat{H}_t &= \Pi\hat{S}_t \qquad \text{(III.15)} \\ \hat{S}_t' &= \left[\hat{K}_{1t}, \hat{K}_{2t}, \hat{K}_{3t}, \hat{M}_{1t-1}, \hat{M}_{2t-1}, \hat{M}_{3t-1}, \hat{A}_{1t}, \hat{A}_{2t}, \hat{A}_{3t}\right] \end{aligned}$$

where the $\Pi$ matrix controls the impact response of choice variables to changes in the state variables.[27] We assume that the innovations, $e_{t+1}$, are normally distributed with the covariance matrix as parameterized in the Section 4. Drawing innovations with these properties,

[27]Since we log-linearize the model around the steady states, we use the circumflex over a variable to denote the logarithm of that variable relative to its steady state level.

we generate predicted time paths for variables by using the systems of equations above. The model's moments are then computed based on Hodrick-Prescott filtered simulated time series and are averages over 100 simulations of 100 periods each.

*(A) International business cycle facts*

Tables 14 through 16 present the predicted volatility and comovement from the model. Starting with volatility, we first confront the model's predictions with the data for three key variables: GDP, consumption and investment.

Table 14. Comparison of Actual and Model Data: Volatility

| | Data | | Model | |
|---|---|---|---|---|
| North | Std | Rel. Std | Std | Rel. Std |
| GDP | 1.53 | 1.00 | 1.48 | 1.00 |
| Consumption | 1.28 | 0.84 | 0.38 | 0.26 |
| Investment | 4.41 | 2.88 | 5.83 | 3.93 |
| South (non-oil) | Std. | Rel. Std | Std. | Rel. Std |
| GDP | 2.00 | 1.00 | 2.97 | 1.00 |
| Consumption | 1.85 | 0.93 | 0.72 | 0.24 |
| Investment | 6.86 | 3.44 | 5.92 | 1.99 |
| South (oil) | Std. | Rel. Std | Std. | Rel. Std |
| GDP | 3.31 | 1.00 | 3.05 | 1.00 |
| Consumption | 3.40 | 1.03 | 0.71 | 0.23 |
| Investment | 10.04 | 3.03 | 5.91 | 1.94 |

The statistics are based on H-P filtered data. Std denotes the percentage Standard Deviation from H-P Trend. Rel. Std denotes the standard deviation of variable relative to that of GDP. The sample period is 1980-2004. Except for the net export to GDP all variables are transformed to logarithms before filtering. Source: WDI database.

Table 14 shows that the simulated standard deviations of GDP in all three countries are pretty close to that of the data since we calibrate the covariance matrix of productivity to match that of output. Turning to consumption and investment, we see that in the data investment is the most volatile variable and consumption is smoother than GDP expect for the oil exporting country. Our model can reproduce this volatility ranking in all regions, although the absolute variability is less than that of the data, considerably so for consumption.

Table 15 displays correlations of GDP across countries. Here the model is less successful. In the simulated data, international output correlations are all positive and fairly high, but in the data, they are weakly correlated. One big discrepancy between the model and the data is that the model predicts a strong positive correlation between non-oil primary good exporting country and oil country, but this correlation is essentially negative in the data (0.99 versus -0.20 ).[28] Most IRBC models have the problems of insufficient comovement of output, suggesting a model more intermediate. For example, one where there is less specialization.

Table 15. Comparison of Actual and Model Data: International Comovement

| | Data | Model |
|---|---|---|
| Cross-region Correlation of GDP | | |
| (North, NonOil) | 0.33 | 0.66 |
| (North, Oil) | 0.13 | 0.65 |
| (NonOil, Oil) | -0.20 | 0.99 |

The statistics are based on H-P filtered data. The sample period is 1980-2004. Except for the net export to GDP all variables are transformed to logarithms before filtering. Source: World Bank WDI.

Table 16 presents the remaining predictions of international comovement for other variables. We do not compare the model's predictions with the data since our time series observations on these variables are limited. In the simulated data, correlations in consumption, investment and other aggregates between regions are generally positive and pretty high. A problem in the model is that consumption correlations are in general higher than output correlations. Thus this model also yields the quantity anomaly problems that arise in standard real business cycle models. One way to deal with the quantity anomaly problem is to introduce incomplete asset markets. Since our major goal here is to examine the driving

[28]Since we have shown the importance of the dynamic correlation patterns for output earlier, we do not emphasize the international contemporaneous correlations here.

forces of commodity price dynamics, we focus on complete markets rather than incomplete markets.

Table 16. Business Cycle Properties of Model Predictions: International Comovement

| Variable | (North, NonOil) | (North, Oil) | (NonOil, Oil) |
|---|---|---|---|
| GDP | 0.66 | 0.65 | 0.99 |
| Consumption | 0.95 | 0.96 | 1.00 |
| Investment | 0.98 | 0.98 | 0.99 |
| Labor | 0.55 | 0.56 | 0.98 |
| Material | -1.00 | -0.98 | 0.98 |
| Wage rate | 0.04 | 0.01 | 0.98 |
| Price | -0.89 | -0.95 | 0.93 |
| Relative Price | | | 0.95 |

The nominal price refers to the nominal commodity price produced in each country.
The relative price is the commodity price relative to the manufactured price.

*(B) Commodity price dynamics*

Table 17 displays some statistics about commodity price dynamics. For the purpose of comparison, we display the statistics from the data and from the model. The top panel of the table reports the standard deviations of commodity prices and quantities. The model does well in predicting the volatility. Commodity prices are predicted to be quite volatile; the standard deviations of non-oil primary price and oil price are 4.87 and 4.71. The model's predictions of terms of trade (commodity prices relative to manufactured price) are even more volatile than that of commodity prices. Contrary to commodity prices, commodity production is predicted to be less volatile, with a standard deviation of 2.97 for non-oil output and 3.05 for oil output. The absolute variability of simulated commodity prices is low compared to that of the data, while the relative standard deviations are much larger in the model predictions than in the data.

