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Commodities and International Business Cycles

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Commodities and International Business Cycles

I introduce commodities and countries’ different commodity trade structures into an otherwise standard two-country model to analyze international business cycles between the U.S. and commodity-exporting countries. In the model, only the foreign country (the commodity-exporting country) produces commodities and exports them to the home country (the U.S., the commodity-importing country). The model produces international business cycle statistics that are closer to the data than a standard model. In particular, the output correlation between the two countries increases and the consumption correlation falls compared to the standard model. Notably, unlike standard models, this model yields an output correlation that exceeds the consumption correlation, which mitigates the “quantity anomaly” that was previously noted in the literature. Commodity consumption and the complementarity between commodities and noncommodity goods in consumption play key roles in generating this result.

Keywords: International Business Cycles, Commodity-exporting countries, Commodity Trade Structures

JEL Classification: F40, F41, F44
I. Introduction

The existing literature does not specifically consider international business cycles between the U.S. and commodity-exporting countries, although they are different from those between the U.S. and commodity-importing countries. To address this shortcoming in the literature, I construct a standard two-country model with commodities and with idiosyncratic commodity trade structures between the two countries. This model generates international business cycle statistics that are closer to the actual data than those generated by the standard model, increasing the output correlation between the two countries and decreasing the consumption correlation between them. Furthermore, this model yields a slightly higher output correlation than consumption correlation, which is consistent with the ranking in the data. On the other hand, standard models typically produce the opposite prediction, which is referred to in the literature as the “quantity anomaly.”

Therefore, adding commodities, with consideration for different commodity trade structures, helps to mitigate the quantity anomaly.

Commodities such as oil, wheat, basic metals, etc. have peculiar features compared to other tradable goods. They are used as inputs in production in almost every sector, as well as consumed by households. Other tradable goods, however, are typically only consumed or only used as inputs in production in a specific sector. Due to these features of commodities, changes in commodity prices affect both households and firms, which means that commodity prices have a more widespread effect on the economy than prices of other tradable goods. Thus, macroeconomists generally regard changes in commodity prices as a critical source of economic fluctuation and one that can affect many countries simultaneously (Blanchard and Galí, 2007).

1) Alternatively, the “international consumption correlation puzzle” or the “BKK puzzle.”
2) For example, energy is not only consumed but also used as an input in all sectors. On the contrary, jeans are consumed, but not used for production. (They can be used in production, I suppose, but very rarely.) Semiconductors are only used for production in the electronics sector, and are not consumed by households.
Furthermore, each country has its own idiosyncratic commodity trade structure. For instance, countries like the U.S. are net commodity-importing countries. Countries like Canada are net commodity-exporting countries. Therefore, each country will be affected by the same shock in a different way. As a result, several papers studying North-South interactions, such as Moutos and Vines (1989), have already emphasized that to properly capture macroeconomic interactions between countries in open economy macro models, the asymmetries of trade and production resulting from commodities should be considered.

As an illustration, output growth triggered by a certain shock in the U.S., a commodity-importing country, would increase its demand for imports of commodities for both production and consumption. Accordingly, commodity prices would go up, since the U.S. is a large economy. This increased demand for commodity imports and the resulting higher prices would have a positive influence on the economies of commodity-exporting countries. Conversely, higher commodity prices would adversely affect the economies of commodity-importing countries. Hence, U.S. output would be expected to have stronger positive correlations with outputs of commodity-exporting countries than those of commodity-importing countries.

In accordance with this hypothesis, the U.S. has higher positive GDP correlations with commodity-exporting countries than with commodity-importing countries based on the data (see Section II for details). It may therefore be reasonable to analyze U.S. international

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3) From 1995 to 2011, the average ratios of net commodity exports to trade (gross exports plus gross imports) in the U.S. and Canada were -5.4% and 6.9%, respectively, according to the OECD Trade in Value Added database. Following the IMF’s commodity price index, this paper defines the commodity sector as the agriculture, hunting, forestry, fishing, mining, quarrying, wood and basic metal industries.

4) In these models, “Northern” economies, i.e., developed countries, produce industrial goods, and “Southern” economies, i.e., developing countries, produce commodities.

5) Although China can be regarded as a large economy like the U.S., it does not have higher positive GDP correlations with commodity-exporting countries than with commodity-importing countries in the data. This might be because it has started to act as a global player since November 2001 when it joined the WTO. Therefore, this paper only focuses on international business cycles between the U.S. and commodity-exporting countries.
business cycles with commodity-exporting countries and those with commodity-importing countries separately. Surprisingly, however, international business cycles between the U.S. and commodity-exporting countries have not been specifically analyzed in the international business cycle literature, even though they are significantly different from those between the U.S. and commodity-importing countries.

To analyze international business cycles between the U.S. and commodity-exporting countries, this paper introduces commodities and different commodity trade structures into the workhorse model with nontradable goods of Stockman and Tesar (1995), henceforth ST. The primary differences of this model from ST’s model are that only the foreign country produces commodities, that commodities are used as an input in the production of tradable goods, and that commodities are consumed as a complement to noncommodity consumption goods.6)

The main goal of this paper is to examine whether this model can replicate the main properties of business cycle comovements between the U.S. and commodity-exporting countries well with a focus on output and consumption correlations; (i) to show that this model yields a higher output correlation between the two countries than the standard model and (ii) that the model produces a higher output correlation than consumption correlation (i.e., mitigates the quantity anomaly). Introducing commodities, with consideration for idiosyncratic commodity trade structures of countries, into a standard model can indeed help strengthen the connection between outputs in the two countries and lower the consumption correlation, and hence mitigate the quantity anomaly. In this model, there is complementarity between commodities and noncommodity goods in consumption. Complementarity and commodity consumption play important roles in this analysis.

As for the output correlation, positive productivity shocks in the

6) There are many empirical studies showing that they (especially oil and non-oil goods) are complements (see Cooper, 2003; Hughes, Knittel and Sperling, 2006; Bodenstein, Erceg and Guerrieri, 2011; etc.).
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home country\(^7\) bring about rises in the home country’s aggregate output and in its demand for imports of both foreign tradable goods and commodities. Thus, the real prices of foreign tradable goods and commodities increase. This rise in home demand for imports of foreign tradable goods is offset by their increased real prices. However, for commodities, despite their increased real price, home commodity consumption goes up, since there is complementarity between commodities and noncommodity goods in consumption and the shocks also raise home noncommodity consumption. Foreign commodity output rises, which leads to a greater increase in foreign aggregate output compared to the standard model without commodities. That is, in this model, productivity shocks in the home country have larger spillovers into the foreign country than in the standard model. Consequently, the output correlation in this model is higher than that in the standard model.

Commodity consumption, which is not in the standard model, together with complementarity plays a key role in lowering the consumption correlation. When a positive productivity shock hits the home tradable sector, home commodity consumption and real commodity prices increase, and the real prices of home tradable goods fall. Foreign noncommodity consumption rises owing to the fall in the real price of home tradable goods. In spite of the rise in real commodity prices, foreign commodity consumption goes up, due to complementarity. Thus, with respect to the shock, home and foreign commodity consumption are positively correlated. On the contrary, in response to a positive productivity shock in the home nontradable sector, home aggregate output and commodity consumption both rise. The real prices of commodity and tradable goods produced in both countries increase, since the increased home aggregate output puts upward pressure on them. Foreign noncommodity consumption falls due to the

---

\(^7\) The responses to productivity shocks in the foreign country in this model, in terms of both home and foreign outputs, are similar to those in the standard model. Thus, mainly due to productivity shocks in the home country, the output correlation in this model is higher than it is in the standard model.
increased real price of tradable goods. Thus, foreign commodity consumption falls as well owing to not only complementarity but also to the increased real commodity prices. Accordingly, home and foreign commodity consumption are negatively correlated with respect to the shock.\(^8\) This negative correlation enables the correlation between home and foreign commodity consumption to be lower than that between home and foreign noncommodity consumption, despite the positively correlated home and foreign commodity consumption with respect to productivity shocks in the tradable sector. As a result, this model yields a lower consumption correlation than in the standard model in which commodity consumption does not exist.

Since the quantity anomaly was first presented in Backus, Kehoe and Kydland (1992), henceforth BKK, which assumes complete asset markets, a number of papers have tried to tackle the anomaly. One strand of the literature attempts to address the anomaly by restricting asset trade between countries (see Baxter and Crucini, 1995; Kollman, 1996; Heathcote and Perri, 2002; Kehoe and Perri, 2002; etc.). This paper is related to the other strand of the literature, which maintains complete asset markets and which adds new elements or disturbances to models to tackle the anomaly. For example, non-traded goods and taste shocks (ST), the distribution sector (Corsetti, Dedola and Leduc, 2008,\(^9\) henceforth CDL), investment composition (Oviedo and Singh, 2013), Greenwood-Hercowitz-Huffman (GHH) preferences with internal habit formation in consumption (Dmitriev and Roberts, 2012), Epstein-Zin-Weil and GHH preferences (Kollman, 2017), etc. Some papers have tried to find factors causing the high output correlation between countries: similar financial market structures

\(^8\) As for productivity shocks in the foreign country, similarly to those in the home country, home and foreign commodity consumption are positively correlated with respect to productivity shocks in the foreign tradable sector, while they are negatively correlated with respect to productivity shocks in the foreign nontradable sector.

