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Abstract

Terms-of-trade shocks are known to be key drivers of business cycles in open economies. This paper argues that terms-of-trade shocks were also important for house price fluctuations in a panel of developed countries over the 1994–2015 period. In a panel vector error-correction model of house prices, household debt and real tradable prices, terms-of-trade shocks explain between 16 and 41 per cent of the long-run variance in house price growth in a typical country, and from 45 to 85 per cent of the long-run variance of the ratio of house prices to non-housing consumption. Most of the variation in the house price/consumption ratio is associated with changes in real import prices, with idiosyncratic shocks to real export prices playing a minor role. On average, a permanent 1 per cent decline in real import prices raises the ratio of real house prices to non-housing consumption by about 0.9 per cent.

Bank topic(s): Housing; Financial stability; International topics
JEL code(s): C32, E32, E51, F36, F41

Résumé

Les chocs des termes de l’échange sont d’importants déterminants des cycles économiques dans les économies ouvertes. Dans cet article, nous soutenons que ces chocs ont aussi eu une incidence notable sur les variations des prix des logements dans un groupe de pays développés, de 1994 à 2015. Dans un modèle vectoriel à correction d’erreurs appliqué à des données de panel sur les prix des logements, l’endettement des ménages et les prix réels des biens échangeables, les chocs des termes de l’échange expliquent entre 16 et 41 % de la variance à long terme de la croissance des prix des logements dans un pays type, et de 45 à 85 % de la variance à long terme du ratio des prix des logements à la consommation hors logement. Le gros de la variation du ratio prix des logements-consommation est associé aux mouvements des prix réels des importations, alors que les chocs idiosyncrasiques touchant les prix réels des exportations jouent un rôle mineur. En moyenne, une baisse durable de 1 % des prix réels à l’importation fait augmenter d’environ 0,9 % le ratio prix réels des logements-consommation hors logement.

Sujet(s) : Logement; Stabilité financière; Questions internationales
Code(s) JEL : C32, E32, E51, F36, F41

Non-technical summary

A large literature discusses the causes of the upward trend of real house prices relative to incomes in the developed world in the past 25 years, and their relative importance. Most commonly examined are financial drivers of housing demand, such as changes in global interest rates and capital inflows that might favour household consumption and purchases of housing. Less often explored is the role of changes in the terms of trade or in the prices of real tradable goods in driving real house prices or house price/income ratios. Not only do positive terms-of-trade shocks have a positive impact on consumption in standard macro models, but large increases in the production of globally traded goods should increase the relative price of non-traded services such as housing services. The paper studies the role of the terms of trade and real tradable prices (real import and real export prices) in driving house price movements in 18 developed countries, both in the very long run and at business cycle frequencies.

To examine the importance of real tradable prices for long-run movements in house prices, a panel co-integrating relationship is estimated between the ratio of real house prices to non-housing consumption and real tradable prices, controlling for changes in long-term interest rates and capital inflows (proxied by the ratio of the trade balance to GDP). A significant negative relationship is found between real prices of imports and the ratio of house prices to consumption, while the relationship between the house price/consumption ratio and interest rates is weaker. Interestingly, the house price/consumption ratio has a much weaker relationship with real prices of exports, even in a sub-panel of exporters of oil and other commodities (Australia, Canada, Norway and New Zealand).

To examine the importance of shocks to real tradable prices for business cycle variations in house prices, a panel vector error-correction model is estimated using real house prices, real household debt, real tradable prices, and a variety of other controls, including non-housing consumption and short and long interest rates. Shocks that raise the terms of trade by lowering the real price of imports significantly increase the ratios of both house prices and household debt to non-housing consumption. Idiosyncratic shocks to real export prices increase the terms of trade but have a weaker positive or even negative impact on house prices. Taken together, terms-of-trade shocks explain between 16 and 41 per cent of long-run variance in house price growth in a typical country, and from 45 to 85 per cent of the long-run variance of the ratio of house prices to consumption.

1. Introduction

Most countries in the developed world saw a boom in house prices relative to incomes in the first decade of the 21st century, with the ratio of house prices to incomes rising 20 per cent in the OECD from 2000 to 2007 (Figure 1a). The boom is frequently attributed to declines in interest rates in the developed world, linked either to substantial easing of monetary policy worldwide (e.g. Taylor 2009) or capital inflows from rapidly developing emerging markets as a result of higher demand for reserve-currency assets (e.g. Bernanke 2005). However, while global interest rates have declined further since the 2008–09 financial crisis, the majority of countries have not seen house prices recover to 2007 levels. Among others, Kuttner (2012), for the United States, and Hirata et al. (2012), who examine a panel of developed countries, argue that shocks to interest rates as such cannot explain a significant amount of fluctuation in global house prices in a sample spanning the financial crisis. As a result, several papers have looked at open-economy influences on house prices more directly. A large literature focuses on an empirical link between current account deficits and house price growth in open economies (e.g. Ahearne et al. 2005; Gete 2015; Aizenman and Jinjarak 2009; Sá et al. 2011, 2014; Ferrero 2015).

Less often examined in the literature is the potential contribution of changes in the terms of trade to house price growth. If prices for imports decline relative to the prices of domestic consumption or output, then the real prices of non-tradable services, such as housing, should grow relative to non-housing consumption prices.[1] Meanwhile, higher prices for exports should increase labour incomes of households that depend on wage income from export industries, and in turn housing demand; an obvious example of this would be an increase in commodity prices that increases incomes, employment and housing demand in commodity-producing countries or regions.

Suggestive evidence in favour of terms of trade having an important role in the housing cycle is the fact that commodity exporting countries, such as Australia, Canada, New Zealand and Norway, saw some of the fastest growth in real house prices in the developed world over the 21st century. Improvements in terms of trade due to a boom in commodity prices lasting from 2000 to 2012 may have spilt over to the housing market in these countries.[2] Over the 2000 to 2007 period, growth in house price to income ratios

[1] Persistent declines in real import prices will reflect greater global productivity for tradable goods, especially in rapidly growing emerging markets. The impact of lower global tradable goods prices on house prices is one example of the Baumol-Bowen effect (Baumol 1967; Baumol and Bowen 1966), by which prices for goods and services experiencing relatively little productivity growth will grow over time relative to those of goods and services with high productivity growth.

[2] In the period 2010 to 2013, all four countries were net exporters of commodities according to UNCTAD data (*Economist* 2015). Net commodity exports as a share of GDP were 6.0 per cent in Canada, 9.4 per cent in Australia, 9.5 per cent in New Zealand, and 21.7 per cent in Norway.

in the four commodity exporters consistently outperformed the OECD average, as well as those of the US and the euro area (Figure 1b). Moreover, the commodity exporters were spared the housing busts seen in most of the rest of the OECD. As of 2015Q3, house price to income ratios were at or near their 21st century peaks in all four countries.

This paper assesses the role of changes in the terms of trade, and in real export as well as real import prices, in house price movements in a panel of data from 18 developed markets from 1994 to 2015. The panel consists of four commodity exporters, Australia, Canada, New Zealand and Norway, as well as 14 developed commodity importers. To study the impact in the very long run, a panel co-integration approach is taken to modelling the long-run co-movement of real tradable prices and its components with real house prices. To study the impact at business cycle frequencies, a panel vector error-correction model (VECM), estimated with Bayesian methods, is used to examine how house prices respond to exogenous terms-of-trade shocks at business cycle frequencies, and the contribution of such shocks to house price fluctuations.

The panel co-integration analysis extends the study by Tumbarello and Wang (2010) of open-economy drivers of house prices, including terms of trade, for three commodity exporters (Australia, Canada and New Zealand) to a wider range of developed economies. It also contributes to a broader literature modelling long-run trends of real house prices in terms of real fundamentals with co-integration methods, both for individual countries (see Girouard et al. (2006) for a survey) and panels (e.g. Terrones and Otrok 2004; Adams and Füss 2010).

The panel VECM analysis extends previous panel vector auto-regression (VAR) studies on the link between house prices and macroeconomic shocks (e.g. Goodhart and Hofmann 2008; Sá et al. 2011, 2014; Cesa-Bianchi et al. 2015). The present paper's methodology most closely resembles that of Sá et al.'s (2011, 2014) study of the link between changes in the current account and house price growth. The biggest differences in Sá et al.'s approach and the one in this paper is the addition of an exogenous block to each country's model (for real import and export prices) and the use of a VECM rather than an unrestricted VAR in levels. VECMs better account for the non-stationarity of key variables, while continuing to allow for the stationarity of relations between their levels, such as the relation between real house prices, consumption and real tradable prices estimated in the long-run analysis.

There are two main findings. First, changes in real tradable prices have made a large contribution to growth in house prices and the ratio of real house prices to non-housing consumption per capita over the

1994–2015 period.[3] Once changes in real tradable prices are accounted for, global interest rates no longer play a significant role in long-run trends of real house prices. Most of the contribution of changes in real tradable prices to house price movements is due to a strong and negative long-run relationship between real import prices and real house prices. A shock to real import prices resulting from an increase in global productivity will increase house prices as well as consumption. Changes in real export prices have a weaker and more ambiguous impact, even in commodity exporters.

Secondly, shocks to the terms of trade also make a substantial contribution to house price fluctuations at business cycle frequencies. In a typical country, terms-of-trade shocks explain between 16 and 41 per cent of the variance of house price growth twenty quarters ahead, with a median estimate of 28 per cent. Terms-of-trade shocks explain the majority of the long-run variation in the ratio of real house prices to non-housing consumption per capita, explaining between 45 and 85 per cent of its variance, with a median estimate of 71 per cent. The vast majority of the contribution of terms-of-trade shocks to house price growth comes from shocks corresponding to declines in real import prices. In a typical country, a terms-of-trade shock lowering real import prices by 1 per cent raises the ratio of house prices to consumption per capita by about 0.9 per cent. Idiosyncratic shocks to export prices have a much weaker impact on house prices, and are generally only important in commodity exporting countries.

This paper contributes to the literature by attempting to fill a gap in our understanding of the factors driving house prices in open economies. This paper is the first, to the author's knowledge, to study the direct impact of changes in the terms of trade on house prices across a broad panel of developed countries, not just commodity exporters (e.g. Tumbarello and Wang 2010). In doing so it helps complement the literature on the indirect impact of improved global productivity in tradable goods on developed world house prices, through the large flows of retained profits from emerging markets to financial markets in the developed world. Specifically, it makes the case that persistent changes in the terms of trade, and in real import prices in particular, have contributed greatly to the upward trend in real house prices seen in most developed countries.

The rest of the paper has the following structure. Section 2 will briefly review relevant literature. Section 3 describes the data used in the analysis. Section 4 focuses on the long-run relationship between real tradable prices and house prices, using both simple long-run correlations and the panel co-integration exercise. Section 5 analyzes the shorter-run impact of terms-of-trade shocks on house prices and

[3] Throughout this paper, "consumption" refers to non-housing consumption, with the house price/consumption ratio being the ratio of house prices to non-housing consumption per capita

household debt using panel VECMs, and assesses the contributions of terms-of-trade shocks to house price variance. Section 6 summarizes and concludes.

2. Literature review

The literature linking changes in house price growth to changes in global productivity growth dates to Case et al. (1999), who documented a link between changes in global output fluctuations and global co-movements in house prices. Terrones and Otrok (2004) and Hirata et al. (2012) use factor-augmented VAR (FAVAR) models of a panel of developed countries, including several indicators of output, asset prices and interest rates, as well as house prices, to determine factors explaining the cross-country synchronicity of house prices. They find that a factor corresponding to global output explained almost a third of global house price fluctuations. Beltratti and Morana (2010), using a similar FAVAR, also find that global supply shocks play a key role in house price fluctuations, using data from the G-7 countries. The global output factor explains a greater share of house price fluctuations in the "globalization" period after 1985 (Hirata et al. 2012), when increased openness of economies would have increased the impact of terms-of-trade shocks.

As for the importance of the terms of trade, several studies (e.g. Easterly et al. 1993, Kohli 2004, Becker and Mauro 2006) have underlined a strong empirical relationship between changes in the terms of trade and the business cycle as a whole, both in developed and emerging markets. Using a structural model Kehoe and Ruhl (2008) downplay the importance for changes in the terms of trade for overall output fluctuations. However, they do underline that a terms-of-trade shock will have effects on consumption and welfare similar to a productivity shock in a standard DSGE model.

A model in which the terms of trade may play a role in housing booms and busts is Tomura's (2008). In his model, expectations of the future path of income and house prices play a role in determining current house prices. If terms of trade are improving, consumers expect that the real value of domestically produced goods, such as housing, will continue to rise, boosting current house prices. If the improvement in terms of trade stops, consumers will revise their expectations of future income growth and house price growth downward, resulting in a drop in current house prices. Such a halt in the improvement in terms of trade could come from a slowdown in global productivity growth.

Tumbarello and Wang (2010) found for Australia, Canada and New Zealand that favourable changes in the terms of trade have a substantial positive impact on real house prices, after controlling for changes in interest rates. Their finding was robust to the addition of other controls, such as measures of net migration. Crowe et al. (2011), in a panel VAR exercise using data from 22 countries from 1990 to 2007, find that shocks to the import price deflator can explain a substantial amount of long-run house price variation, around 16 per cent at the 10-year horizon.

3. Data

This section describes the panel of developed countries to be examined, along with how real house prices, the terms of trade and its components, and other controls are measured for the purposes of the study. For more details regarding data sources and definitions, see the Data Appendix.

3.1. Panel, sub-panels and data period

For the panel co-integration analysis, baseline results are reported below for the full panel of 18 developed markets. Results are also reported for two sub-panels. One sub-panel is of four developed countries, Australia, Canada, New Zealand and Norway, for whom the International Monetary Fund (IMF) estimates net commodity exports to be a positive share of GDP between 1962 and 2010 (Bluedorn et al. 2012). The other is a sub-panel of 14 developed countries that were net importers of commodities over the period. These are Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Japan, the Netherlands, Spain, Sweden, Switzerland, the United Kingdom, and the United States.[4]

In the panel VECM analysis, as the covariance matrix of structural shocks may be very different for commodity importers and commodity exporters, results are also calculated for the commodity exporter sub-panel.

In the results reported here, data for each country start no later than 1994Q1. One reason for this is a desire to avoid issues related to changes in monetary policy before the early 1990s in many countries. Another practical reason is a lack of comparable interest rate data from the Organisation for Economic Co-operation and Development (OECD), and for broad-based real exchange rates from the Bank for International Settlements (BIS), before 1994Q1. For all countries, the sample ends in 2015Q3.

Due to differences in data availability for each country, the panel is unbalanced, with the first observation in the data for each country varying slightly across countries. Binding constraints on data availability include lack of comparable national accounts data from the OECD for the entire period from 1994Q1 through 2015Q3, as well as a lack of comparable data on household debt from the BIS. However, for all

[4] Here, countries are classified as commodity importers and exporters according to the majority of their experience over the sample period. While the shale oil boom moved the United States closer to being a net exporter of oil, the current boom in shale oil production did not begin until the 2010s. Moreover, the IMF's definition of a commodity exporter depends on net exports of a broad range of energy and non-energy commodities, not just oil.

countries, data are available for the global housing boom of the 21st century and the financial crisis that followed.

3.2. *Data series*

3.2.1. *Real house prices*

The house prices used in this paper are nominal house price indices taken from the BIS database of long series on nominal residential property prices. For each country i, real house prices are calculated by dividing a nominal house price index $P_{H,i}$ by the price level for private consumption from national accounts, $P_{C,i,t}$. Most results are similar when reasonable alternatives to the consumption price deflator are used, such as a standard consumer price index or the GDP deflator.

3.2.2. *Terms of trade and components*

The terms of trade are measured for each country i by the ratio of the export deflator from national accounts $P_{X,i}$ to the import deflator $P_{M,i}$. The components of the terms of trade, hereafter collectively "real tradable prices," are calculated by dividing the appropriate deflator by the deflator for private consumption $P_{C,i}$. In other words, real export prices and real import prices are the export and import price deflator (respectively) divided by the consumption deflator. Results reported in this paper are robust to alternative deflators, such as the nominal GDP deflator.

3.2.3 *Controls*

Two variables are used as controls both of the panel co-integration estimation below and in the panel VAR. As is standard in the literature, a long-term interest rate $R_{L,i}$, generally a 10-year government bond rate, is included in the co-integration equation, to capture trends in economy-wide interest rates.[5] The other control is TB_i, the ratio of the trade or current account balance to GDP, capturing capital in- and outflows $\left(TB_i = \left(\left(P_{X,i}X_i - P_{M,i}M_i\right)/P_Y Y_i\right)\right)$.

Two financial variables used in the panel VECMs, but not in the panel co-integration, are a broad-based, trade-weighted real exchange rate ($REER$) and a short-term interest rate (R_S). Shocks that impact the terms of trade will have an impact on the real exchange rate, especially in commodity exporting countries

[5] While in principle a consumer or mortgage interest rate would be more appropriate, no internationally comparable data on consumer lending rates is available, given the heterogeneity of mortgage markets and their development across the panel. Measures of private sector overall lending rates are available from the IMF, but these include business as well as mortgage rates, and are more heterogeneous than risk-free (government) rates.

with freely floating commodity currencies (Chen and Rogoff 2003). Including short-term interest rates allows measurement of the response of monetary policy to terms-of-trade shocks in the VECM, and controls for the effect of any such response. Also included in the VECM is a measure of real household debt (HHC), deflated by the private consumption deflator, capturing possible feedback from household debt to demand, and vice versa.