The second panel presents the first- and second-order autocorrelations of commodity price and production. A notable feature is that, under our benchmark calibration, our

Table 17. Business Cycles Properties of Sectoral Prices and Quantities

| | Data | | Model | |
|---|---|---|---|---|
| Volatility | Std | Rel. Std | Std | Rel. Std |
| Price | | | | |
| Oil | 6.00 | 2.84 | 4.71 | 8.33 |
| Non-oil Commodity | 8.00 | 3.79 | 4.87 | 8.61 |
| Manufactured Good | 2.11 | 1.00 | 0.57 | 1.00 |
| Terms of Trade | | | | |
| Oil / Manufactured Good | | | 5.26 | 9.30 |
| Non-oil / Manufactured Good | | | 5.39 | 9.53 |
| Quantity | | | | |
| Oil | 1.17 | 0.86 | 3.05 | 2.06 |
| Non-oil Commodity | 2.23 | 1.64 | 2.97 | 2.00 |
| Manufactured Good | 1.36 | 1.00 | 1.48 | 1.00 |
| Persistence | a-c 1 | a-c 2 | a-c 1 | a-c 2 |
| Price | | | | |
| Oil | 0.90 | 0.76 | 0.89 | 0.75 |
| Non-oil Commodity | 0.86 | 0.72 | 0.88 | 0.73 |
| Manufactured Good | 0.99 | 0.98 | 0.81 | 0.63 |
| Terms of Trade | | | | |
| Oil / Manufactured Good | | | 0.88 | 0.74 |
| Non-oil / Manufactured Good | | | 0.87 | 0.73 |
| Quantity | | | | |
| Oil | 0.99 | 0.98 | 0.83 | 0.69 |
| Non-oil Commodity | 0.83 | 0.75 | 0.84 | 0.71 |
| Manufactured Good | 0.99 | 0.98 | 0.63 | 0.35 |

a-c 1 and a-c 2 represent the first order and second order autocorrelation coefficients.
The relative standard deviation is the standard deviation relative to manufacured statistics.
Non-oil statistics are based on average data over all non-oil commodities.

model is capable of generating highly persistent commodity prices close to that observed in the data. In this aspect, our model does quite well. The results suggests that incorporating commodity market features and trade in intermediate inputs is important in understanding the commodity price dynamics.

## Sensitivity Analysis

We have presented how macroeconomic aggregates would evolve in response to different productivity shocks and reported the moments of simulated data based on the calibrated parameter values. The question here is whether the model's predictions are sensitive to changes in the structural parameters of the model and stochastic processes. This section provides a sensitivity analysis to answer this question.

We first analyze the impact of the productivity structure. Table 18 presents the sensitivity of our results to changes in the structure of productivity shocks. The first two panels present the statistics from the data and our baseline parameterization reported in Section 4. The existing literature finds it particularly difficult to explain the persistence of commodity relative prices. Some of this difficulty can be traced to the maintained assumption that supply shocks are i.i.d. processes as in Deaton and Laroque (1992). The results of our experiment given in the third panel of Table 18 show that even allowing all productivity shocks to be i.i.d. processes the model still can generate persistent commodity relative prices. However, the model with i.i.d. shocks does not generate as much variability as it does in the benchmark parameterization. The fourth panel reports the predicted statistics when we set the persistence coefficient of productivity shock, $\rho$, to 1. We see that in this case the model can maintain high persistence of commodity prices but cannot generate large commodity price movements. The model also predicts that the correlation of output between the North and the South is very weak, inconsistent with that observed in the data. The last panel of Table 18 shows the results from the model with positive correlation of innovation across regions (the correlation coefficient of shock across countries is set at 0.1). We find that the model's predictions are not sensitive to this specification.

Table 19 reports the sensitivity analysis for changing the model parameter values. An increase in the elasticity of substitution across non-oil primary goods and oil causes a drop in the volatility of the commodity prices and a slight drop in the correlation of output between these countries. The other variables are not sensitive to this change. These results are due to the fact that the producers now are more able to substitute one commodity to the

Table 18. Sensitivity Analysis: Stochastic Processes

| | Standard Deviation | | | | International Comovement | | Persistence | |
|---|---|---|---|---|---|---|---|---|
| | Y | C | I | P | (Y, $Y_{North}$) | (Y,$Y_{Oil}$) | Y | P |
| *Data* | | | | | | | | |
| North | 1.53 | 1.28 | 4.41 | 2.11 | 1.00 | 0.13 | 0.99 | 0.99 |
| Nonoil South | 2.00 | 1.85 | 6.86 | 8.00 | 0.33 | -0.20 | 0.83 | 0.86 |
| Oil South | 3.31 | 3.40 | 10.04 | 6.00 | 0.13 | 1.00 | 0.99 | 0.90 |
| *Benchmark Parameterization* | | | | | | | | |
| North | 1.48 | 0.38 | 5.92 | 0.57 | 1.00 | 0.65 | 0.63 | 0.81 |
| Nonoil South | 2.97 | 0.72 | 5.92 | 4.87 | 0.66 | 0.99 | 0.84 | 0.88 |
| Oil South | 3.05 | 0.71 | 5.92 | 4.71 | 0.65 | 1.00 | 0.83 | 0.89 |
| *i.i.d. Shocks* | | | | | | | | |
| North | 1.22 | 0.16 | 5.85 | 0.21 | 1.00 | 0.46 | -0.03 | 0.78 |
| Nonoil South | 1.44 | 0.30 | 5.85 | 2.26 | 0.48 | 0.98 | 0.61 | 0.67 |
| Oil South | 1.51 | 0.30 | 5.85 | 2.18 | 0.46 | 1.00 | 0.54 | 0.79 |
| *Highly Persistent Shocks* | | | | | | | | |
| North | 1.25 | 1.20 | 0.29 | 2.04 | 1.00 | -0.06 | 0.78 | 0.79 |
| Nonoil South | 0.97 | 1.19 | 0.29 | 1.82 | -0.08 | 0.94 | 0.74 | 0.81 |
| Oil South | 1.24 | 1.19 | 0.29 | 1.47 | -0.06 | 1.00 | 0.76 | 0.97 |
| *Spillover* | | | | | | | | |
| North | 1.49 | 0.38 | 5.96 | 0.56 | 1.00 | 0.67 | 0.64 | 0.81 |
| Nonoil South | 3.05 | 0.73 | 5.96 | 4.96 | 0.68 | 0.99 | 0.83 | 0.87 |
| Oil South | 3.14 | 0.72 | 5.96 | 4.75 | 0.67 | 1.00 | 0.82 | 0.91 |

The parameters that change across cases are: i.i.d. shocks, persistence coefficients are set to zero for all regions; High persistent shocks, persistence coefficients are set to 1 for all regions; Spillover, correlation of innovations across countries is set to 0.1.