\(^9\) Although their baseline model assumes that asset markets are incomplete to address the Backus-Smith puzzle, they also simulate their model with complete asset markets.
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(Faia, 2007), the globalization of banking (Ueda, 2012), and so on. Among these, the model in this paper is closest to models of ST and CDL in which there are tradable and nontradable sectors, and where sectoral productivity shocks are used to generate international business cycle statistics.

The paper is organized as follows. Section II shows the main properties of business cycle comovements between the U.S. and commodity-exporting countries. Section III describes the model in which commodities and different commodity trade structures are considered. Section IV presents the model analysis, and Section V is the conclusion.

II. Properties of U.S. Business Cycle Comovements

In this section, I first present the annual U.S. GDP correlations with major countries to identify whether U.S. GDP correlations with commodity-exporting countries are significantly higher than those with commodity-importing countries. Then I show international business cycle statistics between the U.S and commodity-exporting OECD countries, and between the U.S. and commodity-importing OECD countries, based on annual data of OECD-member countries for the period of 1990-2015. I briefly explain the main properties of the former and the differences between the former and the latter, with a focus on the output and consumption correlations.10)

1. U.S. GDP Comovements

Since the U.S. is a large economy, changes in its demand for commodity imports affect commodity prices. Specifically, a rise in its output will increase its demand for commodity imports, and thus commodity prices will go up. Rises in U.S. demand for imports of

10) See Appendix A for details of the data.
commodities and commodity prices will have a positive effect on outputs in commodity-exporting countries, while an increase in commodity prices will adversely affect outputs in commodity-importing countries. Hence, we would expect the U.S. to have stronger GDP comovements with commodity-exporting countries than with commodity-importing countries.

Figure 1. GDP Correlations with U.S. GDP and Ratios of Net Commodity Exports to Trade

Figure 1 shows the relationship between U.S. GDP correlations with major countries’ GDPs and the ratios of net commodity exports to trade of those major countries. Consistent with our initial expectations, there seems to be a positive relationship between the two measures. In other words, as a country’s weight of net commodity exports in its trade grows, it has a larger GDP correlation with the U.S., i.e., the U.S. GDP correlations with commodity-exporting countries tend to be higher than those with commodity-importing countries.
2. Main Properties of U.S. Business Cycle Comovements with Commodity Exporters

Table 1 shows main international business cycle statistics for the U.S.: the correlations between U.S. GDP and consumption, and the same variables for commodity-exporting and commodity-importing OECD countries.

<table>
<thead>
<tr>
<th>Variables</th>
<th>OECD Exporters</th>
<th>OECD Importers</th>
<th>Commodity Exporters</th>
<th>Commodity Importers</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>0.740</td>
<td>0.504</td>
<td>0.662</td>
<td>0.854</td>
</tr>
<tr>
<td>Consumption</td>
<td>0.585</td>
<td>0.266</td>
<td>0.653</td>
<td>0.624</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.100</td>
<td>0.408</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.100</td>
<td>−0.163</td>
</tr>
</tbody>
</table>

Notes: Statistics are computed using detrended data with Hodrick-Prescott filter. The sample period is 1990-2015. Figures in the first and second columns are trade-weighted averages of commodity-exporting and commodity-importing OECD member countries, respectively. Source: OECD

The correlations between U.S. GDP and GDPs of other major countries are positive and high. Canada has a very large correlation, 0.854. The correlations for Japan (0.408) and Germany (0.375) are relatively small. More importantly, the correlation between the U.S. GDP and the GDP of commodity-exporting OECD countries (0.740) is substantially higher than that between the U.S. GDP and the GDP of commodity-importing OECD countries (0.504).

U.S. consumption is also positively correlated with consumption in other major countries, except Japan. However, consumption correlations are lower than GDP correlations. Specifically, U.S. consumption correlations with consumptions of commodity-exporting (0.585) and commodity-importing (0.266) OECD countries are smaller than U.S. GDP correlations with the GDPs of commodity-exporting (0.740) and commodity-importing (0.504) OECD countries.

In sum, U.S. GDP is more strongly correlated with the GDPs of commodity-exporting countries than with those of commodity-
importing countries. The GDP correlation between the U.S. and commodity-exporting countries is higher than the consumption correlation between them. These are the main properties of international business cycles between the U.S. and commodity-exporting countries that the model in this paper tries to replicate.

Ⅲ. The Model

In this section, I describe the two-country model with commodities in which different commodity trade structures of each country are considered. This research builds on the open economy macro models of several papers (BKK; ST; Backus and Crucini, 2000; CDL). The model is mainly based on ST. I only add commodities to the two-country, two-sector model of ST.

To be specific, the world economy consists of two countries: the home country (the U.S., commodity-importing country) and the foreign country (commodity-exporting country). The home country produces tradable and nontradable goods and imports commodities, while the foreign country produces commodities as well as tradable and nontradable goods and exports commodities. Capital is sector-specific. Labor is mobile between sectors but immobile between countries. Asset markets are complete.11)

The main differences with this model compared to that used by ST are that commodities as a complement to noncommodity goods are in the consumption basket of households, that commodities are used in the production of tradable goods as an input, and that the foreign country produces commodities while the home country does not.

11) According to Baxter and Crucini (1995) and others, models with incomplete asset markets can generate notable differences from those with complete asset markets only when shocks are highly persistent (i.e. unit root shocks) and do not have any international spillovers. Otherwise, models with incomplete and complete asset markets yield very similar international business cycle statistics. Since estimates of the shocks used in this paper are not highly persistent and have international spillovers (for details, see Section Ⅳ), I assume complete asset markets for the model used in this paper.
I next explain the details of this model. I focus on the equations for the home country. Unless stated otherwise, there are symmetric equations for the foreign country.

1. Households

The representative household in each country maximizes the following utility.

\[
U = E_0 \sum_{t=0}^{\infty} \beta^t \left( \ln C_t - \frac{L_t^{1+\chi}}{1+\chi} \right),
\]

where \( E_0 \) is the conditional expectations operation, \( C_t \) is the composite of tradable, nontradable and commodity consumption goods, \( L_t \) is the labor supply by household, \( \beta \) is the discount factor, and \( \chi \) is the inverse of Frisch elasticity of labor supply.

The budget constraint is

\[
C_t + E_t \{ Q_{t,t+1} D_{t+1} \} = W_t L_t + D_t + \Pi_t,
\]

with \( L_t = L_{T,t} + L_{N,t} \). \( Q_{t,t+1} \), \( D_{t+1} \), \( W_t \) and \( \Pi_t \) denote the stochastic discount factor for one-period ahead real pay-offs relevant to the home household, the real pay-off in period \( t+1 \) of the portfolio held at the end of period \( t \), the real wage and the profits remitted by firms, respectively. The subscripts \( T \), \( N \) and \( X \) denote the tradable, nontradable and commodity sectors, respectively. \( E_t[Q_{t,t+1}] \) is related to the risk free rate, \( R_t \), i.e. \( E_t[Q_{t,t+1}] = 1/R_t \).

The composite of consumption goods, \( C_t \), is defined as the following constant elasticity of substitution (CES) aggregator function of

---

12) For the equilibrium conditions of the model, see Appendix B.
13) Since the commodity sector exists in the foreign country, \( L_t^* = L_{T,t}^* + L_{N,t}^* + L_{X,t}^* \). The superscript asterisk (*) denotes the variables in the foreign country.
noncommodity consumption goods, $C_{NC,t}$, and commodity consumption goods, $C_{X,t}$:

$$
C_t = \left\{ \frac{1}{\gamma_0} \frac{\eta_0 - 1}{\eta_0} C_{NC,t}^{\frac{\eta_0}{\eta_0}} + \frac{1}{\gamma_0} \frac{\eta_0 - 1}{\eta_0} C_{X,t}^{\frac{\eta_0}{\eta_0}} \right\}^{\frac{\eta_0}{\eta_0} - 1} \cdot (3)
$$

The noncommodity consumption goods, in turn, are similarly defined by tradable, $C_{T,t}$, and nontradable consumption goods, $C_{N,t}$:

$$
C_{NC,t} = \left\{ \frac{1}{\gamma_1} \frac{\eta_1 - 1}{\eta_1} C_{T,t}^{\frac{\eta_1}{\eta_1}} + \frac{1}{\gamma_1} \frac{\eta_1 - 1}{\eta_1} C_{N,t}^{\frac{\eta_1}{\eta_1}} \right\}^{\frac{\eta_1}{\eta_1} - 1} \cdot (4)
$$