Three other non-financial variables are also added as controls in the VECMs. These are: real consumption per capita (C), measuring growth of permanent income; the private consumption deflator (P_C), measuring inflation; and the ratio of nominal GDP to the sum of private and public consumption, serving as a proxy for the output gap $\left(gap_i = P_{Y,i}Y_i/\left(P_{C,i}C_i + P_{G,i}G_i\right)\right)$. The panel VECM results are robust to reasonable substitutes for each.

4. Terms of trade and the housing cycle in the long run

In this section, the long-run relationship between real house prices and real tradable prices is verified, first by informally examining the long-run correlation between house price growth and real tradable price changes, and then more formally with a standard panel co-integration approach, controlling for changes in interest rates and the trade balance across countries.

4.1. Evidence from scatter plots

To establish a prima facie case for a long-run relationship between real tradable prices and house prices, and motivate the panel co-integration results to follow, Figure 2a compares long-run growth in house prices and select components to long-run growth in the terms of trade and its components, real import and real export prices. In the figure, the scatter plots have average growth rates of the terms of trade and its components (real import and real export prices) on the X-axis. On the Y-axis are average growth rates of the ratio of real house prices to the real consumption per capita, $(P_H * POP)/(P_C C)$, controlling for long-run growth in income across countries. However, plots using “raw” growth in real house prices, deflated with consumption prices only, do not look very different.

Averages are calculated for each country starting in 1994Q1, or as early as possible after that, up to 2015Q3. There is a clear positive relationship ($R^2 = 0.40$) between terms-of-trade growth and growth in real house prices. The five countries that saw the largest changes in the terms of trade over the period help bring the relation into sharp relief. The largest improvements in terms of trade were enjoyed by Australia (an improvement of 64 per cent), Canada (18 per cent), New Zealand (26 per cent) and Norway (84 per cent). By contrast, Japan saw long-term declines both in its terms of trade (43 per cent) and in real house prices. Rises in house prices have a stronger relationship with improvement in the terms of trade in goods than with improvement in the terms of trade for services, bolstering the case that greater manufacturing productivity worldwide has driven the relationship (Figure 2b).

A look at the separate real tradable prices separately, however, shows that most of the relationship between the terms of trade and real house prices comes from a strongly negative relationship ($R^2 = 0.31$) between real import prices and real house prices. While Japan brings the negative relationship into sharpest relief, only Germany experiences lower house prices along with lower real import prices. Meanwhile, during the period between 1994 and 2015, only Norway saw a long-run increase in real export prices. All other economies in the panel saw declines, including the other three commodity exporters, Australia, Canada and New Zealand. In other words, even in most commodity exporters, improvements in the terms of trade, and any resulting boost to house prices, were more likely to have come from lower prices for imported goods than for higher overall prices for exports, including commodities.

This becomes clear after a closer look at trends in terms of trade over the 21st century (Figure 2c) broken out into real import prices (Figure 2d) and real export prices (Figure 2e) for the four countries. Again, only in Norway was the improvement in the terms of trade mostly due to rises in export prices. In Australia, Canada and New Zealand, real export prices at the end of 2014 were at or slightly below the levels seen in 2000, having peaked no later than early 2009.

However, real import prices consistently declined over the period in Australia, Canada and New Zealand, with imports cheaper by about a third in 2015 in Australia and New Zealand than they had been in 2000 and about 16 per cent cheaper in Canada. Only Norway saw little if any decline in real import prices.[6] Also note that real import prices rose in Australia, Canada and New Zealand during the financial crisis, partly reflecting declines in local currency exchange rates.

[6] Determining exactly why Norway has not enjoyed lower prices for imports is beyond the scope of this paper. It may be related to the legal obligation of Norway's Oil Fund to invest oil revenues outside Norway. This policy would reduce the impact of oil price fluctuations on demand for assets denominated in Norwegian crowns (NOK) and thus on the NOK exchange rate with Norway's trading partners. In the other three commodity exporters, no significant analogues to the Oil Fund exist.

4.2. *Evidence from panel co-integration equations*

4.2.1. *Specification of equations*

The panel co-integration equations reported below are estimated using a panel dynamic ordinary least squares (OLS) approach (Mark and Sul 1999), generalizing the single-equation dynamic OLS approach of Stock and Watson (1993); for details on the estimation approach, see Technical Appendix 1.

It is assumed that in the long run, the ratio of house prices to consumption may be affected by real tradable prices (i.e. real export and import prices), capital outflows as measured by the trade balance, and long-term interest rates:

$$\log\left(\frac{P_{H,i,t} * POP_{i,t}}{P_{C,i,t}C_{i,t}}\right) = \alpha_i + \beta_1 R_{L,i,t} + \beta_2 \log\left(\frac{P_{X,i,t}}{P_{C,i,t}}\right) + \beta_3 \log\left(\frac{P_{M,i,t}}{P_{C,i,t}}\right) + \beta_4 TB_{i,t} + \varepsilon_{i,t}$$

Restricting $\beta_2 = \beta_3 = \beta_4 = 0$ reduces the model to a standard long-run house price relationship as seen in Bauer (2014), among many other sources. Restricting $\beta_2 = -\beta_3$ and $\beta_4 = 0$ results in a relationship substantially similar to the co-integrating equations estimated country by country in Tumbarello and Wang (2010). The specification above generalizes the Tumbarello-Wang specification by allowing export and import prices to have different effects, as well as controlling for capital flows.

The ratio of import prices to consumption most closely resembles the terms-of-trade shock described in Tomura (2008). Its effects are most likely to resemble those of a productivity shock; for example, to the extent that imported goods serve as an input to domestic production, a larger supply of imported goods, due to greater global productivity, will increase the marginal product of domestic inputs, including domestic labour as well as capital, residential and non-residential, and raise both real wages and house prices.

Higher real export prices are less likely to be directly related to productivity increases. Even in a commodity exporter, higher oil prices could, for example, be related to a negative supply shock in the global oil market, which would reduce global productivity.

A constraint added here, but not in Tumbarello and Wang (2010), is to fix the long-run elasticity of house prices with respect to per capita consumption at unity. This is motivated by similar constraints implicit in structural models of housing demand such as Iacoviello’s (2005), where the long-run elasticity of demand for housing services with respect to income is unity, ensuring balanced growth. In co-integration analysis of the link between house prices and fundamentals, this assumption is frequently relaxed.[7] However, most results reported here are robust to allowing the long-run income elasticity of housing demand to exceed unity.

4.2.2. Results

There are two key results. First, there is a statistically and economically significant long-run link between real import prices and the ratio of house prices to consumption, both in commodity importers and commodity exporters. Accounting for changes in real tradable prices substantially reduces residuals from the co-integration equation. For a typical country, adding real tradable prices reduces residual variance by 30 per cent. The amount by which the residual variance is reduced does vary by economy, being larger in the commodity exporters (about 55 per cent) than in the United States and the European Union (about 10 per cent).

Second, most of the explanatory power of the terms of trade comes from a tight relationship between real house prices and real import prices; the elasticity of the house price to consumption ratio with respect to real import prices is approximately unity. The relationship of house prices to export prices is far weaker, and dependent on a couple of outliers (Japan and Norway).

4.2.2.1. Full panel

Table 1 shows the co-integrating relationships estimated with the full panel, as well as with the sub-panels of commodity importers and exporters. Standard tests of panel co-integration, such as the Kao (1999) and Maddala-Wu (1999) tests, reject the hypothesis of no co-integration between the variables at any reasonable confidence level over the full panel.

Real export and real import prices have the expected signs and are highly significant. However, a drop in real import prices has a much larger impact than a rise in real export prices of a comparable size. A fall in import prices of 1 per cent would raise real house prices in a typical country by 1.1 per cent, while a rise in export prices would raise house prices only 0.6 per cent.

Also notable is a very low estimate for the long-run interest rate elasticity of house prices. This is especially the case in the period after the 2008–09 financial crisis, which saw large declines in long-term

[7] Girouard et al. (2006) survey estimates of the elasticity of real house prices with respect to household disposable income per capita for individual countries, most of which are well above unity. Terrones and Otrok (2004), in a panel co-integration exercise similar in spirit to the one here, find a long-run income elasticity of real house prices to disposable income of about 1.1, not far from unity.

interest rates, but only limited improvement in most national housing markets. Over the period from 1994 to 2015, a 10-basis-point decline in long-term interest rates reduces house prices by only 0.15 per cent, not significantly different from zero. When the equation is estimated using data only through 2007Q4, a larger interest rate elasticity of house prices is found, with a 10-basis-point drop in long-term interest rates lowering real house prices by 0.30 per cent. The weights of real export prices, real import prices, and the trade balance are comparable to the estimates through 2015Q3. It appears that improvements in the terms of trade, and greater capital inflows, have more consistently corresponded to stronger growth in house prices in individual markets than have long-term declines in interest rates.

4.2.2.2. Sub-panels

While the relative importance of the terms of trade to house price growth varies across countries, the finding that real import prices play a key role and export prices a marginal role is robust to a reasonable splitting of the sample.

The trade balance has a higher coefficient in the equation for the commodity importer sub-sample, reflecting the greater importance for capital inflows and outflows for driving the housing cycles of the importing countries. The commodity importers include several countries that suffered from housing bubbles driven by capital inflows (such as Ireland, Spain, the United Kingdom and the United States). However, changes in real tradable prices, including real import prices, are still significant. Among the commodity importers, a decline in real import prices has a larger-than-average impact on real house prices, with a 1 per cent decline in real import prices raising the house price/consumption ratio by 1.3 per cent. A 1 per cent rise in the terms of trade raises the ratio 0.8 per cent.

Meanwhile, the real export price is only significant at the 10 per cent level in the commodity importer sub-panel. Removing Japan from the commodity importer sub-panel results in the real export price being no longer significant at any reasonable confidence level. However, the impact of a drop in real import prices is essentially unaffected.

In an equation estimated with data from all four commodity exporters, both real export and real import prices are highly significant, and their impacts are close to being symmetric. However, these results are sensitive to the inclusion of Norway in the commodity exporter sub-panel. If Norway is removed, leaving only Australia, Canada and New Zealand, real export prices are no longer significant, and the trade balance is more highly significant. This suggests that capital inflows have played a more important role in housing cycles in Australia, Canada, and New Zealand than in Norway. [8]

However, changes in real import prices remain significant drivers of house prices, regardless of the inclusion of Norway. A drop in real import prices of 1 per cent raises the house price/consumption ratio by 0.7 per cent when Norway is included, below the estimate for the commodity importers, and by 0.9 per cent for Australia, Canada and New Zealand only.

Also noteworthy is that long-term interest rates are not significant in any sub-panel at the 5 per cent level for the house price to consumption ratio. For Australia, Canada and New Zealand, the interest rate elasticity of the ratio approaches zero.

5. Terms of trade and the housing cycle in the short run: evidence from panel VECMs

The panel co-integration analysis has helped establish a long-run relationship between changes in the terms of trade, and especially, declines in real import prices and real house prices. However, assessing the interaction of real tradable prices and other drivers, such as capital flows, is not straightforward in the single-equation panel co-integration framework.

In this section, a panel VECM, is used to assess the impact of more temporary shocks to real tradable prices on house prices. Data for each country are modelled as individual VECMs, whose structures are assumed identical across countries. Each VECM's parameters are assumed to be equal to the sum of a panel-wide average and a country-specific fixed effect, taken to be mean zero. This makes it straightforward to construct a VAR with parameters corresponding to the panel-wide average for their values, which can be taken as the process for a "typical" economy in the panel by simply taking the average of the parameters of the individual VARs.

As in Sá et al. (2011, 2014), no attempt is made to model linkages between any particular home country and foreign economies, except through the impact of the foreign economies on the exogenous real-tradable-price block. A possible alternative approach would be the global VAR (GVAR) approach pioneered by Pesaran et al. (2004) and Dees et al. (2007), in which country-specific indicators are modelled as functions of their global equivalents, proxied by trade-weighted averages of the values of the

[8] In the Canadian case, capital inflows may have been especially important during the financial crisis. The Canadian economy was deemed to be relatively stable financially and offered attractive yields in comparison to the near-zero yields offered by the United States, Germany and Japan (Patel and Yang 2015), resulting in a "flight to quality" that supported demand for Canadian-dollar assets. This would have moderated the impact of the crisis both on the Canadian-dollar exchange rate and on Canadian household interest rates, helping in turn to support Canadian house prices.

equivalent indicators over the rest of the panel, as well as global economic indicator variables such as oil or other commodity prices.[9] The global VAR approach is not taken here for several reasons. First, explicitly modelling global economic conditions (except implicitly through the terms-of-trade channel) greatly increases the number of parameters to be estimated. Secondly, the accuracy of the proxy of global conditions is limited if important trading partners of a given country (say, China with the developed world) have to be omitted from the panel due to lack of adequate data. The approach taken here keeps the number of parameters to be estimated to a manageable level, and avoids the necessity of making assumptions regarding cross-country linkages.

Third, GVARs are designed to examine how the impacts of shocks on global variables differ across individual countries. Here, our focus is on the response of a "typical" country in a panel to a change in the real price of its imports or exports, the precise source of which can vary from country to country depending on the composition of each country's export or import sectors.

5.1. Method

The approach is as follows. An identical structural VECM is estimated for each economy in the panel, in which the subset of the data corresponding to terms of trade (real import prices and the terms of trade itself) are assumed to be block-exogenous to the rest of the variables in the VECM. The intuition here is that each economy in the panel is small enough that real prices of imported and exported goods can be taken to be determined exogenously.

5.1.1. Specification of VECM

Assume data are available for member i of a panel of N economies at T_i time points, beginning at $T_{0,i} = T - T_i + 1$ and ending at time T, for k variables. Of these, a subset of $k_x < k$ variables is block-exogenous to the remaining $k_y < k - k_x$ variables. At time $T_{0,i} \leq t \leq T$, the data-generating process for economy i is assumed to obey

$$\Delta Z_i = Z_{i,-1}\begin{pmatrix} \Pi_{xx,i} & \Pi_{yx,i} \\ 0_{k_y \times k_x} & \Pi_{yy,i} \end{pmatrix} + \Delta Z_{i,-1}\begin{pmatrix} \Gamma_{xx,i} & \Gamma_{yx,i} \\ 0_{k_y \times k_x} & \Gamma_{yy,i} \end{pmatrix} + D_i\begin{pmatrix} \delta_{x,i} \\ \delta_{y,i} \end{pmatrix} + u_{i,t} \qquad (5.1.1)$$

where $Z_i = [X_i \quad Y_i]$ is the $T_i \times k$ matrix of observations of the k_x exogenous variables X_i and the k_y endogenous variables Y_i for economy i, and D_i is a $T_i \times l$ matrix of deterministic variables. In this

[9] GVAR studies of the impact of commodity price shocks on macroeconomies include Gelasi and Lombardi (2009), Cashin et al. (2012), Allegret et al. (2014) and Gruss (2014); GVAR studies of international house price linkages include Hiebert and Vansteenkiste (2009) and Vansteenkiste (2007).

application, $X_i = [\ln P_{M,i}/P_{C,i} \quad \ln P_{X,i}/P_{C,i}]$ is the matrix of real tradable prices ($k_x = 2$), while $Y_i = [\ln REER_i \quad TB_i \quad \ln(P_{H,i}/P_{C,i}) \quad \ln(HHC_i/P_{C,i}) \quad \ln(C_i/POP_i) \quad \ln P_{c,i} \quad gap_i \quad R_{L,i} \quad R_{S,i}]$ is the set of variables assumed to be determined endogenously in the local economy ($k_y = 9$) and D is a simple constant term equal to unity for all t ($l = 1$).

The $T_i \times k$ matrix of residuals $u_i = (u_{x,i} \quad u_{y,i})$ is assumed to be i.i.d. across observations, normally distributed with a co-variance matrix Ω_i. The residuals are assumed to be linear combinations of a $T_i \times k$ matrix of structural shocks $\varepsilon_i = (\varepsilon_{x,i} \quad \varepsilon_{y,i})$ assumed to be i.i.d. with variance one. The mapping from ε_i to u_i obeys

$$u_i = \varepsilon_i C_i = (\varepsilon_{x,i} \quad \varepsilon_{y,i}) \begin{pmatrix} C_{xx,i} & C_{yx,i} \\ 0_{k_x \times k_y} & C_{yy,i} \end{pmatrix} \tag{5.1.2}$$

so that only the $T_i \times k_x$ subset of structural shocks $\varepsilon_{x,i}$ affects the exogenous block.