Table 19. Sensitivity Analysis: Model Parameters

| | Standard Deviation | | | | International Comovement | | Persistence | |
|---|---|---|---|---|---|---|---|---|
| | Y | C | I | P | (Y, $Y_{North}$) | (Y,$Y_{Oil}$) | Y | P |
| *Data* | | | | | | | | |
| North | 1.53 | 1.28 | 4.41 | 2.11 | 1.00 | 0.13 | 0.99 | 0.99 |
| Nonoil South | 2.00 | 1.85 | 6.86 | 8.00 | 0.33 | -0.20 | 0.83 | 0.86 |
| Oil South | 3.31 | 3.40 | 10.04 | 6.00 | 0.13 | 1.00 | 0.99 | 0.90 |
| *Benchmark* | | | | | | | | |
| North | 1.48 | 0.38 | 5.92 | 0.57 | 1.00 | 0.65 | 0.63 | 0.81 |
| Nonoil South | 2.97 | 0.72 | 5.92 | 4.87 | 0.66 | 0.99 | 0.84 | 0.88 |
| Oil South | 3.05 | 0.71 | 5.92 | 4.71 | 0.65 | 1.00 | 0.83 | 0.89 |
| *High Substitution across Inputs* | | | | | | | | |
| North | 1.52 | 0.35 | 6.72 | 0.53 | 1.00 | 0.57 | 0.61 | 0.90 |
| Nonoil South | 0.76 | 0.36 | 6.72 | 1.11 | 0.66 | 0.96 | 0.54 | 0.82 |
| Oil South | 0.88 | 0.35 | 6.72 | 1.04 | 0.57 | 1.00 | 0.17 | 0.95 |
| *Low Material Cost Share* | | | | | | | | |
| North | 1.21 | 0.74 | 2.53 | 1.25 | 1.00 | 0.71 | 0.52 | 0.77 |
| Nonoil South | 3.53 | 0.45 | 2.53 | 5.76 | 0.72 | 0.99 | 0.42 | 0.65 |
| Oil South | 3.60 | 0.43 | 2.53 | 5.74 | 0.71 | 1.00 | 0.45 | 0.66 |

The parameters that change across cases are: High substitution across inputs, the elasticity of substitution between primary good and oil is set to 1; Low material cost share, the material cost share is set to 0.1.

other as relative price changes such that the fluctuations in commodity relative prices are less severe. The last panel of Table 19 presents the sensitivity of the model's predictions to changes in material cost share. We see that this causes a fall in the persistence of commodity prices and some variability in other variables.

## Conclusion

The dynamics of relative commodity prices has been extensively studied in the literature, but it is usually viewed as puzzling since most existing models are incapable of explaining the observed high volatility and persistence of commodity prices. Our model incorporates the North-South trade structure and the role of intermediate inputs in production, based on the calibrated international covariance of productivity, and can generate volatile and highly persistent commodity relative prices. This finding suggests that the trade structure and intermediate input entering production of manufactured good can be an important feature in understanding commodity price dynamics.

In this paper,we have examined the relative importance of supply and demand disturbances in commodity price movements. The results from impulse response analysis shows that both supply and demand shocks play important roles in commodity price dynamics but demand shocks can generate larger price responses than supply shocks. To evaluate the performance of our model, we have also confronted the model against some stylized facts concerning international business cycles between Northern and Southern countries. The model can reproduce some qualitative features but falls short in matching the actual magnitudes of business cycle statistics. What is needed to deal with this problem is perhaps some asset market frictions. Introducing these frictions to our model could be an interesting and promising avenue for future study.

APPENDIX A

Data Appendix

This appendix provides the data description, country list and aggregation method we employ in Chapter III.

## Aggregation

The aggregate price and quantity for non-oil primary commodities are constructed using the fraction of the value of world exports to total world exports of all non-oil primary commodities in our data set. The aggregate non-oil commodity price index is defined as:

$$P_t = \sum_{j=1}^{35} \varphi_j p_t^j$$

where $\varphi_j$ is the export share of commodity $j$ in total world commodity exports where the total is defined over all export values in our data set. $p_t^j$ is the nominal price of commodity $j$ normalized to equal 100 in 1986. The U.S. CPI-U is used as the nominal price index for manufactured goods in the North. The non-oil primary commodity production index is defined analogously using the same weights.

To investigate North-South business cycles, we construct macroeconomic aggregates for three regions in our model using country's weights. A country's weight in the aggregate is based on the US dollar value of their output, consumption, investment, imports and exports.

Table 20. Commodity Price Specifications (I)

| Commodity | Unit | Period | Specification |
|---|---|---|---|
| Aluminum | cents/ lb | 1910-Jan:2005-Dec | Aluminum COMEX: Pig Ingots, New York (Jan. 1910 - Nov. 1986); Pig Ingots, Midwest ( Dec. 1986 - Dec. 2005). |
| Apples | cents/ lb | 1947-Jan:2005-Dec | Average Received by Growers, US (Jan. 1947 - Dec. 2005). |
| Beef | cents/ lb | 1975-Jan:2005-Dec | Wholesale Price of Boxed Beef Cut-out at Central Markets (Livestock & Poultry Monthly): Choice, 1-3, 550-700 Pound (Jan. 1975 - Dec. 2005). |
| Butter | cents/ lb | 1929-Jan:2005-Dec | Grade AA, Chicago (Jan. 1929 - May 1998); 92 Score Creamery (Grade A), Central States (June 1998 - Dec. 2001); Chicago Mercantile Exchange (Jan. 2002 - Dec. 2005). |
| Cocoa | dollars/ Mt | 1927-Jan:2005-Dec | Exchange Standard, New York (Jan. 1927 - Dec. 1947); Accra, New York (Jan. 1948 - Sep. 1980); Ivory Coast (Oct. 1980 - Dec. 2005). |
| Coconut Oil | cents/ lb | 1918-Jan:2002-May | Crude, New Orleans (Sept. 1918 - May 2002). |
| Coffee | cents/ lb | 1910-Jan:2005-Dec | Santos No. 4, New York (Jan. 1910 - July 1975); Exchange Closed during WWII (Sept. 1941 - Sept. 1946); Brazilian, New York (Aug. 1975 - Dec. 2005). |
| Copper | cents/ lb | 1910-Jan:2005-Dec | Electrolytic, New York (Jan. 1910 - Dec. 1983); Electrolytic, United States (Jan. 1984 - Dec. 2005). |
| Corn | cents/ bushel | 1910-Jan:2005-Dec | No. 3 Yellow, Chicago (Jan. 1910 - Apr. 1947); No. 2 Yellow, Chicago (May 1947 - Mar. 1982); No. 2 Yellow, Central, IL (Apr. 1982 - Dec. 2005). |
| Corn Oil | cents/ lb | 1924-Jul: 2005-Dec | F.O.B. Decatur (July 1924 - June 1985); Crude, Wet, Milling, Chicago (July 1985 - Dec. 2005). |
| Cotton | cents/ lb | 1915-Aug:2005-Dec | 7/8” Middling, Designated Markets (Aug. 1915 - July 1930); 15/16” Middling, Designated Markets (Aug. 1930 - Feb. 1967); 1 1/16” 7 Market Average (Mar. 1967 - Dec. 2005). |
| Eggs | cents/ dozen | 1910-Jan:2005-Dec | Fresh Firsts, New York (Jan. 1910 - Dec. 1926); Fresh Firsts, Chicago (Jan. 1927 - June 1943); US Standards, Chicago (July 1943 - Dec. 1947); Large, Chicago (Jan. 1948 - Dec. 2005). |
| Hides | cents/ lb | 1910-Jan:2005-Dec | Heavy Native Steers, Chicago (Jan. 1910 - Dec. 2005). |
| Iron & Steel | dollars/ Mt | 1910-Jan:2005-Dec | AMM Scrap Iron & Steel Price Averages (Pittsburg), No. 1 Heavy, Pittsburg (Jan. 1907 - Dec. 2005). |
| Lead | cents/ lb | 1910-Jan:2005-Dec | Pig, New York (Jan. 1910 - Dec. 2005). |
| Lumber | dollars/ 1000 bf | 1959-Jan:2005-Dec | White-Fir, 2x4 (Jan. 1959 - Dec. 1970); Spruce-Hem-Fir, 2x4 (Jan. 1971 - Mar. 1980); Spruce-Pine-Fir, 2x4 (Apr. 1980 - Dec. 2005). |
| Milk | cents/ lb | 1931-Jan:2005-Dec | Distributors and Associations, U.S. (Jan 1931 to Dec 1936); Plants and Dealers, U.S. (Jan 1937 to Dec 1955); Received by Farmers, U.S. (Jan 1956 to Dec. 2005). |
| Nickel | cents/ lb | 1999-Aug:2005-Dec | Plating Material (Jan. 1999 - Aug. 2005). |