The tradable consumption goods consist of tradable consumption goods produced in the home country, $C_{H,t}$, and tradable consumption goods produced in the foreign country, $C_{F,t}$:

$$
C_{T,t} = \left\{ \frac{1}{\gamma_2} \frac{\eta_2 - 1}{\eta_2} C_{H,t}^{\frac{\eta_2}{\eta_2}} + \frac{1}{\gamma_2} \frac{\eta_2 - 1}{\eta_2} C_{F,t}^{\frac{\eta_2}{\eta_2}} \right\}^{\frac{\eta_2}{\eta_2} - 1} \cdot (5)
$$

The corresponding price indices, $P_t$ (CPI), $P_{NC,t}$ (price of noncommodity consumption goods) and $P_{T,t}$ (price of tradable consumption goods), are the following.\(^{14}\)

$$
P_t = \left\{ (1 - \gamma_0) P_{NC,t}^{1-\eta_0} + \gamma_0 P_{X,t}^{1-\eta_0} \right\}^{\frac{1}{1-\eta_0}}, \quad (6)
$$

$$
P_{NC,t} = \left\{ (1 - \gamma_1) P_{T,t}^{1-\eta_1} + \gamma_1 P_{N,t}^{1-\eta_1} \right\}^{\frac{1}{1-\eta_1}}, \quad (7)
$$

$$
P_{T,t} = \left\{ (1 - \gamma_2) P_{H,t}^{1-\eta_2} + \gamma_2 P_{F,t}^{1-\eta_2} \right\}^{\frac{1}{1-\eta_2}}, \quad (8)
$$

\(^{14}\) The uppercase letter $P$ denotes nominal prices, and the lowercase letter $p$ denotes real prices.
where \( P_{X,t} \) is the price of commodity consumption goods, \( P_{N,t} \) is the price of nontradable consumption goods, \( P_{H,t} \) is the price of tradable consumption goods produced in the home country, and \( P_{F,t} \) is the price of tradable consumption goods produced in the foreign country.

2. Firms

Nontradable goods and commodity producers use labor and capital as inputs for their productions, while tradable goods producers use commodities as well as labor and capital for their production. Both countries produce tradable and nontradable goods with the same production function, but only the foreign country produces commodities. Firms purchase capital at the end of period \( t-1 \) to produce goods in period \( t \), and sell the non-depreciated capital back to capital good producers at the end of period \( t \).

2.1. Nontradable Goods Producers

Nontradable goods producers use labor and capital in production, and both countries produce nontradable goods with the identical production function.

\[
Y_{N,t} = A_{N,t} K_{N,t}^{\alpha_N} L_{N,t}^{1-\alpha_N},
\]

where \( Y_{N,t} \) is the output of nontradable goods, \( A_{N,t} \) is the productivity in the nontradable production, \( K_{N,t} \) is the capital used in the nontradable production, \( L_{N,t} \) is the labor, and \( 1-\alpha_N \) is the labor share of income.

2.2. Tradable Goods Producers

Both countries produce tradable goods by using capital, labor and commodities as inputs. The production function of tradable goods is a
nested CES as in Kim and Loungani (1992) and Backus and Crucini (2000).

\[ Y_{H,t} = A_{T,t} \left\{ (1 - \alpha)K_{T,t}^{-\nu} + \alpha x_t^{-\nu} \right\}^{-\frac{\alpha}{\nu}} L_{T,t}^{1-\alpha}, \]  

where \( Y_{H,t}, A_{T,t}, K_{T,t}, x_t \) and \( L_{T,t} \) denote the output, productivity, capital, commodities and labor for the production of tradable goods, respectively. \( 1 - \alpha \) is the labor share of income. \( a \) determines the importance of commodities, and \( \nu = \frac{1 - \varsigma}{\varsigma} \), where \( \varsigma \) is the elasticity of substitution between capital and commodities.

### 2.3. Commodity Producers

Commodity producers use capital and labor as inputs in production, and only the foreign country produces commodities. The production function is Cobb-Douglas as in Arora and Gomis-Porqueras (2011) and Huynh (2016).

\[ Y_{X,t} = A_{X}^* K_{X,t}^{*\alpha_X} L_{X,t}^{*1-\alpha_X}, \]

where \( Y_{X,t}, A_{X}^*, K_{X,t}^* \) and \( L_{X,t}^* \) are the output, productivity, capital and labor for the commodity production, respectively. \( 1 - \alpha_X \) is the labor share of income.

### 2.4. Capital Goods Producers

The capital goods producers convert final goods to capital goods. In each period they buy \( I_{j,t}, \ j = T,N,X \) of final goods at \( p_{j,t} \) and \( (1 - \delta)K_{j,t} \) of used capital from firms at price \( Q_{j,t} \). Then, they produce \( K_{j,t+1} \) of new capital goods. Thus, the capital goods producer’s problem is given by
\[
\max_{K_{j,t+1}} Q_{j,t} K_{j,t+1} - (1 - \delta) Q_{j,t} K_{j,t} - p_{j,t} I_{j,t},
\]
subject to the law of motion for capital

\[
K_{j,t+1} = (1 - \delta) K_{j,t} + \phi \left( \frac{I_{j,t}}{K_{j,t}} \right) K_{j,t},
\]

(12)

where \(\delta\) is the depreciation rate and \(\phi(\cdot)\) is the adjustment cost function satisfying \(\phi > 0, \phi' > 0\) and \(\phi'' < 0\).

3. Resource Constraints

Output in the nontradable sector in the home country has to be the same as the home country’s demand for nontradable goods plus its investment. Output in the tradable sector in the home country must equal the world demand for the tradable goods produced in the home country plus its investment. Thus, the resource constraints of the home country can be written as:

\[
Y_{N,t} = C_{N,t} + I_{N,t},
\]

(13)

\[
Y_{H,t} = C_{H,t} + C_{H,t} + I_{T,t}.
\]

(14)

\[\text{15) Since output in the commodity sector in the foreign country should be equal to the world demand for commodities for consumption and production plus its investment, the resource constraint of the commodity sector in the foreign country is } Y_{X,t} = C_{X,t} + C_{X,t} + x_{t} + x_{t} + I_{X,t}.\]
IV. Model Analysis

In this section, I first provide model calibration. Then I present international business cycle statistics that the model produces, and explain why the model yields different international business cycle statistics from a standard model in which commodities do not exist. Finally, I apply the model to the “Dutch disease” and conduct a sensitivity analysis of the model’s results in which the productivity shocks used in other papers and various values of the parameters in the newly introduced features, as compared to the standard model, are considered.

In this section, it is further assumed that productivity in the commodity production is fixed, while the productivities in the tradable and nontradable sectors are stochastic, as in ST. This is because the main aim of this paper is to show that instead of adding additional shocks, adding commodities and idiosyncratic commodity trade structures to a standard model can help produce better international business cycle statistics compared to the standard model. Nevertheless, in the sensitivity analysis I examine whether the main results of this paper are maintained when commodity productivity is stochastic.

1. Calibration

Table 2 lists the parameter values for the model, based on U.S. annual data. I assume symmetry between the two countries following standard literature, with the exception of the commodity sector.

I borrow certain parameter values from the standard literature. The discount factor, $\beta$, is 0.96, and the depreciation rate of capital, $\delta$, is 0.1, following ST and CDL. The inverse of Frisch elasticity of labor supply, $\chi$, is set to 3, as in Galí and Monacelli (2005). Following ST, I set the labor shares of income in the nontradable $(1-\alpha_N)$ and tradable $(1-\alpha)$ sectors at 0.56 and 0.61, respectively. With regard to capital adjustment costs, the elasticity of the investment/capital ratio with
respect to the price of capital, \(- (\phi_j^\prime / \phi_j^\prime) / (I_j / K_j)\) for all \(j\), is 30, which generates realistic investment volatility.

The elasticity of substitution between capital and commodities in the tradable production, \(1/(\nu + 1)\), is 1, following Kim and Loungani (1992).\(^{16}\) The parameter related to the weight of commodities in the tradable production, \(a\), is set to 0.193. This value is determined by the values of \(\nu\), \(K_T / x\), \(\beta\) and \(\delta\).\(^{17}\) Based on the assumption that real wages in each sector are identical in the model due to labor mobility between sectors, the labor share of income in the commodity sector, \(1 - \alpha_x\), is set to 0.66.