At this stage, three important assumptions are made to simplify calculation. The first is that for each country, the $k \times k$ coefficient matrix for the first lag of the levels of the variables, $\Pi_i = \begin{pmatrix} \Pi_{xx,i} & \Pi_{yx,i} \\ 0_{k_y \times k_x} & \Pi_{yy,i} \end{pmatrix}$, the $k \times k$ coefficient matrix for the lagged growth rates $\Gamma_i = \begin{pmatrix} \Gamma_{xx,i} & \Gamma_{yx,i} \\ 0_{k_y \times k_x} & \Gamma_{yy,i} \end{pmatrix}$ and the $l \times k$ coefficient matrix for deterministic variables $\delta_i = \begin{pmatrix} \delta_{x,i} \\ \delta_{y,i} \end{pmatrix}$ are assumed to be sums of panel-wide averages $\overline{\Pi}, \overline{\Gamma}$ and $\overline{\delta}$, plus matrices of country-specific fixed effects $\eta_{\Pi,i}$, $\eta_{\Gamma,i}$, and $\eta_{\delta,i}$, such that

$$\Pi_i = \overline{\Pi} + \eta_{\Pi,\mathrm{i}} = \begin{pmatrix} \overline{\Pi}_{xx} & \overline{\Pi}_{yx} \\ 0_{k_y \times k_x} & \overline{\Pi}_{yy} \end{pmatrix} + \begin{pmatrix} \eta_{\Pi,xx,i} & \eta_{\Pi,yx,i} \\ 0_{k_x \times k_y} & \eta_{\Pi,yy,i} \end{pmatrix} \tag{5.1.3}$$

$$\Gamma_i = \overline{\Gamma} + \eta_{\Gamma,\mathrm{i}} = \begin{pmatrix} \overline{\Gamma}_{xx} & \overline{\Gamma}_{yx} \\ 0_{k_y \times k_x} & \overline{\Gamma}_{yy} \end{pmatrix} + \begin{pmatrix} \eta_{\Gamma,xx,i} & \eta_{\Gamma,yx,i} \\ 0_{k_x \times k_y} & \eta_{\Gamma,yy,i} \end{pmatrix} \tag{5.1.4}$$

$$\delta_i = \overline{\delta} + \eta_{\Pi,\mathrm{i}} = \begin{pmatrix} \overline{\delta}_x \\ \overline{\delta}_y \end{pmatrix} + \begin{pmatrix} \eta_{\delta,x,i} \\ \eta_{\delta,y,i} \end{pmatrix} \tag{5.1.5}$$

$$\sum_i \eta_{\Pi,i} = 0_{k \times k}, \sum_i \eta_{\Gamma,i} = 0_{k \times k}, \sum_i \eta_{\delta,i} = 0_{l \times k}. \tag{5.1.6}$$

The second is that the mapping from structural shocks to residuals C_i is also assumed to be equal to a panel-wide average $\bar{C}$ and country-specific fixed effects $\eta_{M,i}$ such that

$$C_i = \bar{C} + \eta_{\mathrm{C},i} = \begin{pmatrix} \bar{C}_{xx} & \bar{C}_{yx} \\ 0_{k_y \times k_x} & \bar{C}_{yy} \end{pmatrix} + \begin{pmatrix} \eta_{C,xx,i} & \eta_{C,yx,i} \\ 0_{k_y \times k_x} & \eta_{C,yy,i} \end{pmatrix}, \sum_i \eta_{\mathrm{C},i} = 0_{k \times k}. \tag{5.1.7}$$

The third assumption is that structural shocks in each country, including those to the exogenous terms of trade, are independent of shocks in all other countries in the panel. In practice, of course, shocks to real tradable prices among a panel of developed countries may well be cross-correlated, even if shocks to local economic conditions are not. The independence assumption, at some admitted cost in realism, has the benefit of greatly simplifying the estimation of the model in practice.

To get draws from the joint posterior distribution of $\bar{\Pi}$, $\bar{\Gamma}$, $\bar{\delta}$, and $\bar{C}$, it is only necessary to sample from the joint posterior distribution of Π_i, Γ_i, δ_i, and C_i for each i, and average the draws for each country to get the panel-wide averages:

$$\begin{aligned} \bar{\Pi}_{draw} &= \frac{1}{N}\sum_i \Pi_{draw,i}\,, \bar{\Gamma}_{draw} = \frac{1}{N}\sum_i \Gamma_{draw,i}, \\ \bar{\delta}_{draw} &= \frac{1}{N}\sum_i \delta_{draw,i}\,, \bar{C}_{draw} = \frac{1}{N}\sum_i C_{draw,i} \end{aligned} \tag{5.1.8}$$

If Π_i is assumed to be of full rank, the model reduces to a simple multivariate regression with an exogenous block; sampling from the posterior distribution of the model parameters is straightforward (Zha 1999). Complicating sampling from the posterior is the fact that in a VECM, Π_i is of rank $q < k$, where q is equal to the number of co-integrating relationships in the data. More specifically, there are assumed to be up to $q_x < k_x$ co-integrating relationships among the variables in X, and $q_y < k_y$ further co-integrating relationships that include at least one member of Y. Members of Y may, but need not necessarily, be co-integrated with members of X.

As is standard in discussion of reduced rank regression (e.g. Geweke 1996), decompose Π_i into two matrices $\Pi_i = B_i A_i$, where the $q \times k$ matrix $A_i = \begin{pmatrix} A_{xx,i} & A_{yx,i} \\ 0_{q_y \times k_x} & A_{yy,i} \end{pmatrix}$ are the loadings of the co-integrating relationships in the k equations of the model, and $B_i = \begin{pmatrix} B_{xx,i} & B_{yx,i} \\ 0_{k_y \times q_x} & B_{yy,i} \end{pmatrix}$ is a $k \times q$ matrix such that $Z_i B_i$ is stationary. The model can be rewritten as

$$\begin{aligned} \Delta Z_i &= Z_{i,-1} B_i \begin{pmatrix} A_{xx,i} & A_{yx,i} \\ 0_{q_y \times k_x} & A_{yy,i} \end{pmatrix} + \Delta Z_{i,-1} \begin{pmatrix} \Gamma_{xx,i} & \Gamma_{yx,i} \\ 0_{k_y \times k_x} & \Gamma_{yy,i} \end{pmatrix} + D_t \begin{pmatrix} \delta_{x,i} \\ \delta_{y,i} \end{pmatrix} + u_{i,t} \\ &= [X_{i,-1} B_{xx,i} \quad X_{i,-1} B_{yx,i} + Y_{i,-1} B_{yy,i}] \begin{pmatrix} A_{xx,i} & A_{yx,i} \\ 0_{q_y \times k_x} & A_{yy,i} \end{pmatrix} \\ &\quad + \Delta Z_{i,-1} \begin{pmatrix} \Gamma_{xx,i} & \Gamma_{yx,i} \\ 0_{k_y \times k_x} & \Gamma_{yy,i} \end{pmatrix} + D_t \begin{pmatrix} \delta_{x,i} \\ \delta_{y,i} \end{pmatrix} + u_{i,t}. \end{aligned} \tag{5.1.9}$$

5.1.2. Sketch of sampling algorithm

Given B_i, the VECM reduces once again to a standard multivariate regression with an exogenous block. Sampling from the conditional distribution is once again straightforward. This leaves only the free parameters in B_i to be sampled using numerical methods.

The Gibbs-sampling algorithm used here for each component model is as follows:

1. Pick a plausible starting point for the free parameters in each B_i.
2. For each economy:
   a. Sample from the exact joint distribution of the parameters of the exogenous block $A_{xx,i}, \Gamma_{xx,i}, \delta_{x,i}$ and $C_{xx,i}$, given B_i.
   b. Sample from the exact joint distribution of the parameters of the endogenous block $A_{yx,i}$, $A_{yy,i}$, $\Gamma_{yx,i}, \Gamma_{yy,i}$, $C_{yx,i}$ and $C_{yy,i}$, given $A_{xx,i}, \Gamma_{xx,i}, \delta_{x,i}, C_{xx,i}$ and B_i.
   c. Sample from the joint distribution of the free parameters in B_i, given A_i, Γ_i, δ_i and C_i, using a Metropolis-in-Gibbs algorithm.
3. Take the draws of $\Pi_i, \Gamma_i, \delta_i$, and C_i from each economy, and take the average to get draws of $\bar{\Pi}, \bar{\Gamma}, \bar{\delta}$, and $\bar{C}$. Calculate desired moments using $\bar{\Pi}, \bar{\Gamma}, \bar{\delta}$, and $\bar{C}$.
4. Return to Step 2, and repeat for a large number of draws until the distribution of the desired moments converges.

Further details of the sampling algorithm are in Technical Appendix 2.

5.1.3. Restrictions on co-integrating relationships

Without placing further restrictions on B_i, both B_i and A_i are unidentified, and posterior distributions for their elements do not exist. To identify B_i, further restrictions on its elements are needed. This is done by assuming long-run common trends between model variables broadly motivated by economic theory, such that linear combinations of those variables should be stationary.

Here, restrictions are imposed on B_i so as to allow for the following co-integrating relationships.

Real import and real export prices: A permanent decline in real import prices, reflecting a decline in the cost of manufactured goods sold on global markets, will also permanently reduce a country's real export prices to the extent that the country exports such goods:

$$\ln\left(P_{X,i}/P_{C,i}\right) - \beta_{i,1}\ln\left(\frac{P_{M,i}}{P_{C,i}}\right) \sim I(0). \tag{5.1.3.1}$$

The terms of trade are stationary in the special case that $\beta_{i,1} = 1$.

Real exchange rate and real import prices: The real exchange rate is defined as the product of the nominal exchange rate e_i and the ratio of the foreign to the home price level: $REER \equiv \frac{e_i P_F}{P_H}$. The nominal price of imported goods $P_{M,i}$ faced by consumers in economy i will obviously be related to the price level in the exporting country P_F. Here it is assumed that the real exchange rate is negatively related to the real import price in the long run:

$$\ln REER_i + \beta_{i,2}\ln\left(P_{M,i}/P_{C,i}\right) \sim I(0).$$

Setting $\beta_{i,2} = 0$ yields a special case where $REER$ is stationary.

House prices, consumption, real import prices and interest rates: A key result of the single-equation panel co-integration analysis above is that the ratio of house prices to consumption per capita should be negatively related to real import prices in the long run, as well as possibly to long-term interest rates:

$$\ln\left(P_{H,i}/P_{C,i}\right) - \ln\left(\frac{C_i}{POP_i}\right) + \beta_{i,3}\ln\left(\frac{P_{M,i}}{P_{C,i}}\right) + \beta_{i,4}R_{L,i} \sim I(0).$$

Household debt, house prices, consumption and interest rates: Real household debt per capita is assumed to be related to real house prices and consumption per capita:

$$\ln\left(\frac{HHC_i}{P_{C,i}POP_i}\right) - \beta_{i,5}\ln\left(\frac{P_{H,i}}{P_{C,i}}\right) - \left(1-\beta_{i,5}\right)\ln\left(\frac{C_i}{POP_i}\right) - \beta_{i,6}R_L \sim I(0).$$

Structural models such as Iacoviello (2005) typically assume that all household debt is secured, and proportional to, the value of housing owned by households. Setting $\beta_{i,5} = 1$ and $\beta_{i,6} = 0$ would impose the Iacoviello credit constraint exactly. In practice, not all household debt is secured by housing. The more general specification above is more flexible, while still ensuring that household debt cannot grow faster than permanent income, barring changes in interest rates or real import prices. This is easily seen by substituting in the house price/real import price relation:

$$\ln\left(\frac{HHC_i}{P_{C,i}}\right) - \beta_{i,5}\beta_{i,3}\ln\left(\frac{P_{M,i}}{P_{C,i}}\right) - \ln(C_i) - \beta_{i,6}R_L \sim I(0).$$

Short- and long-term interest rates: Most structural models assume that short- and long-term interest rates have a common trend, so that the spread between short- and long-term interest rates is stationary. They also assume a stationary ratio for output to consumption (private and public) and a stationary (not necessarily mean zero) trade balance. This suggests imposing the restrictions

$$R_{S,i} - R_{L,i} \sim I(0), gap_i \sim I(0), TB_i \sim I(0).$$

The above relations imply the following restrictions for B_i.

$$B_i = \begin{pmatrix} -\beta_{i,1} & \beta_{i,2} & 0 & 0 & \beta_{i,3} & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -\beta_{i,5} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & -1 & -(1-\beta_{i,5}) & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \beta_{i,4} & \beta_{i,6} & -1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}.$$

5.1.4. Identifying terms-of-trade shocks

As there are two real tradable price variables in X, up to two structural shocks can be identified. Here, for simplicity, the two shocks are identified with a simple upper-triangular Cholesky decomposition of the covariance matrix of the residuals from the exogenous block of the VECM, $\Omega_{xx,i}$:

$$\begin{aligned} u_{x,i} &= [u_{P_M/P_C} \quad u_{P_X/P_C}] = \varepsilon_{x,i} C_{xx,i} \\ &= \varepsilon_{x,i} \begin{pmatrix} c_{i,1,1} & c_{i,1,2} \\ 0 & c_{i,2,2} \end{pmatrix} = [c_{i,1,1}\varepsilon_{P_M/P_C} \quad c_{i,1,2}\varepsilon_{P_M/P_C} + c_{i,2,2}\varepsilon_{P_X/P_C}] \end{aligned} \tag{5.1.4.1}$$

where $C_{xx,i}{}' C_{xx,i} = \Omega_{xx,i}$.

The two shocks are interpreted as follows. One shock, the *global tradable supply shock* ε_{P_M/P_C}, is permitted to affect both real export and import prices during the period of the shock. This captures the idea that a shock that drives down the price of goods traded globally will both reduce the real price of goods imported by country i and possibly impact the real price of exports as well, if country i exports a significant number of close substitutes for the same good. For example, an increase in the productivity of manufacturing industries in emerging markets will reduce prices of manufactured goods exported by developed markets.

The other shock is an idiosyncratic *export price shock*, which is unrelated on impact to changes in the level of real import prices. This can be thought of as an idiosyncratic change to a good exported only by the small open economy in question.

5.2. *Results*

Results reported below are calculated by drawing 1,000,000 times from the posterior, discarding 200,000 burn-in draws, and then, to minimize serial correlation in the draws for B_i introduced by the Metropolis step, calculating moments using each 80th of the remaining draws. As a result, the moments below use 10,000 draws from the approximate posterior. The figures below report 90 per cent confidence bands (5th and 95th percentile) along with the median point estimate.

There are two key results from the panel VECMs. First, after a global tradable supply shock, real house prices and other variables respond in a fashion closely resembling what one would expect during a housing boom. Real house prices and household debt rise, along with real exchange rates, incomes and consumption, both in commodity importing and exporting countries, while interest rates fall.

The impact of export price shocks on house prices is far more ambiguous. In most countries, export price shocks do increase output and consumption. However, their impact on real house prices is much weaker. In commodity exporting countries after 2007, export price shocks appeared to lower real house prices and consumption, not increase them. Even before 2007, export price shocks had a fairly weak positive impact on consumption and house prices in the commodity exporters.

Second, terms-of-trade shocks explain a substantial share in the business cycle variation of house price variation over the 1994–2015 period; taken together, terms-of-trade shocks explain anywhere from 16 to 41 per cent of house price growth, along with 10 to 34 per cent of consumption growth in a typical country. Moreover, terms-of-trade shocks explain the bulk of the variation in the ratio of house prices to consumption. However, global tradable supply shocks account for the vast majority of house price variation explained by terms-of-trade shocks in a typical country; export price shocks are only important for commodity exporters.

5.2.1. *Co-integration equation estimates, country by country*

Before discussing the impulse responses in detail, a brief discussion of the country-by-country model parameters (reported in Table 2) are in order. The main difference between the parameter estimates for the commodity exporters and commodity importers is a smaller or even negative term β_1 in the co-integration relation between real import prices and real export prices among the commodity exporters.

This is in line with the prices of commodity exports being more orthogonal to the prices of manufactured and service imports.

The posterior mean of the elasticity of house prices with respect to real import prices β_3 varies widely across countries, averaging 1.44, but ranging from 0.24 in Switzerland to 3.6 in Denmark. However, only in Switzerland and Denmark is the country-specific mean of the elasticity more than two standard deviations from the panel co-integration estimate of 1.1.

By construction, the elasticity of real house prices with respect to interest rates β_4 is greater than zero in all countries, with the panel-wide average around 0.037. However, only in a few countries (Belgium, Sweden and Switzerland) is the elasticity more than two standard deviations away from zero. Estimates range from a low of 0.008 (Germany) to a higher of 0.107 (Belgium), with most country estimates on the lower end of the range.

5.2.2. Impulse responses

5.2.2.1. Global tradable supply shocks

Figure 3a shows the response to a positive global tradable supply shock for a typical country in the full panel. While both real export and import prices fall, export prices fall by less, resulting in an overall improvement of the terms of trade. On average, a one-standard deviation global tradable supply shock lowers real import prices by 1.6 per cent, real export prices by 0.9 per cent, and the terms of trade by 0.7 per cent on impact. The real exchange rate rises by 1.2 per cent, while the trade balance rises by 0.15 per cent of GDP.