Table 21. Commodity Price Specifications (II)

| Commodity | Unit | Period | Specification |
|---|---|---|---|
| Oranges | dollars/ box | 1947-Jan:2005-Dec | Average Received by Farmers (Jan. 1947 - Dec. 2005). |
| Palm Oil | cents/ lb | 1976-Feb:2005-Dec | Refined, Bleached, New Orleans (Feb. 1976 - Dec. 2004); no data for Oct. 1981-Apr. 1982. |
| Peanuts | cents/ lb | 1930-Sep:2005-Dec | Received by Farmers, U.S. (Sept. 1930 - Dec. 2005). |
| Pepper | cents/ lb | 1919-Dec:2005-Nov | Brazilian Black, New York (Dec. 1919 - Nov. 2005). |
| Petroleum | dollars/ barrel | 1946-Jan:2005-Dec | WTI Crude Oil (Jan. 1946 - Dec. 2005). |
| Potatoes | dollars/ 100 lb | 1913-Jan:2005-Dec | No. 1 White, New York (Jan. 1913 - Dec. 1960); Received by Farmers, U.S. (Jan. 1961 - Dec. 2005). |
| Rice, rough | dollars/ 100 lb | 1914-Oct:2005-Nov | Fancy (Honduras), New Orleans (Oct. 1914 - Dec. 1924); Fancy (Blue Rose), New Orleans (Jan. 1925 - Dec. 1933); |
| | | | Medium to Good (Blue Rose), New Orleans (Jan. 1934 - July 1947); |
| | | | Fancy, No. 2 Zenith Milled, New Orleans (Aug. 1947 - Apr. 1972); |
| | | | No. 2 Medium, Southwest Louisiana (May 1972 - Nov. 2005). |
| Rubber | cents/ lb | 1910-Jan:2005-Dec | Plantation, Ribbed Smoked Sheet, New York (1908- Dec. 2005). |
| Rye | cents/ bushel | 1910-Jan:1997-Dec | No. 2 Minneapolis (July 1909 to Dec. 1997). |
| Soybean Meal | dollars/ ton | 1929-Oct:2005-Dec | Chicago (Oct. 1929 - Oct. 1936); 41% Protein, Chicago (Nov. 1936 - June 1950); |
| | | | 44% Protein, Chicago (July 1950 - Sept. 1965); 44% Protein, Decatur (Oct. 1965 - Oct. 1992); |
| | | | 48% Protein, Decatur (Nov. 1992 - Dec. 2005). |
| Soybean Oil | cents/ lb | 1911-Jan:2005-Dec | Crude, New York (Jan. 1911 - Sept. 1929); Crude, Decatur (Oct. 1929 - Dec. 2005). |
| Soybeans | cents/ bushel | 1913-Oct:2005-Dec | U.S. Farm Price (Jan. 1913 - Sept. 1947); No. 2 Yellow, Chicago (Oct. 1947 - Dec. 1956); |
| | | | No. 1 Yellow, Chicago (Jan. 1957 - Mar. 1982); No. 1 Yellow, Central Illinois (Apr. 1982 - Dec. 2005). |
| Sugar | cents/ lb | 1910-Jan:2005-Dec | Spot Raw (cif) New York (Jan. 1910 - Jan. 1961); No. 8 World Raw, New York (Feb. 1961 - Dec. 1970); |
| | | | No. 11 World Raw, New York (Jan. 1971 - Dec. 2005). |
| Tallow | cents/ lb | 1910-Jan:2005-Dec | Inedible Prime, Chicago (Jan. 1910 - Dec. 1948); Bleachable, Chicago (Jan. 1949 - Dec. 2005). |
| Tin | cents/ lb | 1910-Jan:2005-Dec | Composite, New York (Jan. 1910 - Dec. 2005). |
| Wheat | cents/ bushel | 1910-Jan:2005-Dec | No. 2 Red, Chicago (Jan. 1910 - Mar. 1982); No. 2 Soft, Red, St. Louis (Apr. 1982 - Dec. 2005). |
| Wool | cents/ lb | 1910-Jan:2005-Dec | Fine Combing, Scoured (64's), Boston (Jan. 1910 - Dec. 2005). |
| Zinc | cents/ lb | 1910-Jan:2005-Dec | Prime Western, East St. Louis (Jan. 1910 - Dec. 1970); Prime Western, Domestic (Jan. 1971 - Dec. 2005). |
| US CPI-U | | 1913-Jan:2006-Dec | Base Period: 1982-84=100; Not Seasonally Adjusted. Source: BLS website. |

Source: The CRB Commodity Yearbook 2006.