From the U.S. Energy Information Administration (EIA), the average ratio of the end-use energy expenditure to GDP during the 1997-2015 period is around 8%. Considering that the weight of energy in the IMF’s commodity price index is 0.631, I assume that the ratio of commodity expenditure to GDP is about 12%. During the same period, the average ratio of commodity output to GDP in the U.S. is around 4%, based on the NIPA data. This implies that the average ratio of net commodity imports to GDP \((C_X + x) / Y\) for 1997-2015 is about 8%. Since based on the EIA data the average ratio of energy consumption\(^ {18}\) to the end-use energy expenditure for 1997-2015 is around 51%, the average ratio of commodity consumption to GDP \((C_X / Y)\) is about 4%, which means that the average ratio of commodity inputs to GDP \((x / Y)\) is about 4%. Consistently with these figures, I assume that the steady state capital/commodity ratio in the tradable production, \(K_T / x\), is 29.5 and the weight of commodity consumption goods in the composite of consumption goods, \(\gamma_0\), is 0.0645.

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16) Kim and Loungani (1992) consider two cases, \(1/(\nu + 1) = 1\) and \(1/(\nu + 1) = 0.588\). They refer to the former case as the “Cobb-Douglas” case and the latter as the “CES” case. Considering that the Cobb-Douglas case replicates the business cycle data better than the CES case in Kim and Loungani (1992), this model uses \(1/(\nu + 1) = 1\).

17) From the first order conditions of households and firms in steady state, \(a = [1 + (1/\beta - 1 + \delta) (K_T/x)^{\nu + 1}]^{-1}\). Variables without the time subscript \(t\) denote their steady state values.

18) I use energy expenditure of the residential sector and motor gasoline as energy consumption.
Table 2. Parameter Values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.96</td>
<td>Discount factor</td>
</tr>
<tr>
<td>$\delta$</td>
<td>0.1</td>
<td>Depreciation rate of capital</td>
</tr>
<tr>
<td>$\chi$</td>
<td>3</td>
<td>Inverse of Frisch elasticity of labor supply</td>
</tr>
<tr>
<td>$1 - \alpha$</td>
<td>0.56</td>
<td>Labor share in the nontradable sector</td>
</tr>
<tr>
<td>$1 - \alpha$</td>
<td>0.61</td>
<td>Labor share in the tradable sector</td>
</tr>
<tr>
<td>$1/(\nu+1)$</td>
<td>1</td>
<td>Elasticity of substitution between commodities and capital in the tradable production</td>
</tr>
<tr>
<td>$a$</td>
<td>0.193</td>
<td>Parameter related to the weight of commodities in the tradable production</td>
</tr>
<tr>
<td>$1 - \alpha_X$</td>
<td>0.66</td>
<td>Labor share in the commodity sector</td>
</tr>
<tr>
<td>$\gamma_0$</td>
<td>0.0645</td>
<td>Weight of commodities in the composite of consumption goods</td>
</tr>
<tr>
<td>$\eta_0$</td>
<td>0.3</td>
<td>Elasticity of substitution between commodity and noncommodity consumption goods</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>0.5345</td>
<td>Weight of nontradable goods in the noncommodity consumption goods</td>
</tr>
<tr>
<td>$\eta_1$</td>
<td>0.44</td>
<td>Elasticity of substitution between tradable and nontradable goods</td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>0.4259</td>
<td>Weight of foreign tradable goods in the tradable consumption goods in the home country</td>
</tr>
<tr>
<td>$\gamma^*_2$</td>
<td>0.6971</td>
<td>Weight of home tradable goods in the tradable consumption goods in the foreign country</td>
</tr>
<tr>
<td>$\eta_2$</td>
<td>1</td>
<td>Elasticity of substitution between home and foreign tradable goods</td>
</tr>
</tbody>
</table>

Other parameters associated with consumption are as follows. The elasticity of substitution between commodity and noncommodity consumption goods, $\eta_0$, is 0.3 following Natal (2012). The weight of nontradable consumption goods in the noncommodity consumption goods, $\gamma_1$, is 0.5345.\(^{19}\) The elasticity of substitution between tradable and nontradable consumption goods, $\eta_1$, is 0.44 which is borrowed from ST. The weight of tradable consumption goods produced in the foreign country in the tradable consumption goods in the home country, $\gamma_2$, is 0.4259.\(^{20}\) The weight of tradable consumption goods produced in the

---

\(^{19}\) Since commodities are part of tradable goods, $\gamma_1 = 0.5345$ is consistent that the steady state ratio of consumption of all tradable goods (commodities and tradable goods in the model) to nontradable consumption, $(C_X + C_T)/C_{X}$, is 1, which is the same as ST’s assumption.

\(^{20}\) Considering that commodities are also tradable goods, under $\gamma_2 = 0.4259$ the steady state ratio of imported commodity and tradable consumption goods to total tradable consumption goods in the home
home country in the tradable consumption goods in the foreign country, $\gamma_2^*$, is 0.6971, which is a result of the assumptions that the steady state values of aggregate consumption in both countries are equal ($C = C^*$). The elasticity of substitution between home and foreign tradable consumption goods, $\eta_2$, is set to 1, following ST.

Finally, productivities in the tradable and nontradable sectors in the home and the foreign countries follow an AR(1) process as in BKK, ST and CDL.

$$A_t = \rho A_{t-1} + e_t,$$

where $A_t = [A_{T,t}, A^*_T, A_{N,t}, A^*_N]^T$ and $e_t = [e_{T,t}, e^*_T, e_{N,t}, e^*_N]^T$ is the vector of productivity shocks. As in BKK and CDL, to estimate the process I use annual data of the “index of output per hour in manufacturing” and the “index of output per hour in private services” for the period 1970-2015 from the BLS as the productivity in the home tradable and nontradable sectors, and as the productivity in the foreign tradable and nontradable sectors average of commodity-exporting OECD countries’ indices of manufacturing output and output in services divided by sectoral total employment for the period 1970-2015 from the OECD STAN sectoral database are used.21) The coefficient matrix, $\rho$, and the variance-covariance matrix of productivity shocks, $Var(e_t)$ (in percent), are

$$\rho = \begin{pmatrix} 0.909 & -0.002 & -0.002 & 0.036 \\ -0.002 & 0.909 & 0.036 & -0.002 \\ 0.019 & -0.010 & 0.889 & -0.055 \\ -0.010 & 0.019 & -0.055 & 0.889 \end{pmatrix}, \quad Var(e_t) = \begin{pmatrix} 0.053 & 0.015 & 0.012 & 0.002 \\ 0.015 & 0.053 & 0.002 & 0.012 \\ 0.012 & 0.002 & 0.010 & 0.001 \\ 0.002 & 0.012 & 0.001 & 0.010 \end{pmatrix}.$$
2. International Business Cycles

Table 3 shows the business cycle statistics from the model and a standard model (model without commodities) driven by productivity shocks, in terms of the relative standard deviations of consumption, investment and net exports to output in the home country, their correlations with output in the home country, and correlations of output, consumption and investment between the home and the foreign countries. Nonetheless, since the main aim of this paper is to show that the output correlation in this model is higher than the consumption correlation in this model and the output correlation in the standard model, I focus on the output and consumption correlations between the two countries.

The standard model is unsuccessful in replicating the main properties of international business cycles between the U.S. and commodity-exporting countries explained in Section II. Specifically, the output correlation between the two countries is lower than the data. The consumption correlation between the two is too high and greater than the output correlation. These are very different from the data, but typical in international business cycle models.

The model, however, produces much closer international business cycle statistics to the data than the standard model.

Specifically, the output correlation in the model (0.741) is higher than that in the standard model (0.660) and very close to the data (0.740). Although the consumption correlation in the model (0.709) is still higher than the data (0.585), it is slightly lower and thus closer to the data than that in the standard model (0.712). As a consequence, in this model the output correlation (0.741) is slightly greater than the consumption correlation (0.709), i.e., the quantity anomaly is mitigated. In short, this model produces better business cycle comovements between the U.S. and commodity-exporting countries in terms of the output and consumption correlations compared to the standard model.
Table 3. Business Cycle Statistics

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Data</th>
<th>Model</th>
<th>Model without commodities</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.D. relative to GDP in home</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption</td>
<td>0.986</td>
<td>0.595</td>
<td>0.539</td>
</tr>
<tr>
<td>Investment</td>
<td>3.389</td>
<td>2.543</td>
<td>2.281</td>
</tr>
<tr>
<td>Net exports</td>
<td>3.064</td>
<td>2.319</td>
<td>0.227</td>
</tr>
<tr>
<td>Correlation with GDP in home</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption</td>
<td>0.938</td>
<td>0.944</td>
<td>0.932</td>
</tr>
<tr>
<td>Investment</td>
<td>0.957</td>
<td>0.982</td>
<td>0.979</td>
</tr>
<tr>
<td>Net exports</td>
<td>−0.665</td>
<td>−0.982</td>
<td>−0.329</td>
</tr>
<tr>
<td>Correlation between home and foreign</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDP</td>
<td>0.740</td>
<td>0.741</td>
<td>0.660</td>
</tr>
<tr>
<td>Consumption</td>
<td>0.585</td>
<td>0.709</td>
<td>0.712</td>
</tr>
<tr>
<td>Investment</td>
<td>0.469</td>
<td>0.561</td>
<td>0.503</td>
</tr>
</tbody>
</table>

Notes: The correlation between home and foreign from the data is the trade-weighted average correlation between the same variables in the U.S. and in the commodity-exporting OECD countries. Net exports are defined as detrended exports minus detrended imports, as in ST. The sample period is 1990-2015. The statistics in the second and third columns are the models’ population moments for Hodrick-Prescott filtered results.