Global tradable shocks act as supply shocks, increasing consumption and keeping inflation in check. Consumption rises, with the level rising by 1.2 per cent twenty quarters ahead; put another way, the growth rate of consumption rises by 0.23 per cent a year on average. Meanwhile, consumer prices fall by 0.5 per cent over twenty quarters; in other terms, annualized inflation falls by 0.1 per cent. Lower expected inflation for non-housing consumer goods results in lower long-term interest rates (by about 13 basis points twenty quarters ahead); in the short run, lower expected inflation leads central banks to lower short-term interest rates, with the term spread hitting its trough (falling 17 basis points) three quarters after the shock.

Lower prices for imported consumer goods, as well as lower real interest rates, contribute to a boom in the price of non-tradables such as housing. Twenty quarters after the shock, real house prices rise by 2.7

per cent (or by 0.54 per cent a year), while the ratio of house prices to consumption rises by 1.5 per cent, or by 0.9 per cent for every 1 per cent decline in real import prices.

Household debt also increases, both in absolute terms and in proportion to consumption, though by less than house prices do. Twenty quarters after a one-standard-deviation global tradable supply shock, household debt rises by 2.3 per cent, or by 0.46 per cent a year, and the ratio of household debt to consumption by 1.1 per cent, or by 0.7 per cent for every 1 per cent decline in real import prices.

As the majority of the panel are commodity importers, responses from the commodity importer sub-panel are substantially similar to those for the full panel.[10] The responses of commodity exporters (Figure 3b) are different enough to merit detailed discussion separately. Despite the larger impact on real import prices of the global tradable shock (about 2.2 per cent on impact) and the larger rise in the terms of trade, the impact of the shock on overall consumption is not significantly different from zero after four quarters. The point estimate of the response of household debt turns negative after twelve quarters, and is also not significantly different from zero.

The lack of consumption and household debt response is partly the result of a rise rather than a fall in interest rates after the shock, restraining consumption and consumer borrowing. Long-term interest rates are 12 basis points higher twenty quarters after the shock, despite no change in the price level or inflation. In New Zealand, in particular, household debt is more sensitive than average to interest rate changes.

However, the global tradable shock still boosts real house prices, despite the lack of consumption response. Twenty quarters ahead, the global tradable shock raises house prices by 1.2 per cent on average. Moreover, the median estimate of the response of the house price to consumption ratio is 1.4 per cent; this corresponds to a 0.6 per cent response to a 1 per cent drop in real import prices, not far below the response in the full panel. The finding that a fall in global tradable prices disproportionately benefits house prices is clearly robust to the interest rate and consumption response to the shock.

5.2.2.2. Export price shocks

In a typical country in the panel, an export price shock has a positive impact on consumption (Figure 3c), the trade balance and the output gap, as well as on the terms of trade. However, the response of consumption is weaker than after a global tradable supply shock. After a one-standard-deviation export price shock that raises export prices and the terms of trade by 1.1 per cent, consumption rises only 0.5 per

[10] As a result, they are omitted to save space, but are available on request.

cent after twenty quarters. The export shock acts as an aggregate demand shock; while the increased revenue in exporting industries raises wages, production of consumer goods is partly crowded out.

The response of house prices is also weaker, rising only 0.8 per cent after twenty quarters. Moreover, the export price shock does not result in house prices growing faster than consumption. The 90 per cent confidence band for the house price to consumption ratio comfortably nests zero, with a range of responses from +0.97 to -0.25 per cent twenty quarters ahead being within the range of possibility.

Looking at the commodity exporters only (Figure 3d) reveals why the range for the "average" response bounds zero. After an export price shock that increases terms of trade 2.4 per cent, house prices *fall* by 1.6 per cent after five quarters, recovering to only 0.9 per cent below baseline twenty quarters ahead, while household debt falls by 1.2 per cent. The response is in large part due to a fall in consumption of 0.7 per cent over twenty quarters. The confidence interval for the response of the house price/consumption ratio comfortably nests zero.

5.2.2.3. Sensitivity analysis: Impulse responses in commodity exporters before 2007

In the commodity exporters, over the full sample period, the fall in consumption and house prices after the export price shock may reflect factors only indirectly related to the terms of trade. One possibility is that the measured terms of trade might be disproportionately affected by the impact of the 2008 financial crisis. Another important factor in the case of Australia, Canada and New Zealand is capital outflows from emerging Asian markets fuelling growth in house prices in these markets despite deterioration in the terms of trade. Australian, Canadian and New Zealand real estate, especially in cities with significant Asian populations, is a popular investment vehicle among wealthy investors from emerging markets. Motives for such investment include a desire to arrange housing for children who plan to study at universities in those countries, to expedite possible future immigration, or to get around capital controls at home.[11] The fall in the terms of trade for commodity exporters partly reflects weaker economic growth (and commodity demand growth) in emerging markets, increasing the incentive of foreign investors to boost the share of foreign real estate (including Australian, Canadian and New Zealand real estate) in their portfolios. Moreover, lower real exchange rates for the commodity exporting countries of interest to

[11] A 2014 report listed Vancouver, Toronto, Sydney and Melbourne among the top ten cities in which wealthy Chinese were most likely to buy real estate; these cities, along with New Zealand, were cited as places to which wealthy Chinese would be most willing to emigrate (quoted in Gordon 2016). In Canada, immigration programs targeted at foreign investors have been a strong incentive for these investors to purchase Canadian assets, including real estate, since the 1980s (Ley 2015).

foreign investors would make purchases of real estate in those countries more cost-effective, helping to boost demand and local-currency house prices.

As a check, therefore, the VECM was re-estimated for the commodity exporter sub-panel using data through 2007Q4 only, removing the period before the financial crisis and the decline in commodity prices starting in 2012, and the impulse responses re-simulated for the export price shock (Figure 3e).[12] The point estimate for the response of house prices to an export price shock is now positive. However, the impact of the export price shock on consumption, as well as on house prices and household debt, is still not significantly different from zero.

5.2.3. Variance decompositions

To assess the importance of terms-of-trade shocks for the variance of house prices and household debt at business cycle frequencies, variance decompositions were conducted with both the VECM estimated with the full panel and the VECM using the commodity exporter sub-panel. Variance decompositions are reported for growth in real house prices, real household debt and consumption, as well as for the ratios of house prices and household debt to consumption per capita. A caveat to interpreting the variance decompositions is that the shares of house price and household debt variation attributed here to terms-of-trade shocks apply to a "typical" economy in the panel, and not to any specific economy. This will clearly vary across economies even within the sub-panels.[13]

5.2.3.1. Full panel

In a typical country in the panel (Figure 4a), terms-of-trade shocks explain a substantial share of variation of growth in real house prices and household debt, partly, but not entirely, due to their explaining a substantial share of consumption growth. Twenty quarters ahead, terms-of-trade shocks explain anywhere from 16 to 41 per cent of the variance of house price growth, with a median estimate of 28 per cent, and anywhere from 19 to 50 per cent of the variance of household debt, with a median estimate of 34 per cent. This is in line with their explaining anywhere from 11 to 34 per cent of the variance in consumption growth (median estimate of 21 per cent). The terms-of-trade share of variance converges fairly quickly to

[12] Responses to the global tradable supply shock were more robust to the use of the shorter sample period, and are omitted here to save space. The main difference is that the point estimate of the consumption response is now positive twenty quarters ahead. However, it remains not significantly different from zero.

[13] Historical decompositions of house price and household debt variance for individual countries are straightforward to calculate, but due to much lower degrees of freedom, any such estimates will be much less precise. The country-level variance decompositions are omitted here for space reasons but are available on request.

its long-run level. For example, eight quarters ahead, terms-of-trade shocks already explain 22 per cent variance in house price growth, and 20 per cent of household debt growth.

Moreover, terms-of-trade shocks explain the majority of the variance of the ratio of house prices to consumption. Twenty quarters ahead, the terms-of-trade shocks explain not less than 45 per cent and possibly as high as 85 per cent of the house price/consumption ratio, with a median estimate of 71 per cent. Eight quarters ahead, the median estimate is already as high as 43 per cent, with a confidence interval ranging from 24 to 59 per cent.

The share of the variance of the debt/consumption ratio attributable to terms-of-trade shocks is lower than that for the house price/consumption ratio, and less precisely estimated, but is still non-negligible. Twenty quarters ahead, the median estimate of the share of variance of the debt/consumption ratio explained by terms-of-trade shocks is 57 per cent. It is no less than 21 per cent and may be as high as 78 per cent.

Of the two types of terms-of-trade shocks, global tradable supply shocks are by far the most important for explaining variance in consumption, house prices and household debt. The median estimate of the share of variance explained by export price shocks does not exceed 5 per cent twenty quarters ahead for any of the five variables reported here.

5.2.3.2. Commodity exporters

There are several differences between the variance decomposition for the full panel and that for the commodity exporter sub-panel, for the full 1994–2015 period (Figure 4b). Twenty quarters ahead, terms-of-trade shocks explain anywhere from 25 to 52 per cent of variance in house price growth twenty quarters ahead (median estimate 38 per cent), 16 to 52 per cent of the variance in household debt growth, and 10 to 38 per cent of variance in consumption growth. However, export price shocks explain much more of the variance than in the full panel. Median estimates suggest that, twenty quarters ahead, export price shocks explain 23 per cent of the variance of house price growth, 21 per cent for household debt growth and 14 per cent for consumption growth.

Moreover, the shares of variance of the ratios of house prices and household debt to consumption are smaller, and less precisely estimated, for the commodity exporters than for the full panel. Estimates for the share of variance of the house price/consumption ratio explained by terms-of-trade shocks range from 23 to 82 per cent, with a median estimate of 59 per cent. Estimates of the share of variance for the debt/consumption ratio are lower, with the median at 30 per cent, though shares as low as 5 per cent cannot be ruled out. Moreover, the bulk of the variation comes from the export price shock, not the global tradable supply shock.

A variance decomposition using the commodity exporter sub-panel through 2007Q4 (Figure 4c) is more in line with the results in the full panel, though less precise given the reduced sample period and number of countries. The share of terms-of-trade shocks in the twenty-quarter-ahead variance of the house price/consumption ratio ranges from 26 to 92 per cent, with the median at 72 per cent. The share of variance for the debt/consumption ratio ranges from 26 to 92 per cent, with a median of 74 per cent. For both ratios, the share of export price shocks is relatively minor, with a median estimate of only 14 per cent for each ratio.

6. Conclusions

This paper has argued that changes in the terms of trade are an important driver of house prices and household debt in developed economies, especially, but not only, in commodity exporting countries such as Canada. Most of the link is attributable to a strong relationship between import prices and house prices, with declines in the price of imports raising the ratio of house prices to non-housing consumption; the relationship of real export prices to house prices or household debt is generally weak even in commodity exporting countries. A large share of the variation of house prices and household debt, both in the long run and at business cycle frequencies, can be attributed to changes in real import prices.

A key result from a monetary policy perspective is that the link between changes in real import prices and changes in real house prices is more robust than the link of real house prices to interest rates over the 1994-2015 period. If global productivity improvements for tradable goods did indeed play a greater role than interest rates in driving up house prices, ratios of house prices to incomes and consumption may remain above their pre-21st century levels in most of the developed world for the foreseeable future, even if global interest rates rise.

A more refined assessment of the relative importance of terms-of-trade shocks to house price movements would better account for local supply-side factors, such as construction costs (e.g. Adams and Füss 2010), urbanization and/or regulation. Other possibly fruitful extensions could focus on whether the results here can be generalized to emerging markets, including but not limited to rapidly developing commodity exporters such as Brazil, Russia, and South Africa, and how adding the emerging commodity exporters to the panel would impact observed differences between commodity exporters and importers. As the impact of changes in the terms of trade due to changes in commodity prices is also unlikely to be uniform even within a country, it would be worthwhile to examine how these impacts would differ across regions (states or provinces). These extensions are left to future work.

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Technical Appendix 1: Panel co-integration estimation with dynamic ordinary least squares (OLS)

This technical appendix gives a few details on the panel dynamic OLS estimation of co-integration relationships used in the text. As panel DOLS is a well-known technique, and no attempt is made to innovate econometrically, the details will be limited to those needed to reproduce the results. For a detailed description and derivation of the technique, see Mark and Sul (1999); Mark and Sul (2003) describe an application of pooled weighted DOLS to money demand.

The following equation is estimated using OLS:

$$\bar{y}_{i,t} = \bar{X}'_{i,t}\beta + \sum_{j=-q}^{r} \Delta\bar{X}'_{i,t+j}\delta_i + v_{i,t} \tag{A.1.1}$$

where $y_{i,t}$ is the value of the variable y to be explained at time t for country i, while $X_{i,t}$ is the value of the vector of explanatory variables X at time t for country i. Before estimation the deterministic portions of $y_{i,t}$and $X'_{i,t}$ are removed to control for country-specific fixed effects. In the results reported below, the deterministic portion is assumed to be a simple mean, so that $\bar{y}_{i,t}$ and $\bar{X}'_{i,t}$ are simply the de-meaned versions of $y_{i,t}$and $X'_{i,t}$.

The coefficient terms δ_i for $\Delta X_{i,t}$, its r leads and its q lags are country-specific. In this exercise, the optimal lead and lag length are found for each country using the Schwarz criterion. Given the shortness of the data for each country, which never include than 84 observations, no more than one lead or lag is ever necessary.

The estimation takes a two-step approach. Let the matrix of explanatory variables be $W'_{i,t} = [X'_{i,t} \quad Z'_{i,t}]$, where $Z'_{i,t}$ is a matrix of the interactions of the leads and lags of $\Delta X_{i,t}$ with country-specific dummies. Then the equation coefficients are yielded by:

$$\begin{bmatrix} \beta_{OLS} \\ \delta_{1,OLS} \\ \vdots \\ \delta_{N,OLS} \end{bmatrix} = \left(\sum_{i=1}^{N} \sum_{t=T_i}^{T} \bar{W}_{i,t}\bar{W}'_{i,t} \right)^{-1} \left(\sum_{i=1}^{N} \sum_{t=T_i}^{T} \bar{W}_{i,t}\bar{y}'_{i,t} \right), \tag{A.1.2}$$

where N is the number of countries in the panel, T is the end point of the data assumed uniform throughout the panel, and T_i is the starting point of data for country i.

Even if the long-run variance of the equation residuals is not constant across countries, OLS will still yield consistent estimates of the model parameters. Hence, the residuals from the equation for each country $v_{i,t,OLS}$ can be used to calculate an estimate $\omega_{i,OLS}$ of the long-run variance of the residuals $v_{i,t}$ of the equation for each country i.

As $v_{i,t,OLS}$ is rarely i.i.d., some allowance for serial correlation must be made to obtain a consistent estimate for variances. One option cited by Mark and Sul (1999) is an approach following Hamilton (1994), in which each $v_{i,t,OLS}$ is assumed to follow an AR(1) process, estimating the auto-regressive process for each country, and then taking the long-run variance estimate to equal

$$\omega_{i,OLS} = \frac{\sigma^2_{\eta,i}}{(1-\rho^2_{v,i})}, \sigma^2_{\eta,i} = \frac{\sum_{t=T_i+1}^{T} \eta^2_{i,t}}{T-T_i}, \qquad \text{(A.1.3)}$$

where $\sigma^2_{\eta,i}$ is the variance of $\eta_{i,t}$, the residuals from an AR model of $v_{i,t,OLS}$:

$$v_{i,t,OLS} = \rho v_{i,t-1,OLS} + \eta_{i,t}. \qquad \text{(A.1.4)}$$

With each $\omega_{i,OLS}$ in hand, a weighted least-squares estimate of the parameters is yielded by

$$\begin{bmatrix} \beta_{WLS} \\ \delta_{1,WLS} \\ \vdots \\ \delta_{N,WLS} \end{bmatrix} = \left(\sum_{i=1}^{N} \omega_{i,OLS}^{-1} \sum_{t=T_i}^{T} \bar{W}_{i,t}\bar{W}'_{i,t}\right)^{-1}\left(\sum_{i=1}^{N} \omega_{i,OLS}^{-1} \sum_{t=T_i}^{T} \bar{W}_{i,t}\bar{y}'_{i,t}\right). \qquad \text{(A.1.5)}$$

V_{WLS} , the variance-covariance matrix of the model parameters, is estimated with the consistent estimator

$$V_{WLS} = \left(\frac{1}{N}\sum_{i=1}^{N} \omega_{i,OLS}^{-1} \left(\frac{1}{(T-T_i+1)^2}\sum_{T_i}^{T} \bar{W}_{i,t}\bar{W}'_{i,t}\right)\right)^{-1}. \qquad \text{(A.1.6)}$$

Technical Appendix 2: Sampling from panel VECM posterior

This appendix discusses the details of how to draw from the posterior distributions of the individual VECMs with exogenous blocks estimated in this paper. For a more general treatment of sampling from VAR's with exogenous blocks, see Zha (1999).