Table 22. Data Availability

| Commodity | Price (Monthly frequency) | Quantity (Annual frequency) |
|---|---|---|
| Aluminum | 1910-Jan:2005-Dec | 1900:2003 |
| Apples | 1947-Jan:2005-Dec | 1970:2005 |
| Beef | 1975-Jan:2005-Dec | 1970:2005 |
| Butter | 1929-Jan:2005-Dec | 1970:2005 |
| Cocoa | 1927-Jan:2005-Dec | 1945:2004 |
| Coconut Oil | 1918-Jan:2002-May | 1961:1996 |
| Coffee | 1910-Jan:2005-Dec | 1926:2004 |
| Copper | 1910-Jan:2005-Dec | 1923:2002 |
| Corn | 1910-Jan:2005-Dec | 1930:2004 |
| Corn Oil | 1924-Jul: 2005-Dec | 1970:2005 |
| Cotton | 1915-Aug:2005-Dec | 1920:2004 |
| Eggs | 1910-Jan:2005-Dec | 1970:2005 |
| Hides | 1910-Jan:2005-Dec | 1970:2005 |
| Iron | 1910-Jan:2005-Dec | 1970:2003 |
| Lead | 1910-Jan:2005-Dec | 1970:2003 |
| Lumber | 1959-Jan:2005-Dec | 1964:2003 |
| Milk | 1931-Jan:2005-Dec | 1970:2005 |
| Nickel | 1999-Aug:2005-Dec | 1970:2002 |
| Oranges | 1947-Jan:2005-Dec | 1965:2003 |
| Palm Oil | 1976-Feb:2005-Dec | 1964:2003 |
| Peanuts | 1930-Sep:2005-Dec | 1970:2005 |
| Pepper | 1919-Dec:2005-Nov | 1970:2005 |
| Petroleum | 1946-Jan:2005-Dec | 1970:2004 |
| Potatoes | 1913-Jan:2005-Dec | 1970:2005 |
| Rice, rough | 1914-Oct:2005-Nov | 1960:2004 |
| Rubber | 1910-Jan:2005-Dec | 1970:2003 |
| Rye | 1910-Jan:1997-Dec | 1970:2005 |
| Soybean Meal | 1929-Oct:2005-Dec | 1970:2005 |
| Soybean Oil | 1911-Jan:2005-Dec | 1970:2003 |
| Soybeans | 1913-Oct:2005-Dec | 1964:2004 |
| Sugar | 1910-Jan:2005-Dec | 1960:2005 |
| Tallow | 1910-Jan:2005-Dec | 1970:2003 |
| Tin | 1910-Jan:2005-Dec | 1970:2003 |
| Wheat | 1910-Jan:2005-Dec | 1960:2004 |
| Wool | 1910-Jan:2005-Dec | 1970:2003 |
| Zinc | 1910-Jan:2005-Dec | 1970:2003 |

There is a missing data problem for coffee during the period 1947-1973.
Commodity price and production specifications are available upon request.

Table 23. Country List

| | | | |
|---|---|---|---|
| Northern Countries | | | |
| Australia | Germany | United Kingdom | |
| Canada | Italy | United States | |
| France | Japan | | |
| Southern Countries (non-oil exporting) | | | |
| Argentina | Egypt, Arab Rep. | Malaysia | Thailand |
| Bangladesh | El Salvador | Mali | Togo |
| Benin | Ethiopia | Mauritania | Trinidad and Tobago |
| Bolivia | Gabon | Mauritius | Tunisia |
| Botswana | Gambia | Morocco | Turkey |
| Brazil | Ghana | Nicaragua | Uganda |
| Burkina Faso | Greece | Pakistan | Uruguay |
| Cameroon | Guatemala | Panama | Zambia |
| Chile | Guyana | Paraguay | Zimbabwe |
| China | Honduras | Peru | |
| Colombia | India | Philippines | |
| Congo, Dem. Rep. | Jordan | Rwanda | |
| Costa Rica | Kenya | Senegal | |
| Cote d'Ivoire | Lesotho | South Africa | |
| Dominican Republic | Madagascar | Sudan | |
| Ecuador | Malawi | Syrian Arab Republic | |
| Southern Countries (oil exporting) | | | |
| Algeria | Iran, Islamic Rep. | Nigeria | Venezuela, RB |
| Angola | Kuwait | Saudi Arabia | |
| Indonesia | Mexico | United Arab Emirates | |

# APPENDIX B

## Technical Appendix

We solve the benchmark model presented in Chapter III by taking four steps. First, we calculate the first-order conditions of the model and yield a dynamic system of equations. Second, we derive equations for the steady state and the steady state ratios. Third, we log-linearize the first-order conditions around the steady state. Finally, the linearized equation system is solved using the KPR method. Some published estimates of the key parameters are used in the calibration, but not all model parameters are available in the literature. In this case, we use the model's first-order conditions to determine the size of the remaining parameters.

The Lagrangian we solve is:

$$
\begin{aligned}
Max\ \mathcal{L} \quad = \quad & E_0 \sum_{t=0}^{\infty} \beta^t \{\pi_1 U(C_{1t}, Z_{1t}) + \pi_2 U(C_{2t}, Z_{2t}) + \pi_3 U(C_{3t}, Z_{3t}) \qquad \text{(B.1)} \\
& + \pi_1 W_{1t}(1 - Z_{1t} - N_{1t}) \\
& + \pi_2 W_{2t}(1 - Z_{2t} - N_{2t}) \\
& + \pi_3 W_{3t}(1 - Z_{3t} - N_{3t}) \\
& + \pi_1 \lambda_{1t}[(1-\delta)K_{1t} - K_{1t+1} + \phi(\frac{I_{1t}}{K_{1t}})K_{1t}] \\
& + \pi_2 \lambda_{2t}[(1-\delta)K_{2t} - K_{2t+1} + \phi(\frac{I_{2t}}{K_{2t}})K_{2t}] \\
& + \pi_3 \lambda_{3t}[(1-\delta)K_{3t} - K_{3t+1} + \phi(\frac{I_{3t}}{K_{3t}})K_{3t}] \\
& + P_{1t}[\pi_1 A_{1t} F(K_{1t}, N_{1t}, M_{1t-1}) - Y_{1t}] \\
& + P_{2t}[\pi_2 A_{2t} F(K_{2t}, N_{2t}, M_{2t-1}) - Y_{2t}] \\
& + P_{3t}[\pi_3 A_{3t} F(K_{3t}, N_{3t}, M_{3t-1}) - \pi_1(C_{1t} + I_{1t}) - \pi_2(C_{2t} + I_{2t}) - \pi_3(C_{3t} + I_{3t})] \\
& + Q_t[(\omega_1 Y_{1t}^{1-\frac{1}{\varepsilon}} + \omega_2 Y_{2t}^{1-\frac{1}{\varepsilon}})^{\frac{1}{1-\frac{1}{\varepsilon}}} - \pi_1 M_{1t} - \pi_2 M_{2t} - \pi_3 M_{3t}]\}
\end{aligned}
$$