Source: OECD

As for other business cycle statistics, the model displays some discrepancies with the data, i.e., consumption, investment and net exports are less volatile relative to GDP, which is common in international business cycle models such as ST and CDL. Nonetheless, overall the model generates better business cycle statistics than the standard model, although it produces worse correlation of home investment with home GDP and correlation between the two countries’ investments. The standard deviations of consumption, investment and net exports relative to GDP in the home country and the correlation of net exports with GDP in the home country are all improved in this model, compared to the standard model.

Finally, it should be noted that these results cannot be of general application to all countries. These results can instead only be applied to international business cycles between the U.S. and commodity-exporting countries.
3. Features of the Model Generating the Output and Consumption Correlation Outcomes

In this section, I explain how the model generates better international business cycle statistics than the standard model (model without commodities), with a focus on the output and consumption correlations. Better international business cycle statistics in this model compared to the standard model are primarily because of the complementarity between commodity and noncommodity consumption goods and commodity consumption, which are not present in the standard model.

3.1. Output Correlation

With regard to the output correlation, when productivity shocks hit the home country, home and foreign aggregate outputs are highly correlated thanks to the complementarity between commodity and noncommodity consumption goods ($\eta_0 < 1$). However, they are weakly correlated when productivity shocks hit the foreign country, as in the standard model. That is, positive productivity shocks in the foreign country lead to an increase in its aggregate output, and its demand for home tradable goods thus goes up, which results in a rise in the real price of home tradable goods. The increased real price substantially offsets the increased demand for home tradable goods, which restricts an increase in output in the home tradable sector. Home aggregate output therefore increases by much less compared to the rise in foreign aggregate output. This is very similar to the standard model.

In contrast, outputs of the two countries are strongly correlated with respect to productivity shocks in the home country compared to the standard model. Positive productivity shocks in the home country raise its aggregate output and consumption, which leads to an increase in its demand for imports of commodities and foreign tradable goods. The increased demand causes rises in the real prices of commodities
and foreign tradable goods. Differently from foreign tradable goods whose increased demand is substantially offset by the increased real price, although the real commodity price increases, home commodity consumption goes up thanks to the complementarity between commodity and noncommodity consumption goods, and hence the home country imports more commodities. Output in the foreign commodity sector rises, which leads to a larger increases in foreign aggregate output compared to the standard model.

Putting all this together, although the model does not generate notable differences in output correlation from the standard model with respect to productivity shocks in the foreign country, the output correlation in this model with respect to productivity shocks in the home country is greater than that in the standard model thanks to the complementarity. Therefore, the model in which only foreign country produces commodities yields a higher output correlation compared to the standard model in which commodities are not considered.

How the real commodity price, home commodity consumption and foreign commodity output respond to a positive one standard deviation shock to the productivities in the home tradable and nontradable sectors is presented in Figure 2. For simplicity, in computing impulse responses I abstract from the productivity spillover implied in the coefficient matrix of productivities and assume that productivity shocks are uncorrelated, i.e., the off-diagonal elements of $\rho$ and $Var(c_t)$ are all zero. Figure 2 clearly shows that even though the real commodity price goes up in response to positive productivity shocks in the home country, home commodity consumption increases and hence foreign commodity output rises.

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22) Impulse response analysis with the productivity spillover and correlated productivity shocks results in all shocks hitting at the same time, which makes it hard to understand how a certain variable in this model responds to a certain shock.
Figure 2. Responses to Positive Productivity Shocks in the Home Country

(a) Home Real Commodity Price  (b) Home Commodity Consumption  (c) Foreign Commodity Output

Note: Responses are computed under conditions where the off-diagonal elements of $\rho$ and $\text{Var}(\sigma_i)$ are all zero.

3.2. Consumption Correlation

With regard to the consumption correlation, productivity shocks in the home and foreign countries yield similar results. Therefore, I explain only the case of productivity shocks in the home country.

When a positive productivity shock hits the home tradable sector, home commodity consumption (see (b) in Figure 2) and the real commodity price both rise, and the real price of home tradable goods falls. The decrease in the real price of home tradable goods leads to a fall in the real price of tradable goods in the foreign country. Foreign noncommodity consumption increases due to the fall in the real price of tradable goods. In spite of the rise in the real commodity price, foreign commodity consumption goes up owing to the complementarity between commodity and noncommodity consumption goods. Hence, home and foreign commodity consumption are positively correlated with respect to productivity shocks in the tradable sector. These responses to a positive one standard deviation shock to the productivity in the home tradable sector are clearly presented in Figure 3.
On the contrary, in response to a positive productivity shock in the home nontradable sector, home aggregate output and commodity consumption (see (b) in Figure 2) both increase. The real prices of commodities and tradable goods produced in both countries go up, because the increased home aggregate output gives them upward pressure. Foreign noncommodity consumption goes down owing to the increased real price of tradable goods. Foreign commodity consumption drops due to the complementarity and increased real commodity prices. Thus, home and foreign commodity consumption are negatively correlated with respect to productivity shocks in the nontradable sector. Figure 4 clearly shows these responses to a positive one standard deviation shock to the productivity in the home nontradable sector well.

In sum, the negative correlation with respect to productivity shocks in the nontradable sector enables the correlation between home and foreign commodity consumption to be lower\(^{23}\) than that between home and foreign noncommodity consumption in the model. Therefore,

\(^{23}\) Since productivity shocks in the nontradable sector are far weaker than those in the tradable sector, as usually shown in previous studies, the consumption correlation between the home and foreign commodity consumption is positive. The standard deviation of the latter is about 2.3 times larger than the former, which is implied in the variance-covariance matrix of productivity shocks, \(\text{Var}(\epsilon_t)\).
this model generates a slightly lower consumption correlation compared to the standard model in which commodity consumption does not exist.

Figure 4. Responses to a Positive Productivity Shock in the Home Nontradable Sector

- (a) F Real Commodity Price
- (b) F Noncommodity Consumption
- (c) F Commodity Consumption

Notes: Responses are computed under conditions where the off-diagonal elements of $\rho$ and $\text{Var}(x_t)$ are all zero. F stands for the foreign country.

4. Further Experiments

In this section, I first show that this model clearly explains the Dutch disease. Then, there is a sensitivity analysis of this model's results with regards to the parameters in the newly introduced features, as compared to the standard model, and the productivity shock process.

4.1. Application to the Dutch Disease

This model can be applied to a typical example of the Dutch disease, as outlined in Corden and Neary (1982). According to that study, a boom in the commodity sector can have effects on the economy in two ways: (i) the “resource movement effect” in which the boom in the commodity sector causes a rise in the marginal product of labor (the mobile factor) in the sector, and thus draws labor; and (ii) the
“spending effect” in which the increased real income resulting from the boom leads to an increase in consumption of nontradables. The spending effect results in an increase in prices of nontradable goods. Since the real exchange rate is defined as the relative real price of nontradable goods to tradable goods, it rises, which means that the real exchange rate appreciates. Consequently, the boom leads to a rise in output in the nontradable sector, but to a fall in output in the tradable sector.

In this model, we can show all aspects of the Dutch disease in the responses of the foreign country to a positive productivity shock in the home tradable sector, which leads to a boom in the foreign commodity sector.

Figure 5 shows the responses of the foreign country in this model to a positive one standard deviation shock to the productivity in the home tradable sector. The shock leads to an increase in home demand for commodities. Since the home country imports commodities from the foreign country, the shock results in a boom in the foreign commodity sector. Thus, the sector draws labor from other sectors. Labor in the sector jumps. This clearly explains the resource movement effect. With regard to the spending effect, the boom triggered by the shock brings about a rise in the consumption of nontradable goods in the foreign country, which causes an increase in the real price of nontradable goods. Accordingly, labor in the foreign nontradable sector rises and the real exchange rate, defined as the relative real price of nontradable goods to foreign tradable goods, as in Corden and Neary (1982), appreciates. Since the foreign commodity and nontradable sectors draw labor, labor in the foreign tradable sector falls. Therefore, the boom causes a rise in output in the foreign nontradable sector and a fall in output in the foreign tradable sector.
4.2. Sensitivity Analysis

In this model, the parameters for the elasticity of substitution between commodity and noncommodity consumption goods ($\eta_0$), the weight of commodity consumption goods in the composite consumption goods ($\gamma_0$), and the elasticity of substitution between commodities and capital in the production of tradable goods ($1/(1 + \nu)$) are all new parameters due to the introduction of commodities, compared to the standard model.\(^{24}\) Thus, whether the main results of this model (a higher output correlation than the consumption correlation and than the output correlation in the standard model) are sensitive to changes in the values of these three parameters needs to be assessed. To do so, I set reasonable ranges for the parameter values. Specifically, $\eta_0 \in [0.03, 0.4]$ based on previous studies.\(^ {25}\) $\gamma_0 \in [0.03, 0.085]$ matches the minimum and maximum ratios of commodity consumption to GDP in

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\(^{24}\) In fact, the parameter related to the weight of commodities in the production of tradable goods ($\alpha$) is also a new one. However, since the discount factor ($\beta$), the depreciation rate ($\delta$), the steady state ratio of capital to commodities in the tradable production ($K_F/x$) and $\nu$ determine its value, the assessment of the sensitivity to changes in its value is not conducted.