Step 1: Sampling for parameters of exogenous block given B_i

The exogenous block takes the form

$$\Delta X_i = X_{i,-1} B_{xx,i} A_{xx,i} + \Delta X_{i,-1} \Gamma_{xx,i} + D_i \delta_{x,i} + u_{x,i}, \qquad \text{(A2.1.1)}$$

which is a simple multivariate regression. It is well known (e.g. Zellner 1971) that the posterior distribution of the covariance matrix $\Omega_{xx,i}$ of the residuals $u_{x,i}$ is an inverse-Wishart distribution, such that

$$\Omega_{x,i} | X_i, B_{xx,i}, D \sim IW\left(u_{xx,i,OLS}{}' u_{xx,i,OLS}, T_i - q_x - k_x - l\right), \qquad \text{(A2.1.2)}$$

assuming a diffuse prior on $\Omega_{x,i}$ satisfying $p_{prior}\left(\Omega_{xx,i}\right) \propto \left|\Omega_{x,i}\right|^{-\frac{k_x+1}{2}}$.

$$u_{x,i,OLS} = \Delta X_i - X_{i,-1} B_{xx,i} A_{xx,i,OLS} - \Delta X_{i,-1} \mathit{\Gamma}_{xx,i,OLS} - D_i \delta_{x,i,OLS} \qquad \text{(A2.1.3)}$$

is simply the matrix of residuals given by equation-by-equation OLS estimation of the system. The mapping of residuals to shocks $C_{xx,i,draw}$ is simply the upper-triangular Cholesky decomposition of $\Omega_{x,i}$.

Let $\Xi_{x,i} = [X_{i,-1} B_{xx,i} \quad \Delta X_{i,-1} \quad D]$ be the $T_i \times (q_x + k_x + l)$ matrix of right-hand variables in the equations of the exogenous block. The $(q_x + k_x + l) \times k_x$ matrix of coefficients $\Theta_{x,i} = \left[A_{xx,i}{}' \quad \Gamma_{xx,i}{}' \quad \delta_{x,i}{}'\right]'$ has the multivariate normal distribution

$$vec\left(\Theta_{x,i}\right) | \Omega_{x,i}, X_i, B_{xx,i}, D \sim MN\left(vec\left(\Theta_{x,i,OLS}\right), \Omega_{x,i} \otimes \left(\Xi_{x,i}' \Xi_{x,i}\right)^{-1}\right), \qquad \text{(A2.1.4)}$$

where $\Theta_{x,i,OLS} = \left(\Xi_{x,i}' \Xi_{x,i}\right)^{-1} \left(\Xi_{x,i}' \Delta X_i\right)$ is the OLS point estimate of $\Theta_{xx,i}$.

Step 2: Sampling for parameters of exogenous block given B_i, $A_{xx,i}$, $\Gamma_{xx,i}$, $\delta_{x,i}$ and $C_{xx,i}$

For a more general treatment of sampling from multivariate regressions with exogenous blocks, see Zha (1999). The endogenous block of the VECM obeys

$$\Delta Y_i = X_{i,-1}B_{yx,i}A_{yx,i} + Y_{i,-1}B_{yy,i}A_{yy,i} + \Delta X_{i,-1}\Gamma_{yx,i} + \Delta Y_{i,-1}\Gamma_{yy,i} + D_i\delta_{y,i} + u_{y,i} \qquad \text{(A2.2.1)}$$

or, equivalently,

$$\Delta Y_i = X_{i,-1}B_{yx,i}A_{yx,i} + Y_{i,-1}B_{yy,i}A_{yy,i} + \Delta X_{i,-1}\Gamma_{yx,i} + \Delta Y_{i,-1}\Gamma_{yy,i} + D_i\delta_{y,i} + \varepsilon_{x,i}C_{yx,i} + \varepsilon_{y,i}C_{yy,i}. \qquad \text{(A2.2.2)}$$

As

$$\varepsilon_{x,i} = u_{x,i}C_{xx,i}^{-1} = \left(\Delta X_i - X_{i,-1}B_{xx,i}A_{xx,i} - \Delta X_{i,-1}\Gamma_{xx,i} - D_i\delta_{x,i}\right)C_{xx,i}^{-1} \qquad \text{(A2.2.3)}$$

(A2.2.2) can be rewritten as

$$\Delta Y_i = X_{i,-1}B_{yx,i}A_{yx,i}^{*} + Y_{i,-1}B_{yy,i}A_{yy,i} + \Delta X_{i,-1}\Gamma_{yx,i}^{*} + \Delta Y_{i,-1}\Gamma_{yy,i} + D_i\delta_{y,i}^{*} + \Delta X_i\Upsilon_i + \varepsilon_{y,i}C_{yy} \qquad \text{(A2.2.4)}$$

where $A_{yx,i}^{*} = A_{yx,i} - A_{xx,i}C_{xx,i}^{-1}$, $\Gamma_{yx,i}^{*} = \Gamma_{yx,i} - \Gamma_{xx,i}C_{xx,i}^{-1}$, $\delta_{y,i}^{*} = \delta_{y,i} - \delta_{x,i}C_{xx,i}^{-1}$ and $\Upsilon_i = C_{xx,i}^{-1}C_{yx,i}$. Let $\Xi_{y,i} = [X_{i,-1}B_{yx,i} \quad X_{i,-1}B_{yy,i} \quad \Delta X_{i,-1} \quad \Delta Y_{i,-1} \quad \Delta X_i \quad D]$ be the $T_i \times (q + k + k_x + l)$ matrix of right-hand variables in the endogenous block, and $\Omega_{y,i}$ be the co-variance matrix of $v_{yy,i} = \varepsilon_{y,i}C_{yy}$, the portion of the residuals of the equations in the endogenous block that is orthogonal to ΔX_i. Also, let $\Theta_{y,i} = \left[A_{yx,i}^{*}{}' \quad A_{yy,i}{}' \quad \Gamma_{yx,i}^{*}{}' \quad \Gamma_{yy,i}{}' \quad \delta_{y,i}^{*}{}' \quad \Upsilon_i{}'\right]'$ be the $(q + k + k_x + l) \times k_y$ matrix of parameters in the equations of the endogenous block. Assuming a diffuse prior on $\Omega_{y,i}$ such that $p_{prior}\left(\Omega_{yy,i}\right) \propto \left|\Omega_{yy,i}\right|^{-\frac{k_y+1}{2}}$, the posterior distribution of $\Omega_{yy,i}$ is another inverse-Wishart distribution, such that

$$\Omega_{y,i}|X_i, Y_i, B_{yx,i}, B_{yy,i}, D \sim IW\left(v_{y,i,OLS}{}'v_{y,i,OLS}, T_i - q - k - k_x - l\right) \qquad \text{(A2.2.5)}$$

where $v_{y,i,OLS} = \Delta Y_i - \Xi_{y,i}\Theta_{y,i,OLS}$ is the matrix of residuals from OLS estimation of the endogenous block equation by equation, so that $\Theta_{y,i,OLS} = \left(\Xi_{y,i}'\Xi_{y,i}\right)^{-1}\left(\Xi_{y,i}'\Delta Y_i\right)$. Meanwhile, the posterior distribution of $\Theta_{y,i}$ conditional on $\Omega_{yy,i}$ is multivariate normal:

$$vec\left(\Theta_{y,i}\right)|\Omega_{y,i}, X_i, Y_i, B_{yx,i}, B_{yy,i}, D \sim MN\left(vec\left(\Theta_{y,i,OLS}\right), \Omega_{y,i} \otimes \left(\Xi_{y,i}'\Xi_{y,i}\right)^{-1}\right). \qquad \text{(A2.2.6)}$$

Given the draws for $C_{xx,i}$ in step 1, it is straightforward to calculate the draws for $A_{yx,i}$, $\Gamma_{yx,i}$, $\delta_{y,i}$ and $C_{yx,i}$ implied by the draws of $A^*_{yx,i}$, $\Gamma^*_{yx,i}$, $\delta^*_{y,i}$ and Υ_i.

Step 3: Sampling for free parameters of B_i given A_i, Γ_i, δ_i and C_i

To sample from the posterior distribution for the free parameters of B_i , an adaptive Metropolis algorithm is used to similar to one found in Roberts and Rosenthal (2006).

The algorithm works as follows. Let $\beta_i = [\beta_{1,i} \quad \cdots \quad \beta_{j,i}]$ be the vector of the j free parameters of B_i, and let $\beta_{i,d-1}$ be a vector containing the values of the free parameters of B_i that were assumed when taking the dth draw for A_i, Γ_i, δ_i and C_i.

At each draw, we draw in sequence for each $\beta_{\mu,i}$ where $\mu \epsilon [1, \dots, j]$. For each $\beta_{\mu,i}$, draw a candidate new value for $\beta_{\mu,i}$ from the proposal distribution

$$\beta_{\mu,i,cand} \sim N\left(\beta_{\mu,i,d-1}, \varphi^2_{\mu,i,d-1}\right). \tag{A2.3.1}$$

Calculate the ratio of the posterior probabilities

$$\rho_d = \frac{p_{post}\left(\beta_{i,cand} | Z_i, A_{i,d}, \Gamma_{i,d}, \delta_{i,d}, C_{i,d}\right)}{p_{post}\left(\beta_{i,d-1} | Z_i, A_{i,d}, \Gamma_{i,d}, \delta_{i,d}, C_{i,d}\right)} \tag{A2.3.2}$$

where $A_{i,d}, \Gamma_{i,d}, \delta_{i,d}$ and $C_{i,d}$ are the draws for A_i, Γ_i, δ_i and C_i taken in steps one and two above, and $\beta_{i,cand}$ is a vector such that $\beta_{\mu,i} = \beta_{\mu,i,cand}$ and $\beta_{\nu,i} = \beta_{\nu,i,d-1}$ for all $\nu \neq \mu$.

Accept the draw, and set $\beta_{i,d} = \beta_{i,cand}$, with probability $\min(\rho_d, 1)$ (e.g. by drawing r from a uniform distribution bounded by zero and one and accepting the draw if $\rho_d > r$). If the draw is rejected, set $\beta_{i,d} = \beta_{i,d-1}$.

The proposal standard deviation $\varphi_{\mu,i}$ is updated along with the empirical mean and covariance matrix of β_i, to ensure that draws are not accepted too often or too rarely. If the acceptance rate is judged to be too low, φ_μ is lowered so that jumps are smaller, and more likely to be accepted. An acceptance rate that is too high suggests jumps are too small (and draw the shape of the posterior density too slowly); in that case, φ_μ is raised to make jumps larger. Specifically, $\varphi_{\mu,d}$ is updated such that

$$\ln \varphi_{\mu,i,d} - \ln \varphi_{\mu,i,d-1} = \phi(d)(\rho_d - \rho^*), \tag{A2.3.3}$$

where ρ^* is a target acceptance rate chosen so as to ensure optimal convergence of the distributions of the model parameters; Roberts and Rosenthal (2006) suggest 0.44. The error correction term $\phi(d)$ must satisfy $\phi(d) \to 0$ to ensure convergence; the results reported above use $\phi(d) = \min(0.01, d^{-0.5})$. However, none of the estimation results are sensitive to reasonable changes in the form of $\phi(d)$.

Flat priors are assumed for all β_i, on condition the parameters have economically sensible signs, so that

$$\begin{aligned}\rho_d &= \frac{p_{post}\left(\beta_{i,cand}|Z_i, A_{i,d}, \Gamma_{i,d}, \delta_{i,d}, C_{i,d}\right)}{p_{post}\left(\beta_{i,d-1}|Z_i, A_{i,d}, \Gamma_{i,d}, \delta_{i,d}, C_{i,d}\right)} \\ &= \frac{p_{prior}(\beta_{i,cand}) L\left(Z_i|A_{i,d}, \Gamma_{i,d}, \delta_{i,d}, C_{i,d}, \beta_{i,cand}\right)}{p_{prior}(\beta_{i,d-1}) L\left(Z_i|A_{i,d}, \Gamma_{i,d}, \delta_{i,d}, C_{i,d}, \beta_{i,d-1}\right)}\end{aligned} \tag{A2.3.4}$$

where

$$p_{prior}\left(\beta_{i,cand}\right) = \left\{\begin{matrix} 1 & \begin{matrix}\text{if } \beta_{2,i,cand} < 0, \beta_{3,i,cand} < 0, \beta_{4,i,cand} < 0, \\ 0 < \beta_{5,i,cand} < 1, \beta_{6,i,cand} < 0\end{matrix} \\ 0 & \text{otherwise}\end{matrix}\right\}. \tag{A2.3.5}$$

Let B_{i,β_i} be the B_i matrix implied by a given value of β_i. The likelihood $L\left(Z_i|A_{i,d}, \Gamma_{i,d}, \delta_{i,d}, C_{i,d}, \beta_i\right)$ satisfies

$$\begin{aligned}&\ln L\left(Z_i|A_{i,d}, \Gamma_{i,d}, \delta_{i,d}, C_{i,d}, \beta_i\right) \\ &\propto -\frac{1}{2}\mathrm{tr}\left(\Omega_{x,i,d}^{-1}\left(u_{x,i,d,\beta_i}{}' u_{x,i,d,\beta_i}\right)\right) - \frac{1}{2}\mathrm{tr}\left(\Omega_{y,i,d}^{-1}\left(v_{y,i,d,\beta_i}{}' v_{y,i,d,\beta_i}\right)\right)\end{aligned} \tag{A2.3.6}$$

where

$$u_{x,i,d,\beta_i} = \Delta X_i - X_{i,-1} B_{xx,i,\beta_i} A_{xx,i,d} - \Delta X_{i,-1} \Gamma_{xx,i,d} - D_i \delta_{x,i,d} \tag{A2.3.7}$$

and

$$v_{y,i,d,\beta_i} = \Delta Y_i - \Xi_{y,i,\beta_{i,d}} \Theta_{y,i,d} \tag{A2.3.8}$$

where

$$\Xi_{y,i} = [X_{i,-1} B_{yx,i,\beta_i} \quad X_{i,-1} B_{yy,i,\beta_i} \quad \Delta X_{i,-1} \quad \Delta Y_{i,-1} \quad \Delta X_i \quad D] \tag{A2.3.9}$$

and $\Theta_{y,i,d} = \left[A^*_{yx,i,d}{}' \quad A_{yy,i,d}{}' \quad \Gamma^*_{yx,i,d}{}' \quad \Gamma_{yy,i,d}{}' \quad \delta^*_{y,i,d}{}' \quad \Upsilon_{i,d}{}'\right]'$.

Appendix of figures and tables

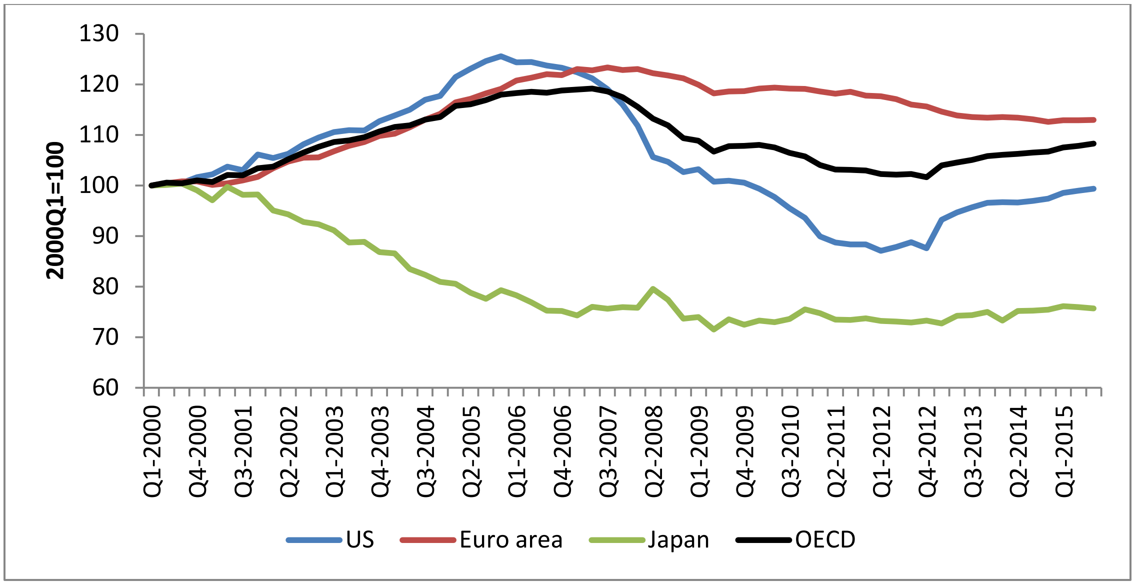

Figure 1a: Growth of house price to income ratios in select major economies versus OECD average, 2000Q1 through 2015Q3