## Linearization

The first-order conditions of the model are approximately linearized around the steady state.

$$C_{1t} \quad : \quad \xi_{cc}\hat{C}_{1t} + \xi_{cz}\hat{Z}_{1t} = \hat{P}_{3t} \qquad \text{(B.2)}$$

$$C_{2t} \quad : \quad \xi_{cc}\hat{C}_{2t} + \xi_{cz}\hat{Z}_{2t} = \hat{P}_{3t} \qquad \text{(B.3)}$$

$$C_{3t} \quad : \quad \xi_{cc}\hat{C}_{3t} + \xi_{cz}\hat{Z}_{3t} = \hat{P}_{3t} \qquad \text{(B.4)}$$

$$Z_{1t} \quad : \quad \xi_{zc}\hat{C}_{1t} + \xi_{zz}\hat{Z}_{1t} = \hat{W}_{1t} \tag{B.5}$$

$$Z_{2t} \quad : \quad \xi_{zc}\hat{C}_{2t} + \xi_{zz}\hat{Z}_{2t} = \hat{W}_{2t} \tag{B.6}$$

$$Z_{3t} \quad : \quad \xi_{zc}\hat{C}_{3t} + \xi_{zz}\hat{Z}_{3t} = \hat{W}_{3t} \tag{B.7}$$

$$N_{1t} \quad : \quad \hat{P}_{1t} + \hat{A}_{1t} + s_1\hat{K}_{1t} + s_2\hat{N}_{1t} + s_3\hat{M}_{1t-1} = \hat{W}_{1t} \tag{B.8}$$

$$N_{2t} \quad : \quad \hat{P}_{2t} + \hat{A}_{2t} + s_4\hat{K}_{2t} + s_5\hat{N}_{2t} + s_6\hat{M}_{2t-1} = \hat{W}_{2t} \tag{B.9}$$

$$N_{3t} \quad : \quad \hat{P}_{3t} + \hat{A}_{3t} + s_7\hat{K}_{3t} + s_8\hat{N}_{3t} + s_9\hat{M}_{3t-1} = \hat{W}_{3t} \tag{B.10}$$

$$I_{1t} \quad : \quad \hat{\lambda}_{1t} + \frac{\phi^{''}(\frac{I_1}{K_1})}{\phi^{'}(\frac{I_1}{K_1})}\frac{I_1}{K_1}(\hat{I}_{1t} - \hat{K}_{1t}) = \hat{P}_{3t} \tag{B.11}$$

$$I_{2t} \quad : \quad \hat{\lambda}_{2t} + \frac{\phi^{''}(\frac{I_2}{K_2})}{\phi^{'}(\frac{I_2}{K_2})}\frac{I_2}{K_2}(\hat{I}_{2t} - \hat{K}_{2t}) = \hat{P}_{3t} \tag{B.12}$$

$$I_{3t} \quad : \quad \hat{\lambda}_{3t} + \frac{\phi^{''}(\frac{I_3}{K_3})}{\phi^{'}(\frac{I_3}{K_3})}\frac{I_3}{K_3}(\hat{I}_{3t} - \hat{K}_{3t}) = \hat{P}_{3t} \tag{B.13}$$

$$\begin{aligned} K_{1t+1} \quad &: \quad \hat{\lambda}_{1t} - \beta\mu(\frac{I_1}{K_1})\hat{\lambda}_{1t+1} - \beta(\frac{I_1}{K_1})\mu^{'}(\frac{I_1}{K_1})(\hat{I}_{1t+1} - \hat{K}_{1t+1}) \\ &= \quad [1 - \beta\mu(\frac{I_1}{K_1})][\hat{P}_{1t+1} + \hat{A}_{1t+1} + g_1\hat{K}_{1t+1} + g_2\hat{N}_{1t+1} + g_3\hat{M}_{1t}] \end{aligned} \tag{B.14}$$

$$\begin{aligned} K_{2t+1} \quad &: \quad \hat{\lambda}_{2t} - \beta\mu(\frac{I_2}{K_2})\hat{\lambda}_{2t+1} - \beta(\frac{I_2}{K_2})\mu^{'}(\frac{I_2}{K_2})(\hat{I}_{2t+1} - \hat{K}_{2t+1}) \\ &= \quad [1 - \beta\mu(\frac{I_2}{K_2})][\hat{P}_{2t+1} + \hat{A}_{2t+1} + g_4\hat{K}_{2t+1} + g_5\hat{N}_{2t+1} + g_6\hat{M}_{2t}] \end{aligned} \tag{B.15}$$

$$\begin{aligned} K_{3t+1} \quad &: \quad \hat{\lambda}_{3t} - \beta\mu(\frac{I_3}{K_3})\hat{\lambda}_{3t+1} - \beta(\frac{I_3}{K_3})\mu^{'}(\frac{I_3}{K_3})(\hat{I}_{3t+1} - \hat{K}_{3t+1}) \\ &= \quad [1 - \beta\mu(\frac{I_3}{K_3})][\hat{P}_{3t+1} + \hat{A}_{3t+1} + g_7\hat{K}_{3t+1} + g_8\hat{N}_{3t+1} + g_9\hat{M}_{3t}] \end{aligned} \tag{B.16}$$

$$\mu(Z) \quad = \quad [\phi(Z) - Z\phi^{'}(Z) + (1 - \delta)] \text{ and } \mu^{'}(Z) = -Z\phi^{''}(Z)$$

$$Y_{1t} \quad : \quad \hat{P}_{1t} = \hat{Q}_t - \frac{1}{\varepsilon}\hat{Y}_{1t} + \frac{1}{\varepsilon}h_1\hat{Y}_{1t} + \frac{1}{\varepsilon}h_2\hat{Y}_{2t} \tag{B.17}$$

$$Y_{2t} \quad : \quad \hat{P}_{2t} = \hat{Q}_t - \frac{1}{\varepsilon}\hat{Y}_{2t} + \frac{1}{\varepsilon}h_1\hat{Y}_{1t} + \frac{1}{\varepsilon}h_2\hat{Y}_{2t} \tag{B.18}$$

$$M_{1t} \quad : \quad \hat{Q}_t = \hat{P}_{1t+1} + \hat{A}_{1t+1} + b_1\hat{K}_{1t+1} + b_2\hat{N}_{1t+1} + b_3\hat{M}_{1t} \tag{B.19}$$