\(^{25}\) To my knowledge, among the previous studies that mainly analyze energy or oil, the lowest value of $\eta_0$ is 0.034 in Hughes, Knittel and Sperling (2006) and the highest value of it is 0.4 in Bodenstein, Erceg and Guerrieri (2011).
the EIA and NIPA data for 1997-2015.26) Also, I set a range of \(1/(1+\nu) \in [0.59, 1]\), again based on previous studies.27)

In addition, in the previous section it is assumed that the productivity in the commodity production is constant. However, if it is stochastic, the simulation results of the model could be different. Moreover, the productivity shock process has an effect on the simulation results of the model, too. Therefore, I assess whether the main results of this paper are maintained even with the productivity shocks in the commodity production and under alternative productivity shock processes, rather than the estimated shock process. For alternative productivity shock processes, I consider the shocks from ST and CDL.

Figure 6 shows the output and consumption correlations between the two countries, according to changes in the values of the three parameters. Table 4 presents the correlations that the model generates with the productivity shocks in the commodity production and under alternative productivity shock processes.

4.2.1. Elasticity of Substitution between Commodity and Noncommodity Consumption Goods \((\eta_0)\)

(a) in Figure 6 shows the output and consumption correlations between the two countries according to changes in the elasticity of substitution between commodity and noncommodity consumption goods \((\eta_0)\).

As already shown, a rise in the output correlation and a fall in the

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26) Based on EIA and NIPA data, the minimum ratio of end-use energy expenditure to GDP was 5.8% in 1999 and the maximum was 9.6% in 2008. By using the weight of energy in the IMF’s commodity price index (0.631), these two values correspond to 9.2% and 15.2% of the ratios of commodity expenditure to GDP. The minimum and maximum ratios of commodity output to GDP were 3.9% in 2009 and 4.9% in 1997, respectively. The minimum and maximum ratios of energy consumption to the end-use energy expenditure were 49.0% in 2008 and 51.8% in 2009, respectively. Using these values, the minimum and maximum ratios of commodity consumption to GDP are 2.1% and 5.9%, respectively.

27) Ever since Kim and Loungani (1992), who used 0.59 and 1 for the value of \(1/(1+\nu)\), many papers, such as Dhawan and Jeske (2008), have used one of those two values for it.
consumption correlation are associated with the complementarity between commodity and noncommodity consumption goods. A fall in $\eta_0$ means stronger complementarity. Hence, as $\eta_0$ decreases, the output correlation increases and the consumption correlation falls. However, changes in the correlations are very marginal, and thus they are not noticeable. In short, as long as $\eta_0$ is in a reasonable range, the main results of this paper hold.

### 4.2.2. Weight of Commodity Consumption Goods in the Composite Consumption Goods ($\gamma_0$)

Now consider changes to the weight of commodity consumption goods in the composite consumption goods ($\gamma_0$). (b) in Figure 6 shows the output and consumption correlations in the model under various values of $\gamma_0$.

A rise in $\gamma_0$ means an increase in the weight of commodity consumption goods in consumption. The existence of commodity consumption in the model plays a key role in reducing the consumption correlation between the two countries. Hence, as $\gamma_0$ goes up, the consumption correlation drops. The output correlation is almost insensitive to changes in $\gamma_0$. Overall, the output correlation is higher than that in the standard model and than the consumption correlation in this model, as long as $\gamma_0$ is in a reasonable interval.

### 4.2.3. Elasticity of Substitution between Commodities and Capital in the Tradable Production ($1/(1+\nu)$)

As the elasticity of substitution between commodities and capital in the production of tradable goods ($1/(1+\nu)$) goes up, both the output and consumption correlations slowly fall (see (c) in Figure 6).

As for the output correlation, when $1/(1+\nu)$ is high, it is easier for commodity inputs to be substituted with capital inputs, which means
weaker complementarity between the two. Therefore, when $1/(1+\nu)$ is high, the increased home demand for imports of commodities for the production of tradable goods in response to positive productivity shocks in the home country is offset by the increased real commodity prices by more than when $1/(1+\nu)$ is small. This causes foreign commodity output to rise by less, which brings about a smaller increase in foreign aggregate output, i.e., the larger $1/(1+\nu)$ is, the smaller the positive spillover into the foreign country from positive productivity shocks in the home country. Therefore, the output correlation decreases slowly as $1/(1+\nu)$ becomes greater. With regard to the consumption correlation, $1/(1+\nu)$ is not directly related to commodity consumption. Therefore, although $1/(1+\nu)$ increases, changes in commodity consumption are very marginal in response to productivity shocks. Nevertheless, when $1/(1+\nu)$ is high, in response to positive productivity shocks in the home country, foreign aggregate consumption goes up by less due to a smaller rise in its aggregate output compared to the case of a low $1/(1+\nu)$, which leads to a fall in the consumption correlation. As a consequence, a high $1/(1+\nu)$ results in less positively correlated consumption in the two countries.

Overall, when $1/(1+\nu)$ is set at a reasonable value, the output correlation is higher than that in the standard model and than the consumption correlation in this model.

**Figure 6. Sensitivity Analysis**

(a) $\eta_0$  
(b) $\gamma_0$  
(c) $1/(1+\nu)$
4.2.4. Productivity Shock Process

The first column in Table 4 shows the output and consumption correlations that the model generates under the estimated productivity shocks in the previous section and the productivity shocks in the foreign commodity sector.\(^{28}\) Figures in parentheses in Table 4 are the output correlations that the standard model (model without commodities) yields under various productivity shocks. Even if it is assumed that productivity in the foreign commodity sector is stochastic, the main results of this paper still hold. That is, the output correlation (0.745) is greater than both the consumption correlation (0.713) and the output correlation in the standard model (0.660). More specifically, the output and consumption correlations become slightly higher than those in this model without productivity shocks in the foreign commodity sector. This is because a positive productivity shock in the foreign commodity sector increases foreign aggregate output and consumption, and decreases real commodity prices. Since commodities are used in the production of home tradable goods, the lower real commodity prices reduce input costs, which increases output in the home tradable sector. Thus, home aggregate output rises. Due to the fall in real commodity prices, home commodity consumption goes up, which increases home aggregate consumption. That is, the home and foreign aggregate outputs and home and foreign aggregate consumptions are both positively correlated with respect to the productivity shocks in the foreign commodity sector. As a consequence, adding productivity shocks in the foreign commodity sector to the model brings about a slight rise in the output and consumption correlations.

\(^{28}\) Following Backus and Crucini (2000), the productivity in the foreign commodity sector follows an AR(1) process. The productivity shocks in the sector are not correlated with those in other sectors. They have no spillover to other sectors, and the autocorrelation of the productivity is 0.882. I further assume that the standard deviation of the shocks is equal to the average of those of the shocks in the tradable and nontradable sectors.
The output and consumption correlations that the model produces under CDL and ST shocks are given in the second and third columns in Table 4, respectively. Even under alternative productivity shocks, the main results of this paper still hold up.

<table>
<thead>
<tr>
<th></th>
<th>Shocks in the commodity sector</th>
<th>CDL shocks</th>
<th>ST shocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output correlation</td>
<td>0.745</td>
<td>0.691</td>
<td>0.515</td>
</tr>
<tr>
<td></td>
<td>(0.660)</td>
<td>(0.649)</td>
<td>(0.492)</td>
</tr>
<tr>
<td>Consumption correlation</td>
<td>0.713</td>
<td>0.650</td>
<td>0.487</td>
</tr>
</tbody>
</table>

Notes: The statistics are the models’ population moments for Hodrick-Prescott filtered results. Figures in parentheses are the output correlations in the standard model (model without commodities).