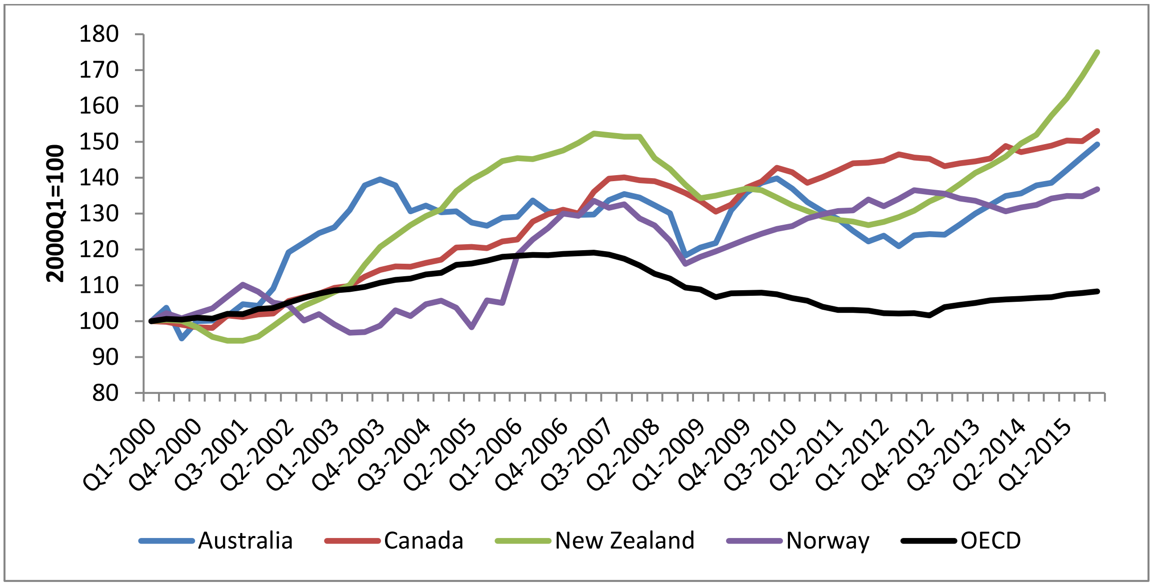

Figure 1b: Growth of house price to income ratios in commodity exporters versus OECD average, 2000Q1 through 2015Q3

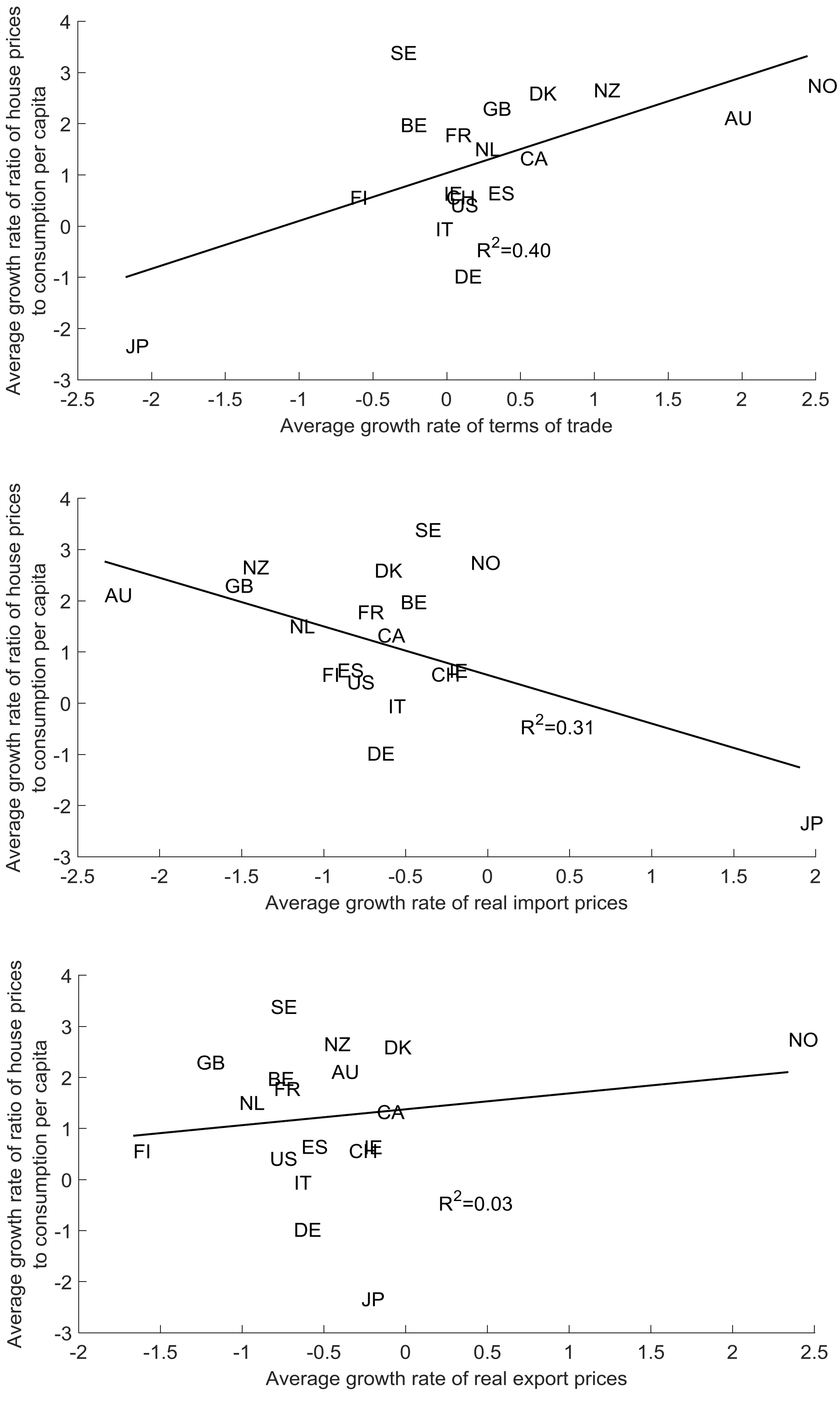

Figure 2a: Correlation of growth of terms of trade and components with growth in real house prices, 1994Q1 to 2015Q3

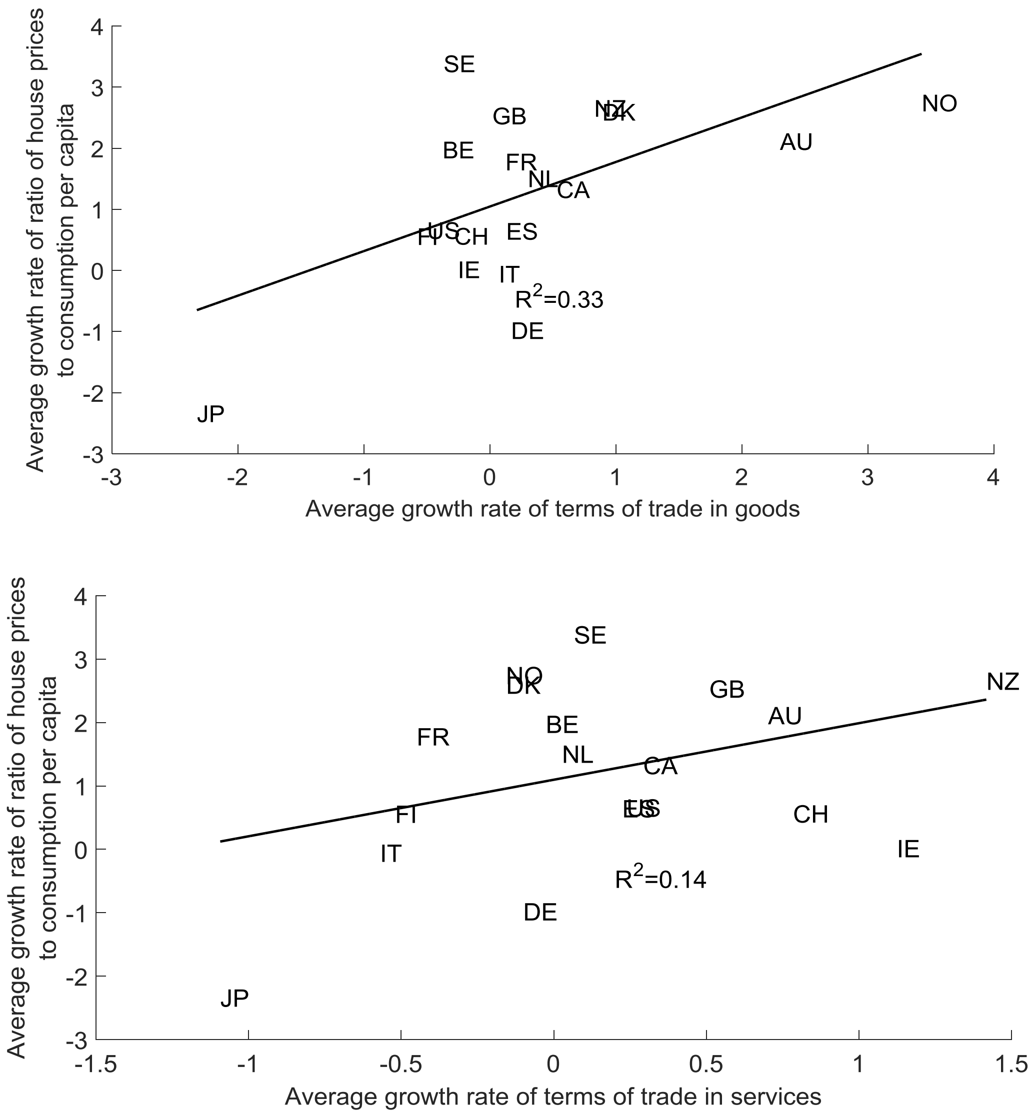

Figure 2b: Correlation of growth of terms of trade in goods and services with growth in real house prices, 1994Q1 to 2015Q3

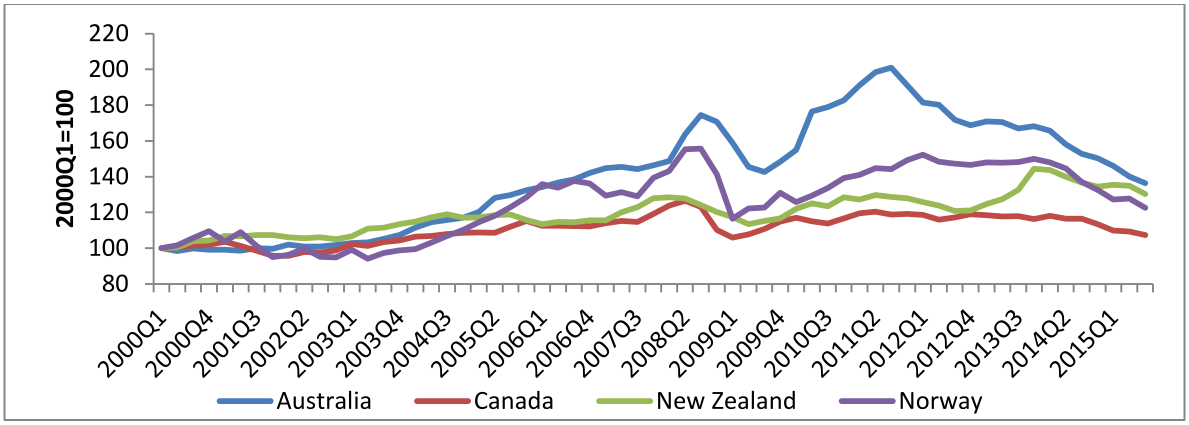

Figure 2c: Terms of trade for commodity exporters, 2000Q1 through 2015Q3

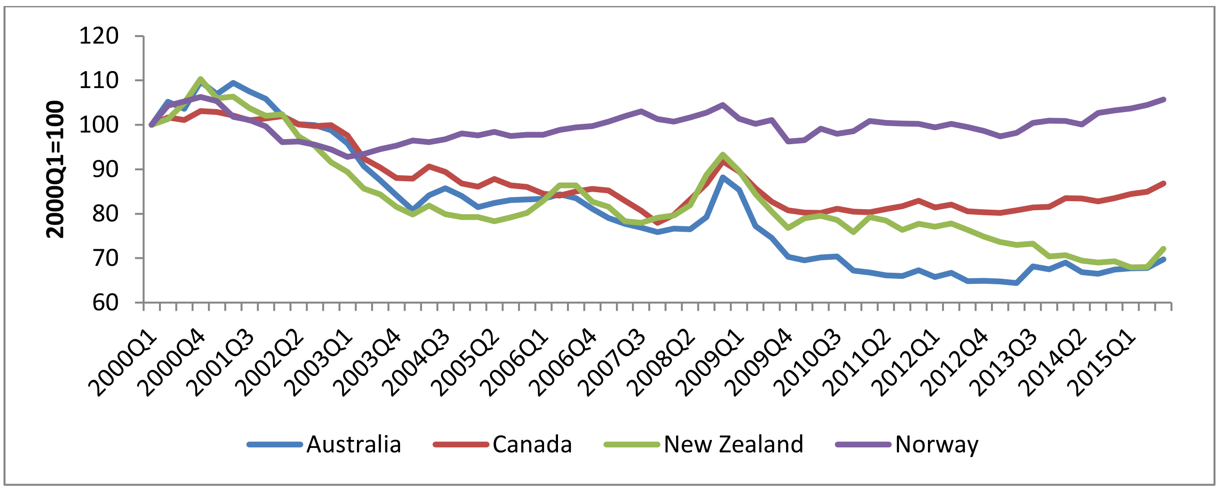

Figure 2d: Real import prices for commodity exporters, 2000Q1 through 2015Q3

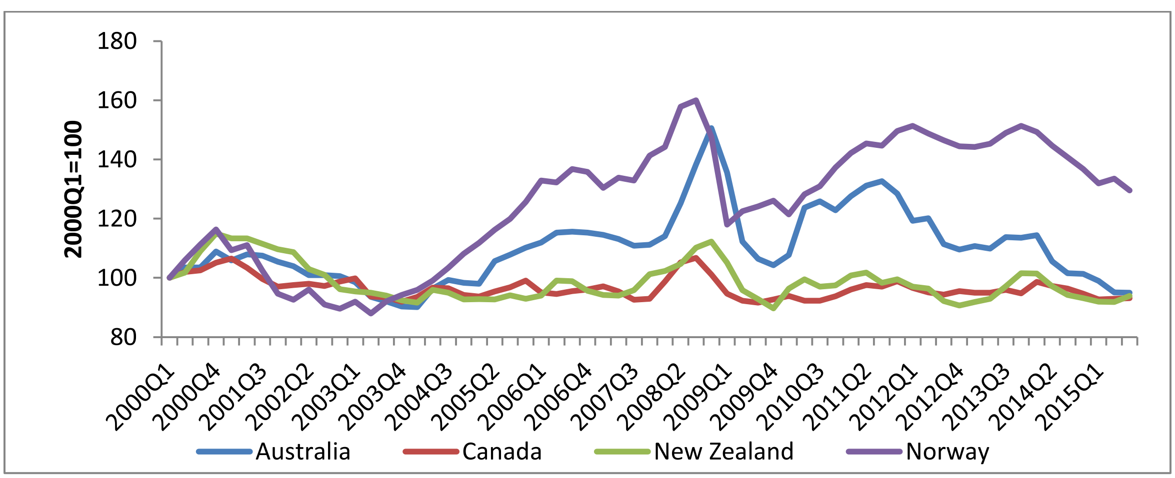

Figure 2e: Real export prices for commodity exporters, 2000Q1 through 2015Q3

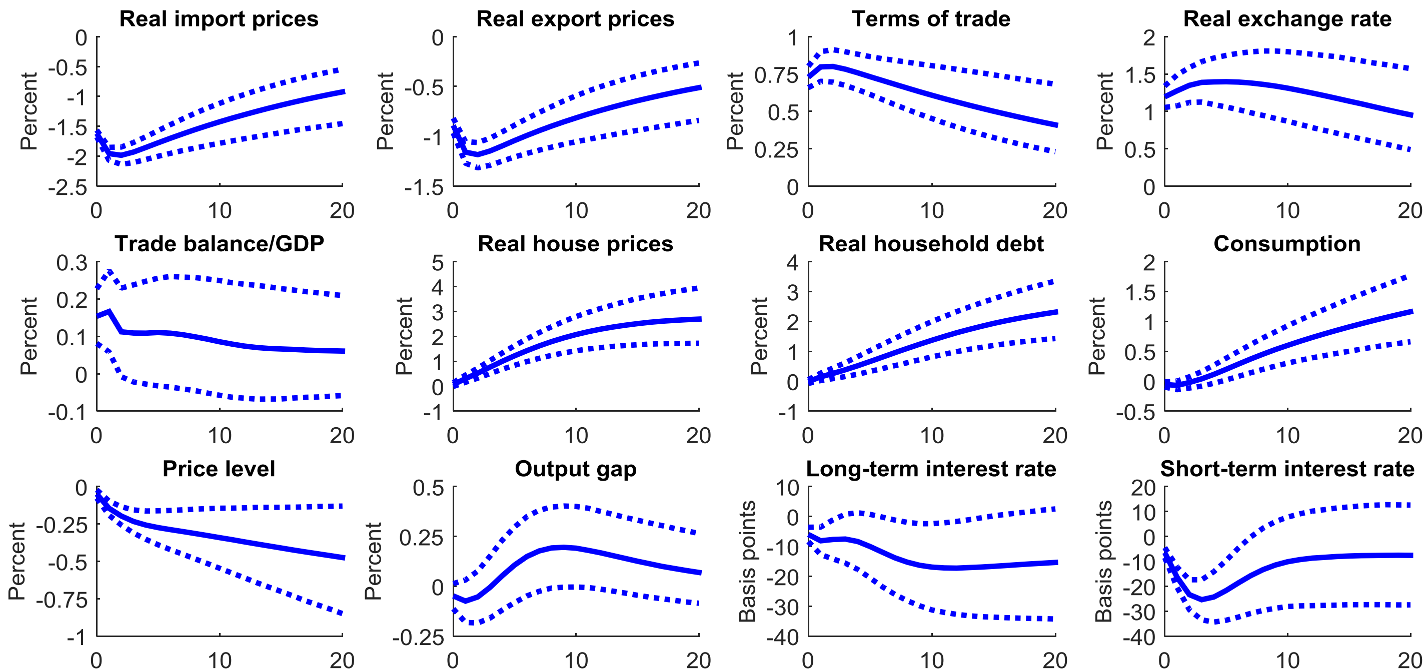

Figure 3a: Impulse response to one-standard-deviation global tradable supply shock, full panel. Solid lines show median response; dotted lines show 90 per cent confidence interval (5th percentile and 95th percentile from posterior distribution).