$$M_{2t} \quad : \quad \hat{Q}_t = \hat{P}_{2t+1} + \hat{A}_{2t+1} + b_4\hat{K}_{2t+1} + b_5\hat{N}_{2t+1} + b_6\hat{M}_{2t} \tag{B.20}$$

$$M_{3t} \quad : \quad \hat{Q}_t = \hat{P}_{3t+1} + \hat{A}_{3t+1} + b_7\hat{K}_{3t+1} + b_8\hat{N}_{3t+1} + b_9\hat{M}_{3t} \tag{B.21}$$

$$W_{1t} \quad : \quad (1 - N_1)\hat{Z}_{1t} + N_1\hat{N}_{1t} = 0 \tag{B.22}$$

$$W_{2t} \quad : \quad (1 - N_2)\hat{Z}_{2t} + N_2\hat{N}_{2t} = 0 \tag{B.23}$$

$$W_{3t} \quad : \quad (1 - N_3)\hat{Z}_{3t} + N_3\hat{N}_{3t} = 0 \tag{B.24}$$

$$\lambda_{1t} \quad : \quad \hat{K}_{1t+1} = \mu(\frac{I_1}{K_1})\hat{K}_{1t} + (\frac{I_1}{K_1})\phi^{'}(\frac{I_1}{K_1})\hat{I}_{1t} \tag{B.25}$$

$$\lambda_{2t} \quad : \quad \hat{K}_{2t+1} = \mu(\frac{I_2}{K_2})\hat{K}_{2t} + (\frac{I_2}{K_2})\phi^{'}(\frac{I_2}{K_2})\hat{I}_{2t} \tag{B.26}$$

$$\lambda_{3t} \quad : \quad \hat{K}_{3t+1} = \mu(\frac{I_3}{K_3})\hat{K}_{3t} + (\frac{I_3}{K_3})\phi^{'}(\frac{I_3}{K_3})\hat{I}_{3t} \tag{B.27}$$

$$P_{1t} \quad : \quad \hat{Y}_{1t} = \hat{A}_{1t} + H_1\hat{K}_{1t} + H_2\hat{N}_{1t} + H_3\hat{M}_{1t-1} \tag{B.28}$$

$$P_{2t} \quad : \quad \hat{Y}_{2t} = \hat{A}_{2t} + H_4\hat{K}_{2t} + H_5\hat{N}_{2t} + H_6\hat{M}_{2t-1} \tag{B.29}$$

$$P_{3t} \quad : \quad \hat{Y}_{3t} = \frac{\pi_1}{\pi_3}(\frac{C_1}{y_3}\hat{C}_{1t} + \frac{I_1}{y_3}\hat{I}_{1t}) + \frac{\pi_2}{\pi_3}(\frac{C_2}{y_3}\hat{C}_{2t} + \frac{I_2}{y_3}\hat{I}_{2t}) + (\frac{C_3}{y_3}\hat{C}_{3t} + \frac{I_3}{y_3}\hat{I}_{3t}) \tag{B.30}$$

$$Q_t \quad : \quad \hat{M}_t = \pi_1\frac{M_1}{M}\hat{M}_{1t} + \pi_2\frac{M_2}{M}\hat{M}_{2t} + \pi_3\frac{M_3}{M}\hat{M}_{3t} \tag{B.31}$$

$$Y_{3t} \quad : \quad \hat{Y}_{3t} = \hat{A}_{3t} + H_7\hat{K}_{3t} + H_8\hat{N}_{3t} + H_9\hat{M}_{3t-1} \tag{B.32}$$

$$M_t \quad : \quad \hat{M}_t = h_1\hat{Y}_{1t} + h_2\hat{Y}_{2t} \tag{B.33}$$

**Elasticities of Preference and Production Technology**

For simplicity, we introduce two new notations here:

$$\rho^K = \frac{\omega K^{1-\frac{1}{\sigma}}}{\omega K^{1-\frac{1}{\sigma}} + (1-\omega)M^{1-\frac{1}{\sigma}}}, \rho^M = \frac{(1-\omega)M^{1-\frac{1}{\sigma}}}{\omega K^{1-\frac{1}{\sigma}} + (1-\omega)M^{1-\frac{1}{\sigma}}}.$$

where $\rho^K$ and $\rho^M$ are the fractions of factor payments to capital and material, respectively. Note that $\rho^K + \rho^M = 1$. We then derive the following elasticities and shares:

| | |
|---|---|
| $\xi_{cc} = \frac{D_{11}U(C,Z)}{D_1U(C,Z)}C = \theta(1-\gamma) - 1$ | $\xi_{cz} = \frac{D_{12}U(C,Z)}{D_1U(C,Z)}Z = (1-\theta)(1-\gamma)$ |
| $\xi_{zc} = \frac{D_{21}U(C,Z)}{D_2U(C,Z)}C = \theta(1-\gamma)$ | $\xi_{zz} = \frac{D_{22}U(C,Z)}{D_2U(C,Z)}Z = (1-\theta)(1-\gamma) - 1$ |
| $s_1 = \frac{D_{21}F}{D_2F}K_1 = \frac{1-\alpha}{\sigma}\rho_1^V + \frac{(1-\alpha)(\sigma-1)}{\sigma}$ | $g_1 = \frac{D_{11}F}{D_1F}K_1 = \frac{1-\alpha}{\sigma}\rho_1^V + (\frac{\alpha-1}{\sigma} - \alpha)$ |
| $s_2 = \frac{D_{22}F}{D_2F}N_1 = \frac{\alpha}{\sigma}\rho_1^V + \frac{\alpha(\sigma-1)}{\sigma} - 1$ | $g_2 = \frac{D_{12}F}{D_1F}N_1 = \frac{\alpha}{\sigma}\rho_1^V + (-\frac{\alpha}{\sigma} + \alpha)$ |
| $s_3 = \frac{D_{23}F}{D_2F}M_1 = \frac{1}{\sigma}\rho_1^M$ | $g_3 = \frac{D_{13}F}{D_1F}M_1 = \frac{1}{\sigma}\rho_1^M$ |
| $b_1 = \frac{D_{31}F}{D_3F}K_1 = \frac{1-\alpha}{\sigma}\rho_1^V$ | $H_1 = \frac{D_1F}{F}K_1 = (1-\alpha)\rho_1^V$ |
| $b_2 = \frac{D_{32}F}{D_3F}N_1 = \frac{\alpha}{\sigma}\rho_1^V$ | $H_2 = \frac{D_2F}{F}N_1 = \alpha\rho_1^V$ |
| $b_3 = \frac{D_{33}F}{D_3F}M_1 = \frac{1}{\sigma}\rho_1^M - \frac{1}{\sigma}$ | $H_3 = \frac{D_3F}{F}M_1 = \rho_1^M$ |
| $h_1 = \frac{\omega_1}{\omega_1+\omega_2(\frac{Y_2}{Y_1})^{1-\frac{1}{\varepsilon}}}$ | $h_2 = \frac{\omega_2}{\omega_1(\frac{Y_1}{Y_2})^{1-\frac{1}{\varepsilon}}+\omega_2}$ |

Expressions for $s_4$ through $s_9$, $g_4$ through $g_9$, and $b_4$ through $b_9$ can be obtained by the same method.