V. Conclusion

In this paper, I set up a two-country model with commodities and idiosyncratic commodity trade structures to analyze international business cycles between the U.S. and commodity-exporting countries. The model produces international business cycle statistics that are closer to the data than those generated from a standard international business cycle model in which commodities are not considered. The complementarity between commodity and noncommodity consumption goods enables the connection between outputs in the two countries to be stronger than in the standard model. Moreover, the consumption correlation in the model becomes smaller than that in the standard model.
model, since commodity consumption in both countries, which is not present in the standard model, is less positively correlated compared to noncommodity consumption. As a result, the model generates an output correlation that is slightly greater than the consumption correlation, unlike in the standard model, thus mitigating the quantity anomaly. This model also clearly explains a typical Dutch disease by showing that a boom in the commodity sector leads to a rise in output in the nontradable sector, and to a fall in output in the tradable sector. Finally, the sensitivity analysis of this model’s results shows that the main results of this paper hold up under various values of the newly introduced parameters and alternative productivity shocks.

Adding commodities to open economy macro models with consideration for different commodity trade structures of countries appears to be useful, as it helps to explain key features of international business cycle correlations between the U.S. and commodity-exporting countries. The framework that this paper proposes is therefore promising for further research on the international macroeconomic interactions between the U.S. and commodity-exporting countries, especially the international transmission of monetary and fiscal policies. Finally, considering that the aggregate size of the economies of China, Japan and South Korea is comparable to that of the U.S., and that they are all commodity-importing countries, changes in their demand for commodities could also affect commodity prices and the global commodity trade, just like in the U.S. This implies that to properly analyze the effects of economic policies on their economies, the framework of the model in this paper should be considered.
References


Appendix

A. Data Sources

This section describes the data used in this paper. The data is mainly from two sources, the OECD and the IMF.

Figure 1 The term “major countries” means advanced countries according to the IMF’s classifications. Countries in Figure 1 are those whose data are available in the OECD Trade in Value Added.

Annual real GDPs for computing GDP correlations are taken from the IMF World Economic Outlook, since annual real GDP data from some countries, such as Cyprus and Malta, are not available in the OECD National Accounts. Trade is the gross exports plus imports, and net commodity exports are the gross exports minus imports of agriculture, hunting, forestry, fishing, mining, quarrying, wood and basic metal industries in the OECD Trade in Value Added. The ratio of net commodity exports to trade is the average of dividing the net commodity exports by the trade for the period of 1995-2011.

Tables 1 and 3 Annual real GDP, real private consumption and real private fixed investment of OECD countries are taken from the OECD National Accounts. Since the pre-1990 data for most Eastern European countries are not available, the data cover the period 1990-2015, with the exception of Estonia, which covers 1993-2015, Hungary, which covers 1991-2015, Latvia, which covers 1994-2015, and Slovak Republic, which covers 1992-2015.

For the trade-weighted average, the average trade weight of an OECD country $i$ for the period 1995-2011 is constructed by summing exports from an OECD country $i$ to the U.S. and imports from the U.S. to the OECD country $i$, and dividing that by the total OECD countries’ trade with the U.S. The trade data is drawn from OECD Trade in Value Added.
The commodity-exporting OECD countries are Australia, Canada, Chile, Iceland, Latvia, Luxembourg, Mexico, the Netherlands and Norway. All their net commodity exports are positive.

**B. Equilibrium Conditions of the Model**

In this section, I present the equilibrium system for the model described in Section III.

- **Home households’ intertemporal problem:**

\[
1 = \beta E_t \left[ \frac{C_t}{C_{t+1}} R_t \right],
\]

(A.1)

\[
W_t = L_t^* C_t,
\]

(A.2)

\[
C_t = \partial e_t C_t^*,
\]

(A.3)

with \( L_t = L_{T,t} + L_{N,t} \). \( e_t \) denotes the real exchange rate.

- **Foreign households’ intertemporal problem:**

\[
1 = \beta E_t \left[ \frac{C_t^*}{C_{t+1}^*} R_t^* \right],
\]

(A.4)

\[
W_t^* = L_t^{**} C_t^*,
\]

(A.5)

with \( L_t^* = L_{T,t}^* + L_{N,t}^* + L_{X,t}^* \).

- **Home households’ consumption allocation:**

\[
C_{NC,t} = (1 - \gamma_0) p_{NC,t}^{-\eta_0} C_t,
\]

(A.6)

\[
C_{X,t} = \gamma_0 p_{X,t}^{-\eta_0} C_t,
\]

(A.7)

\[
C_{T,t} = (1 - \gamma_1) \left( \frac{p_{T,t}}{p_{NC,t}} \right)^{-\eta_1} C_{NC,t},
\]

(A.8)
\[ C_{N,t} = \gamma_1 \left( \frac{p_{N,t}}{p_{NC,t}} \right)^{-\eta_1} C_{NC,t}, \]  
\[ C_{H,t} = (1 - \gamma_2) \left( \frac{p_{H,t}}{p_{T,t}} \right)^{-\eta_2} C_{T,t}, \]  
\[ C_{F,t} = \gamma_2 \left( \frac{p_{F,t}}{p_{T,t}} \right)^{-\eta_2} C_{T,t}. \]  

- Foreign households' consumption allocation:

\[ C_{NC,t}^* = (1 - \gamma_0) p_{NC,t} C_t^*, \]  
\[ C_{X,t}^* = \gamma_0 p_{X,t} C_t^*, \]  
\[ C_{T,t}^* = (1 - \gamma_1) \left( \frac{p_{T,t}^*}{p_{NC,t}} \right)^{-\eta_1} C_{NC,t}^*, \]  
\[ C_{N,t}^* = \gamma_1 \left( \frac{p_{N,t}^*}{p_{NC,t}} \right)^{-\eta_1} C_{NC,t}^*, \]  
\[ C_{F,t}^* = (1 - \gamma_2) \left( \frac{p_{F,t}^*}{p_{T,t}} \right)^{-\eta_2} C_{T,t}^*, \]  
\[ C_{H,t}^* = \gamma_2 \left( \frac{p_{H,t}^*}{p_{T,t}} \right)^{-\eta_2} C_{T,t}^*. \]  

- Home price indices:

\[ 1 = (1 - \gamma_0) p_{NC,t}^{1-\eta_0} + \gamma_0 p_{X,t}^{1-\eta_0}, \]  
\[ p_{NC,t}^{1-\eta_0} = (1 - \gamma_1) p_{T,t}^{1-\eta_1} + \gamma_1 p_{N,t}^{1-\eta_1}, \]  
\[ p_{T,t}^{1-\eta_2} = (1 - \gamma_2) p_{H,t}^{1-\eta_2} + \gamma_2 p_{F,t}^{1-\eta_2}. \]
- Foreign price indices:

\begin{align}
1 &= (1 - \gamma_0) P_{NC,t}^* + \gamma_0 P_{X,t}, \\
P_{NC,t}^* &= (1 - \gamma_1) P_{T,t}^* + \gamma_1 P_{N,t}, \\
P_{T,t} &= (1 - \gamma_2^*) P_{F,t}^* + \gamma_2 P_{H,t}.
\end{align}

(A.21) - (A.23)

- Laws of one price:

\begin{align}
p_{H,t} &= e_t^* p_{H,t}, \\
p_{F,t} &= e_t^* p_{F,t}, \\
p_{X,t} &= e_t^* p_{X,t}.
\end{align}

(A.24) - (A.26)

- Home nontradable good producers' optimality conditions:

\begin{align}
Y_{N,t} &= A_{N,t} R_{N,t}^{* \alpha_N} L_{N,t}^{1-\alpha_N}, \\
W_t &= (1 - \alpha_N) p_{N,t} \frac{Y_{N,t}}{L_{N,t}}, \\
R_{t-1} &= \frac{1}{Q_{N,t-1}} \left\{ (1 - \delta) Q_{N,t} + \alpha_N p_{N,t} \frac{Y_{N,t}}{K_{N,t}} \right\}.
\end{align}

(A.27) - (A.29)

- Foreign nontradable good producers' optimality conditions:

\begin{align}
Y_{N,t}^* &= A_{N,t}^* R_{N,t}^{* \alpha_N} L_{N,t}^{1-\alpha_N}, \\
W_t^* &= (1 - \alpha_N) p_{N,t}^* \frac{Y_{N,t}^*}{L_{N,t}^*}, \\
R_{t-1}^* &= \frac{1}{Q_{N,t-1}^*} \left\{ (1 - \delta) Q_{N,t}^* + \alpha_N p_{N,t}^* \frac{Y_{N,t}^*}{K_{N,t}^*} \right\}.
\end{align}

(A.30) - (A.32)
- Home tradable good producers’ optimality conditions:

\[
Y_{H,t} = A_{T,t} \left\{ (1-a)K_{T,t}^{-\nu} + ax_t^{-\nu} \right\}^{-\frac{\alpha}{\nu}} L_{T,t}^{1-\alpha},
\]

(A.33)

\[
W_t = (1-\alpha)p_{H,t} \frac{Y_{H,t}}{L_{T,t}},
\]

(A.34)

\[
R_{t-1} = \frac{1}{Q_{T,t-1}} \left\{ (1-\delta)Q_{T,t} + \alpha(1-a)p_{H,t}K_{T,t}^{-\nu} \frac{Y_{H,t}}{(1-a)K_{T,t}^{-\nu} + ax_t^{-\nu}} \right\},
\]