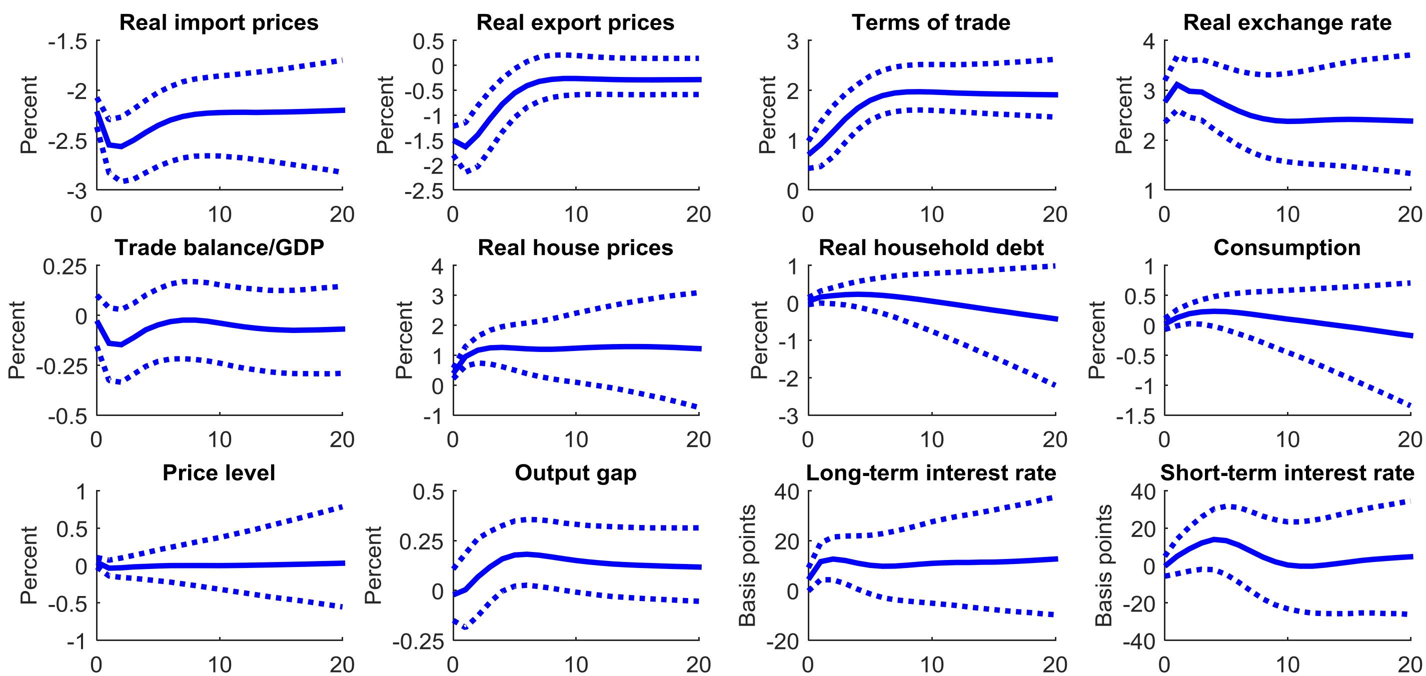

Figure 3b: Impulse response to one-standard-deviation global tradable supply shock, commodity exporters only. Solid lines show median response; dotted lines show 90 per cent confidence interval (5th percentile and 95th percentile from posterior distribution).

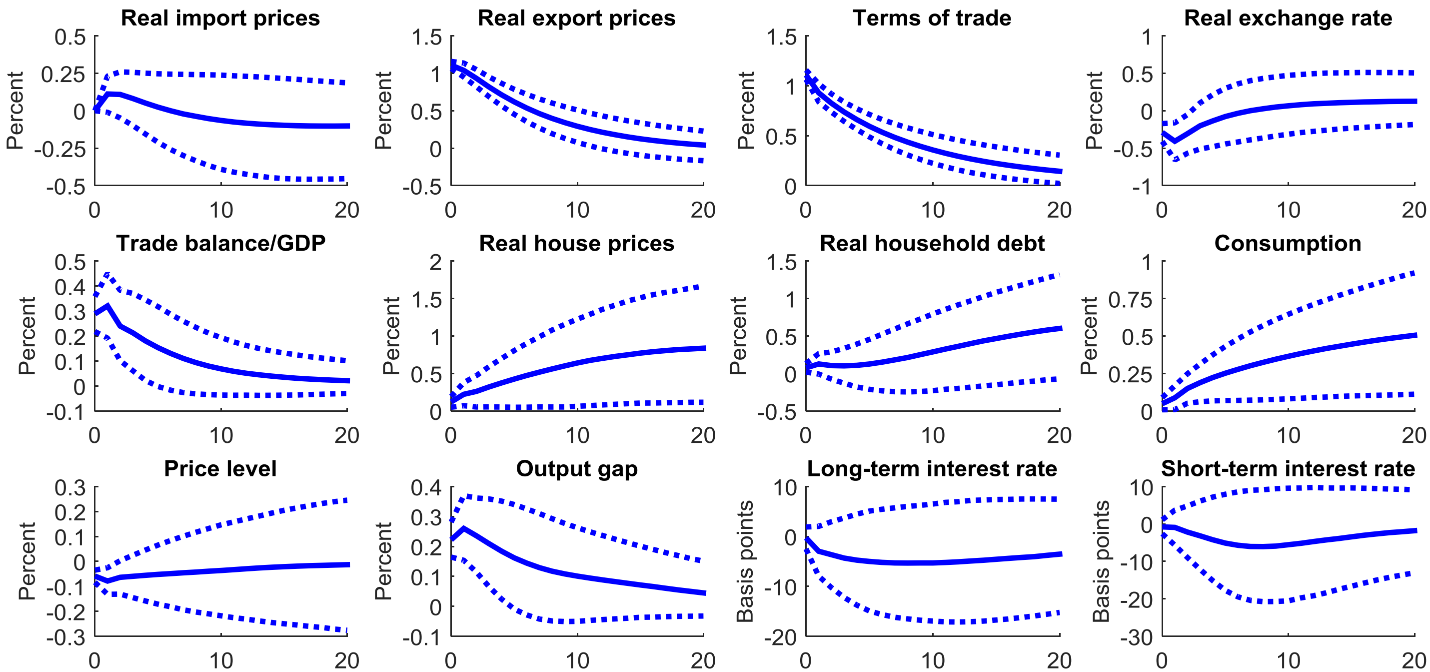

Figure 3c: Impulse response to one-standard-deviation export price shock, full panel. Solid lines show median response to shock; dotted lines show 90 per cent confidence interval (5th percentile and 95th percentile).

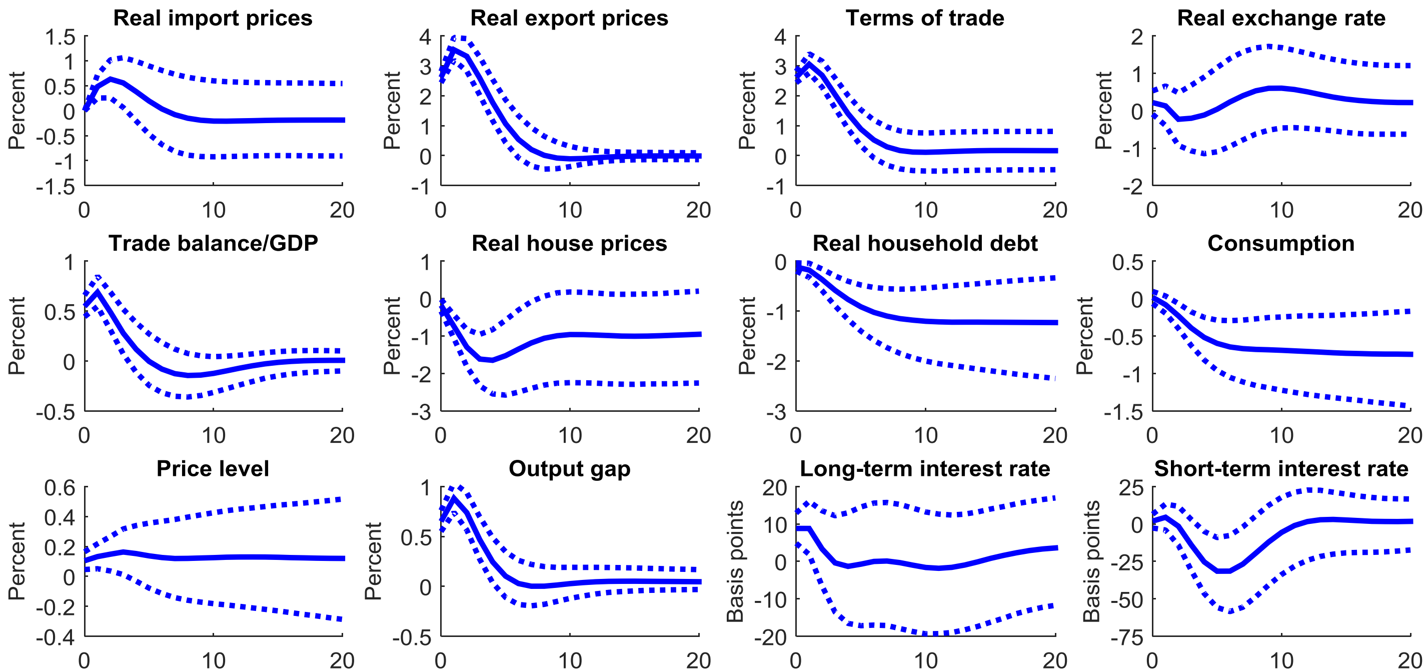

Figure 3d: Impulse response to one-standard-deviation export price shock, commodity exporters only. Solid lines show median response; dotted lines show 90 per cent confidence interval (5th percentile and 95th percentile from posterior distribution).

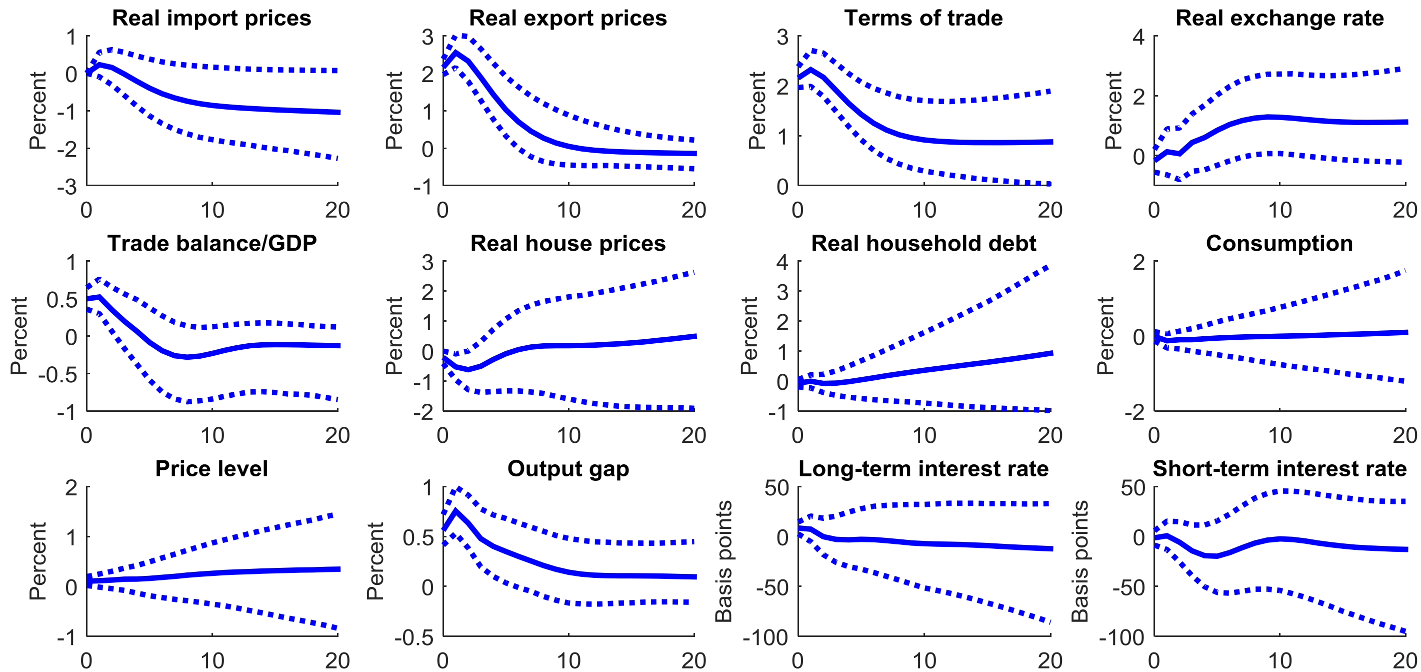

Figure 3e: Impulse response to one-standard-deviation export price shock, commodity exporters through 2007Q4. Solid lines show median response; dotted lines show 90 per cent confidence interval (5th percentile and 95th percentile from posterior distribution).

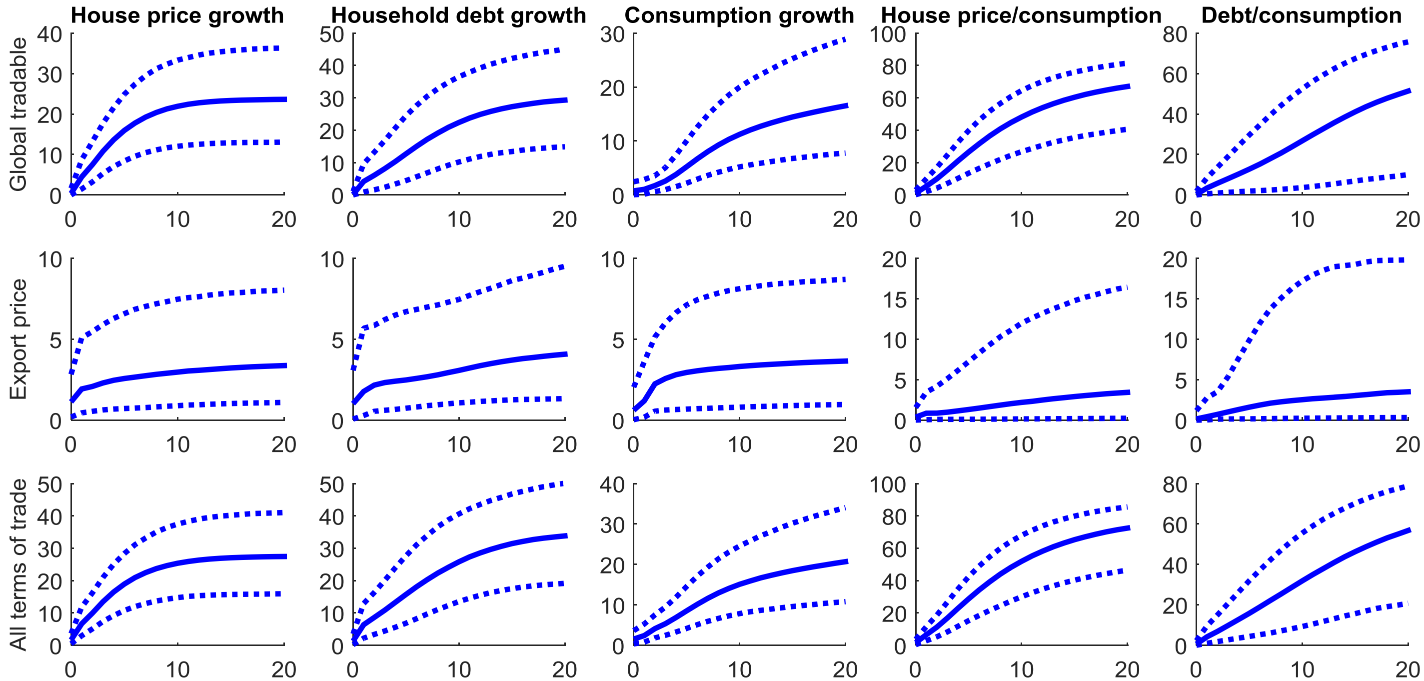

Figure 4a: Variance decompositions for select variables, full panel. Solid lines show median percentage of variable's variance accounted for by structural shock; dotted lines show 90 per cent confidence interval (5th percentile and 95th percentile from posterior distribution).