# BIBLIOGRAPHY

[1] Backus, D. K. and Crucini, M. J., "Oil Prices and the Terms of Trade," Journal of International Economics 50, 185-213, 2000.

[2] Backus, D. K. and Kehoe, P. J. and Kydland, F. E., "International Business Cycles: Theory and Evidence,"in Thomas F. Cooley, ed., Frontiers of Business Cycle Research (Princeton University Press), 1995.

[3] Baxter, M. and Crucini, M. J., "Explaining Saving-Investment Correlations," American Economic Review 83, 416-436, 1993

[4] Berndt, E. R. and Wood, D. O., "Engineering and Econometric Interpretations of Energy-Capital Complementarity," American Economic Review 69, 342-354, 1979

[5] Bidarkota, P. and Crucini, M. J., "Commodity Prices and the Terms of Trade," Review of International Economics 8, 647-666, 2000.

[6] Bleaney, M. and Greenaway, D., "Longrun Trends in the Relative Price of Primary Commodities and in the Terms of Trade of Developing Countries," Oxford Economic Papers 45, 349-363, 1993.

[7] Borensztein, E. and Reinhart, C., "The Macroeconomic Determinants of Commodity Prices," IMF Staff Papers 41, 236-261, 1994.

[8] Chambers, M. and Bailey, R., "A Theory of Commodity Price Fluctuations," Journal of Political Economics 104, 924-957, 1996.

[9] Chari, V. V., Kehoe, P. J. and McGrattan, E. R., "Can Sticky Price Models Generate Volatile and Persistent Real Exchange Rate?," Review of Economic Studies 69, 533-563, 2002.

[10] Chu, K. Y. and Morrison, T. K., "World Non-Oil Primary Commodity Markets: A Medium Term Framework of Analysis, " IMF Working Paper 33, 139-184, 1986.

[11] Cochrane,J. H., "Permanent and Transitory Components of GNP and Stock Prices," Quarterly Journal of Economics, 30, 241-265, 1994.

[12] Cody,Brian J. and Mills, L., "Role of Commodity Prices in Formulating Monetary Policy," Review of Economics and Statistics, 73, 358-365, 1991.

[13] Crucini, M. J., "International Real Business Cycles," in the New Palgrave Dictionary of Economics, Stephen Durlauf and Lawrence Blume, editors, forthcoming, 2008.

[14] Crucini, M. J. and Shintani, M., "International Comovement: Is Theory Ahead of Business Cycle Measurement?," Working paper, 2008.

[15] Cuddington, J. and Urzua, C., "Trends and Cycles in the Net Barter Terms of Trade: A New Approach," Economic Journal 99, 426-442, 1989.

[16] Deaton, A. and Laroque, G., "On the Behaviour of Commodity Prices," Review of Economic Studies 59, 1-23, 1992.

[17] Deaton, A. and Laroque, G., "Competitive Storage and Commodity Price Dynamics," Journal of Political Economics 104, 896-923, 1996.

[18] Deaton, A. and Miller, R., "International Commodity Prices, Macroeconomic Performance and Politics in Sub-Saharan Africa," Journal of African Economies 5, 99-191, 1996.

[19] Dickey, D., and Fuller, W., "Likelihood Ratio Tests for Autoregressive Time Series with a Unit Root," Econometrica 49, 1057–1072, 1981.

[20] Garner, C. A., "How Useful Are Leading Indicators of Inflation?" Federal Reserve Bank of Kansas City Economic Review, 2nd Quarter, 5–18, 1995.

[21] Kim, I. and Loungani, P., "The Role of Energy in Real Business Cycle Models," Journal of Monetary Economics 29, 173-189, 1992.

[22] King, R. G., Plosser C. I. and Rebelo, S., "Production, Growth and Business Cycles, I: The Basic Neo-Classical Model," Journal of Monetary Economics 21, 195-232, 1988.

[23] King, R. G., Plosser C. I. and Rebelo, S., "Production, Growth and Business Cycles, II: New Directions," Journal of Monetary Economics 21, 309-343, 1988.

[24] Kose, M. A., "Explaining Business Cycles in Small Open Economies 'How Much Do World Prices Matter?'," Journal of International Economics 56, 299-327, 2002.

[25] Kouparitsas, M., "North-South Business Cycles," Working Paper, Federal Reserve Bank of Chicago, 1997.

[26] Kugler, P., "Common Trends, Commodity Prices and Consumer Prices," Economics Letters, 37, 345–349, 1991.

[27] Kydland, F. E. and Prescott, E. C., "To to Build and Aggregate Fluctuations," Econometrica 50, 1345-1370, 1982.

[28] Long, J. and Plosser, C., "Real Business Cycles," Journal of Political Economics 91, 39-69, 1983.

[29] Mendoza, E., "The Terms of Trade, the Real Exchange Rate, and Economic Fluctuations," International Economic Review 36, 101-137, 1995.

[30] Newbery, D. M. and Stiglitz, J. E., "Optimal Commodity Stockpiling Rules," Oxford Economic Papers 91, 39-69, 1982.

[31] Otrok, C. and Whiteman, C. H., "Bayesian Leading Indicators: Measuring and Predicting Economic Conditions in Iowa," International Economic Review 39, 997-1014, 1998.

[32] Reinhart, C. and Wickham, P., "Commodity Prices: Cyclical Weakness or Secular Decline?," IMF Working Paper 104, 94-7, 1994.

[33] Rotemberg, J. J. and Woodford, M., "Imperfect Competition and the Effects of Energy Price Increases on Economic Activity," Journal of Money, Credit and Banking 28, 549-577, 1996.

[34] Silverman, B. W., Density Estimation for Statistics and Data Analysis, (Chapman and Hall), 1986.

[35] Tomek, W. G. and Wang, D., "Commodity Prices and Unit Root Tests," American Journal of Agricultural Economics, 89, 873–889, 2007.

[36] Williams, J. C. and Wright, B. D., Storage and Commodity Markets, (Cambridge University Press), 1991.