(A.35)

\[
p_{X,t} = \alpha p_{H,t}x_t^{-\nu-1} \frac{Y_{H,t}}{(1-a)K_{T,t}^{-\nu} + ax_t^{-\nu}}.
\]

(A.36)

- Foreign tradable good producers’ optimality conditions:

\[
Y_{F,t}^* = A_{T,t}^* \left\{ (1-a)K_{T,t}^{-\nu} + ax_t^{-\nu} \right\}^{-\frac{\alpha}{\nu}} L_{T,t}^{1-\alpha},
\]

(A.37)

\[
W_t^* = (1-\alpha)p_{F,t}^* \frac{Y_{F,t}^*}{L_{T,t}^*},
\]

(A.38)

\[
R_{t-1}^* = \frac{1}{Q_{T,t-1}^*} \left\{ (1-\delta)Q_{T,t}^* + \alpha(1-a)p_{F,t}^*K_{T,t}^{-\nu} \frac{Y_{F,t}^*}{(1-a)K_{T,t}^{-\nu} + ax_t^{-\nu}} \right\},
\]

(A.39)

\[
p_{X,t}^* = \alpha p_{F,t}^*x_t^{-\nu-1} \frac{Y_{F,t}^*}{(1-a)K_{T,t}^{-\nu} + ax_t^{-\nu}}.
\]

(A.40)

- Foreign commodity producers’ optimality conditions:

\[
Y_{X,t}^* = A_{X}^* K_{X,t}^{\alpha \nu} L_{X,t}^{1-\alpha \nu},
\]

(A.41)

\[
W_t^* = (1-\alpha_X) p_{X,t}^* \frac{Y_{X,t}^*}{L_{X,t}^*},
\]

(A.42)

\[
R_{t-1}^* = \frac{1}{Q_{X,t-1}^*} \left\{ (1-\delta)Q_{X,t}^* + \alpha_X p_{X,t}^* \frac{Y_{X,t}^*}{K_{X,t}^*} \right\}.
\]

(A.43)
- Laws of motion for capital and the prices of capital:

\[ K_{N,t+1} = (1 - \delta)K_{N,t} + \phi \left( \frac{I_{N,t}}{K_{N,t}} \right)K_{N,t}, \quad (A.44) \]

\[ K^*_t,_{N,t+1} = (1 - \delta)K^*_t,_{N,t} + \phi \left( \frac{I^*_t,_{N,t}}{K^*_t,_{N,t}} \right)K^*_t,_{N,t}, \quad (A.45) \]

\[ K_{T,t+1} = (1 - \delta)K_{T,t} + \phi \left( \frac{I_{T,t}}{K_{T,t}} \right)K_{T,t}, \quad (A.46) \]

\[ K^*_t,_{T,t+1} = (1 - \delta)K^*_t,_{T,t} + \phi \left( \frac{I^*_t,_{T,t}}{K^*_t,_{T,t}} \right)K^*_t,_{T,t}, \quad (A.47) \]

\[ K^*_t,_{X,t+1} = (1 - \delta)K^*_t,_{X,t} + \phi \left( \frac{I^*_t,_{X,t}}{K^*_t,_{X,t}} \right)K^*_t,_{X,t}, \quad (A.48) \]

\[ Q_{N,t} = p_{N,t} \left[ \phi' \left( \frac{I_{N,t}}{K_{N,t}} \right) \right]^{-1}, \quad (A.49) \]

\[ Q^*_t,_{N,t} = p^*_t,_{N,t} \left[ \phi' \left( \frac{I^*_t,_{N,t}}{K^*_t,_{N,t}} \right) \right]^{-1}, \quad (A.50) \]

\[ Q_{T,t} = p_{H,t} \left[ \phi' \left( \frac{I_{T,t}}{K_{T,t}} \right) \right]^{-1}, \quad (A.51) \]

\[ Q^*_t,_{T,t} = p^*_t,_{T,t} \left[ \phi' \left( \frac{I^*_t,_{T,t}}{K^*_t,_{T,t}} \right) \right]^{-1}, \quad (A.52) \]

\[ Q^*_t,_{X,t} = p^*_t,_{X,t} \left[ \phi' \left( \frac{I^*_t,_{X,t}}{K^*_t,_{X,t}} \right) \right]^{-1}. \quad (A.53) \]

- Resource constraints:

\[ Y_{N,t} = C_{N,t} + I_{N,t}, \quad (A.54) \]

\[ Y_{H,t} = C_{H,t} + C^*_t,_{H,t} + I_{T,t}, \quad (A.55) \]
\[ Y_{N,t}^* = C_{N,t}^* + I_{N,t}, \quad (A.56) \]
\[ Y_{F,t}^* = C_{F,t}^* + C_{T,t}^* + I_{T,t}^*, \quad (A.57) \]
\[ Y_{X,t}^* = C_{X,t}^* + x_t^* + x_t + I_{X,t}^*. \quad (A.58) \]

- Productivity shocks:
\[ \delta_t = \rho \delta_{t-1} + \epsilon_t. \quad (A.59) \]

**C. The Standard Model**

The equilibrium conditions under the standard model in which commodities are not considered are given by equations (A.1)-(A.5), (A.10), (A.11), (A.16), (A.17), (A.20), (A.23)-(A.25), (A.27)-(A.32), (A.34), (A.38), (A.44)-(A.47), (A.49)-(A.52), (A.54)-(A.57) and (A.59), and the following 10 equations.

\[ C_{T,t} = (1 - \gamma_1) p_{T,t}^{-\eta} C_t, \quad (A.60) \]
\[ C_{N,t} = \gamma_1 p_{N,t}^{-\eta} C_t, \quad (A.61) \]
\[ C_{T,t}^* = (1 - \gamma_1) p_{T,t}^{-\eta} C_t^*, \quad (A.62) \]
\[ C_{N,t}^* = \gamma_1 p_{N,t}^{-\eta} C_t^*, \quad (A.63) \]
\[ 1 = (1 - \gamma_1) p_{T,t}^{1-\eta} + \gamma_1 p_{N,t}^{1-\eta}, \quad (A.64) \]
\[ 1 = (1 - \gamma_1) p_{T,t}^{1-\eta} + \gamma_1 p_{N,t}^{1-\eta}, \quad (A.65) \]
\[ Y_{H,t} = A_{T,t} K_{T,t}^{\alpha} L_{T,t}^{1-\alpha}, \quad (A.66) \]
\[ \delta_{t-1} = \frac{1}{Q_{T,t-1}} \left\{ (1 - \delta) Q_{T,t} + \beta R_{H,t} \frac{Y_{H,t}}{K_{H,t}} \right\}, \quad (A.67) \]
\begin{equation}
Y_{F,t}^* = A_{T,t}^* K_{T,t}^\alpha L_{T,t}^{1-\alpha}, \tag{A.68}
\end{equation}

\begin{equation}
R_{t-1}^* = \frac{1}{Q_{T,t-1}^*} \left\{ (1-\delta)Q_{T,t}^* + \alpha p_{F,t}^* \frac{Y_{F,t}^*}{K_{T,t}^*} \right\}. \tag{A.69}
\end{equation}

Moreover, since there are no commodities in the standard model, \( \gamma_2 = \gamma_2^* = 0.5 \) and \( L_t^* = L_{T,t}^* + L_{N,t}^* \).
원자재 무역구조와 국제경기변동

김명현*

본고는 미국과 원자재 수출국 간의 국제경기변동을 분석하기 위하여 일반적인 2국 모형(standard two-country model)에 원자재와 원자재 무역구조를 고려하였다. 구체적으로 외국(원자재 수출국)은 원자재를 생산하는 반면 본국(미국, 원자재 수입국)은 원자재를 생산하지 못함에 따라 원자재를 외국으로부터 수입하도록 모형화하였다. 시뮬레이션 결과, 일반적인 2국 모형에 비해 양국 간의 생산 상관계수가 올라가고 소비 상관계수가 하락하는 등 본고의 모형이 미국과 원자재 수출국 간의 국제경기변동을 일반적인 모형보다 잘 설명하는 것으로 나타났다. 특히, 일반적인 모형들과 달리 본고의 모형은 소비 상관계수보다 높은 생산 상관계수를 산출함에 따라 기존 문헌에서 언급된 국제 소비 상관계수 퍼즐(international consumption correlation puzzle 또는 quantity anomaly)을 일정 부분 완화시키는 것으로 나타났다.

핵심 주제어: 국제경기변동, 원자재 무역구조, 원자재 수출국

JEL Classification: F40, F41, F44

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이 연구내용은 집필자의 개인의견이며 한국은행의 공식견해와는 무관합니다. 따라서 본 논문의 내용을 보도하거나 인용할 경우에는 집필자명을 반드시 명시하여주시기 바랍니다.
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