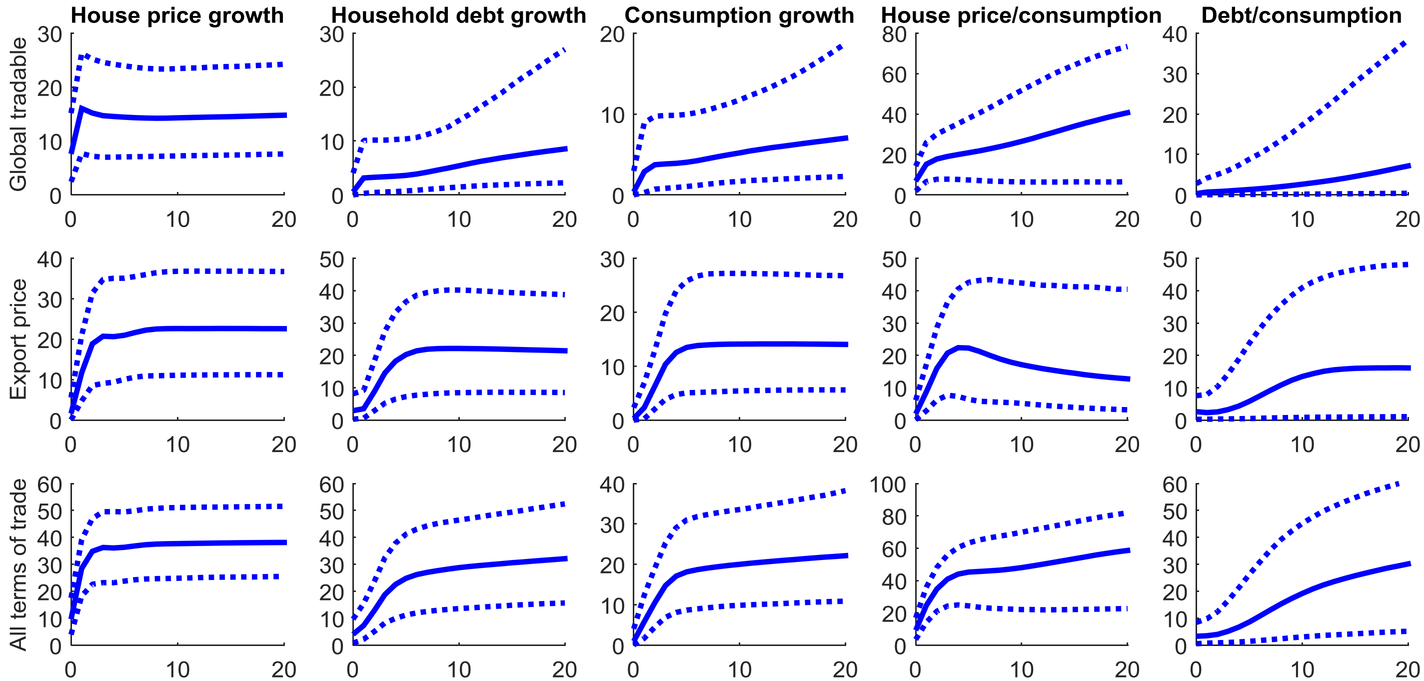

Figure 4b: Variance decompositions for select variables, commodity exporters. Solid lines show median percentage of variable's variance accounted for by structural shock; dotted lines show 90 per cent confidence interval (5th percentile and 95th percentile from posterior distribution)

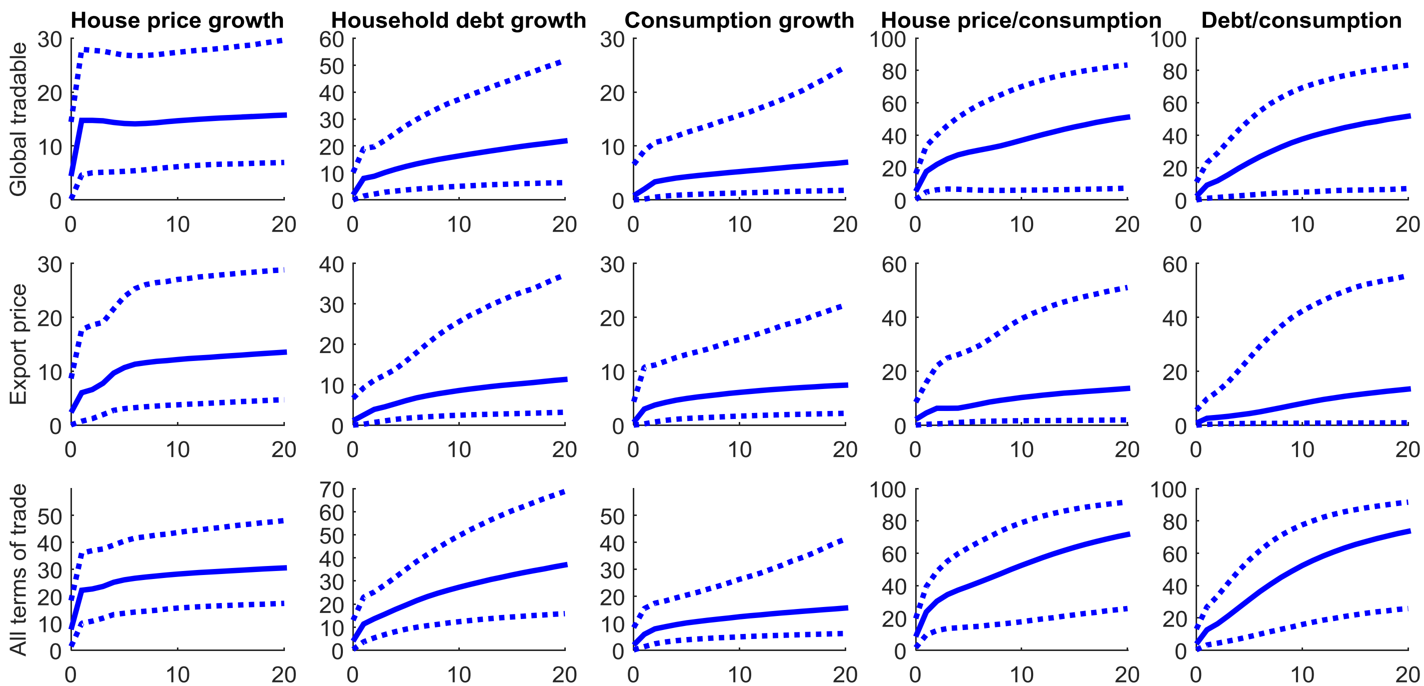

Figure 4c: Variance decompositions for select variables, commodity exporters through 2007Q4. Solid lines show median percentage of variable's variance accounted for by structural shock; dotted lines show 90 per cent confidence interval (5th percentile and 95th percentile from posterior distribution).

Variable	Full panel	Full panel through 2007Q4	Commodity importers	US and EU only	Commodity exporters	Australia, Canada, New Zealand
R_L	-0.015 *(0.009)*	-0.030 *(0.010)*	-0.018 *(0.010)*	-0.019 *(0.012)*	-0.029 *(0.019)*	-0.000 *(0.016)*
$\log(P_X/P_C)$	0.614 *(0.144)*	0.566 *(0.200)*	0.475 *(0.288)*	0.213 *(0.546)*	0.547 *(0.175)*	0.124 *(0.319)*
$\log(P_M/P_C)$	-1.118 *(0.135)*	-1.306 *(0.229)*	-1.285 *(0.164)*	-1.299 *(0.600)*	-0.730 *(0.238)*	-0.871 *(0.200)*
TB	-1.941 *(0.517)*	-1.488 *(0.548)*	-2.460 *(0.558)*	-2.293 *(0.640)*	-0.534 *(0.756)*	-2.885 *(0.941)*
R^2	0.9960	0.9971	0.9963	0.9965	0.9899	0.8607
Adjusted R^2	0.9956	0.9966	0.9960	0.9962	0.9892	0.8503
Regression SE	0.1198	0.1069	0.1233	0.1240	0.0818	0.0703
Number of obs.	1511	953	1163	1077	348	261

Table 1: Panel co-integration equations. Except where stated, data samples end in 2015Q3. Standard deviations are in parentheses and italics.

	Variable					
	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_3}$	$\boldsymbol{\beta_4}$	$\boldsymbol{\beta_5}$	$\boldsymbol{\beta_6}$
Commodity exporters						
Australia	-0.006	-0.561	-1.686	-0.018	0.920	-0.044
	(0.194)	*(0.215)*	*(0.487)*	*(0.017)*	*(0.080)*	*(0.024)*
Canada	0.256	-1.076	-2.972	-0.034	0.535	-0.039
	(0.043)	*(0.312)*	*(0.945)*	*(0.040)*	*(0.164)*	*(0.027)*
New Zealand	0.124	-0.994	-1.350	-0.051	0.324	-0.111
	(0.135)	*(0.358)*	*(0.427)*	*(0.059)*	*(0.258)*	*(0.063)*
Norway	-0.857	-0.872	-1.970	-0.008	0.695	-0.030
	(1.022)	*(0.289)*	*(1.043)*	*(0.007)*	*(0.251)*	*(0.022)*
Commodity importers						
Belgium	1.560	-0.780	-2.062	-0.107	0.303	-0.074
	(0.190)	*(0.378)*	*(1.556)*	*(0.042)*	*(0.182)*	*(0.031)*
Denmark	0.341	-0.694	-3.609	-0.023	0.601	-0.09
	(0.095)	*(0.200)*	*(0.766)*	*(0.019)*	*(0.198)*	*(0.025)*
Finland	1.552	-0.209	-0.659	-0.086	0.631	-0.12
	(0.246)	*(0.259)*	*(0.608)*	*(0.056)*	*(0.259)*	*(0.104)*
France	0.789	-0.736	-1.149	-0.029	0.635	-0.021
	(0.203)	*(0.511)*	*(0.681)*	*(0.020)*	*(0.113)*	*(0.009)*
Germany	0.344	-1.161	-0.480	-0.008	0.187	-0.012
	(0.145)	*(0.720)*	*(0.428)*	*(0.010)*	*(0.134)*	*(0.013)*
Ireland	0.680	-0.894	-1.998	-0.009	0.257	-0.126
	(0.162)	*(0.159)*	*(0.643)*	*(0.011)*	*(0.184)*	*(0.047)*
Italy	0.333	-0.916	-0.437	-0.014	0.491	-0.035
	(0.122)	*(0.295)*	*(0.436)*	*(0.013)*	*(0.329)*	*(0.02)*
Japan	0.003	-0.613	-1.087	-0.028	0.194	-0.031
	(0.145)	*(0.285)*	*(0.174)*	*(0.015)*	*(0.054)*	*(0.009)*
Netherlands	0.789	-0.718	-1.579	-0.014	0.737	-0.031
	(0.032)	*(0.251)*	*(0.309)*	*(0.013)*	*(0.145)*	*(0.019)*
Spain	0.805	-0.732	-2.039	-0.052	0.259	-0.111
	(0.108)	*(0.157)*	*(0.864)*	*(0.031)*	*(0.220)*	*(0.027)*
Sweden	1.381	-1.111	-0.610	-0.067	0.379	-0.073
	(0.389)	*(0.512)*	*(0.499)*	*(0.021)*	*(0.310)*	*(0.029)*
Switzerland	0.788	-1.028	-0.235	-0.054	0.629	-0.015
	(0.066)	*(0.465)*	*(0.218)*	*(0.018)*	*(0.196)*	*(0.011)*
United Kingdom	0.650	-0.355	-1.311	-0.031	0.479	-0.01
	(0.046)	*(0.169)*	*(0.423)*	*(0.022)*	*(0.139)*	*(0.011)*
United States	0.699	-0.792	-0.809	-0.033	0.236	-0.009
	(0.278)	*(0.551)*	*(0.618)*	*(0.030)*	*(0.148)*	*(0.012)*

Table 2: VECM co-integration equation parameter estimates, for data sample ending in 2015Q3. Means of draws from posterior distribution are in regular type, with standard deviations in italics and parentheses.

Data Appendix: Sources and definitions

Nominal house prices:

***Source*:** Bank for International Settlements, database of Long-Term Series on Nominal Residential Property Prices

***Definition*:** Residential property price index (1995=100), nominal, long series, not seasonally adjusted, quarterly averages

Household debt:

***Source*:** Bank for International Settlements, Database of Long Series on Total Credit to the Non-Financial Sectors

***Definition*:** Credit to households and non-profits serving households from all sectors, market value, domestic currency, adjusted for breaks

National accounts series (including real tradable prices):

***Source*:** OECD.Stat, National Accounts, Quarterly National Accounts tables, "GDP – Expenditure approach" sub-tables.

Definitions:

Nominal series:

- *Nominal total consumption*: Final consumption expenditure (P3), national currency, current prices, quarterly levels, seasonally adjusted
- *Nominal private consumption*: Private final consumption expenditure (P3S14_S15), national currency, current prices, quarterly levels, seasonally adjusted
- *Nominal exports*: Exports of goods and services (P6), national currency, current prices, quarterly levels, seasonally adjusted
- *Nominal exports of goods*: Exports of goods (P61), national currency, current prices, quarterly levels, seasonally adjusted
- *Nominal exports of services*: Exports of goods (P62), national currency, current prices, quarterly levels, seasonally adjusted
- *Nominal imports*: Imports of goods and services (P7), national currency, current prices, quarterly levels, seasonally adjusted

Real series:

- *Real private consumption*: Private final consumption expenditure (P3S14_S15), national currency, chained volume estimates, national reference year, quarterly levels, seasonally adjusted
- *Real exports*: Exports of goods and services (P6), national currency, chained volume estimates, national reference year, quarterly levels, seasonally adjusted
- *Real exports of goods*: Exports of goods (P61), national currency, chained volume estimates, national reference year, quarterly levels, seasonally adjusted
- *Real exports of services*: Exports of goods (P62), national currency, chained volume estimates, national reference year, quarterly levels, seasonally adjusted
- *Real imports*: Imports of goods and services (P7), national currency, chained volume estimates, national reference year, quarterly levels, seasonally adjusted
- *Real imports of goods*: Imports of goods and services (P71), national currency, chained volume estimates, national reference year, quarterly levels, seasonally adjusted
- *Real imports of services*: Imports of goods and services (P72), national currency, chained volume estimates, national reference year, quarterly levels, seasonally adjusted

Deflators: Deflators are calculated simply by dividing the nominal version of a given indicator by the real version.

Real exchange rate:

Source*:* Bank of International Settlements

Definition: Effective exchange rate, real (CPI-based), broad index (2010=100), quarterly averages of monthly data

Long-term interest rates:

Source**:** OECD.Stat, Finance, Monthly Monetary and Financial Statistics tables, Long-Term Interest Rate sub-table

Definition*:* Long-term interest rates (mostly 10-year government bond rates), quarterly averages of monthly figures

Short-term interest rates:

Source**:** OECD.Stat, Finance, Monthly Monetary and Financial Statistics, Short-term Interest Rates sub-table

Definition*:* Short-term interest rates (mostly overnight financing rates), quarterly averages of monthly figures

Population:

Source: OECD.Stat, Demography and Population, Population Statistics table, Historical population data and projections (1950–2050) sub-table

Definition: Population by broad age groups, population (historical and projected), all ages, all persons, thousands, annual data interpolated to quarterly values using a log-linear interpolation, with annual value assumed for mid-year (Q2).

Table A1: Data periods for each country in panel

Country	**Data period**	
	Correlations and panel co-integration	*Panel VAR*
Australia	1994Q1-2015Q3	1994Q1-2015Q3
Belgium	1995Q1-2014Q4	1995Q1-2015Q3
Canada	1994Q1-2015Q3	1994Q1-2015Q3
Denmark	1995Q1-2015Q3	1995Q2-2015Q3
Finland	1994Q1-2015Q3	1994Q1-2015Q3
France	1994Q1-2015Q3	1994Q1-2015Q3
Germany	1994Q1-2015Q3	1994Q1-2015Q3
Ireland	1997Q1-2015Q3	2002Q1-2015Q3
Italy	1996Q1-2015Q3	1996Q2-2015Q3
Japan	1994Q1-2015Q3	1994Q2-2015Q3
Netherlands	1996Q1-2015Q3	1996Q2-2015Q3
New Zealand	1994Q1-2015Q3	1994Q1-2015Q3
Norway	1994Q1-2015Q3	1994Q1-2015Q3
Spain	1995Q1-2015Q3	1995Q2-2015Q3
Sweden	1994Q1-2015Q3	1994Q1-2015Q3
Switzerland	1994Q1-2015Q3	1999Q4-2015Q3
United Kingdom	1995Q1-2015Q3	1995Q2-2015Q3
United States	1994Q1-2015Q3	1995Q1-2015Q3