Terms of Trade Shocks and Investment in Commodity-Exporting Economies*

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Abstract

We study the effects of commodity price shocks in small open commodity-exporting economies, focusing on metals prices and their impact on sectoral investment. First, using a standard SVAR approach, we conduct estimations for major commodity exporters (Australia, Canada, Chile, New Zealand, Peru and South Africa) to identify general cross-country patterns. Second, we use a DSGE model for Chile to study the propagation channels of commodity price changes and to implement counterfactual policy exercises. Our results suggest expansionary effects of commodity price increases in most countries, driven by positive responses of commodity investment that spill over to non-commodity sectors. The size of these responses depends mainly on the share of commodity exports and on the persistence of the shock. Finally, our policy exercises highlight the importance of flexible inflation targeting, floating exchange rates and structural fiscal rules to efficiently manage commodity price volatility.

Keywords: Commodity prices; Terms of trade shocks; Commodity-exporting economies; Investment; Inflation targeting; Fiscal rules.

JEL classification: E32; F41.

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> Gold and silver, like other commodities, have an intrinsic value, which is not arbitrary, but is dependent on their scarcity, the quantity of labour bestowed in procuring them, and the value of the capital employed in the mines which produce them.
>
> David Ricardo, High Price of Bullion (1810).

1 Introduction

Commodity prices have experienced significant swings over the past two decades. More specifically, real commodity prices have on average more than doubled in the last decade compared to the previous one, while the prices of some commodities such as copper and other industrial metals have more than tripled in real terms. Commodity-exporting economies such as Chile have therefore enjoyed very favorable terms of trade (ToT) by historical standards (see Figure 1). (For Chile, the only main exception is the golden period of saltpeter mineral extraction from 1895 to 1930.) Hence, it is not surprising that many policy discussions in commodity-exporting economies have focused on the effects of commodity price fluctuations on output, inflation, real exchange rates, the current account and other macroeconomic variables, as well as appropriate policy frameworks to deal with commodity price volatility.[1] This issue is also highly relevant in the present context where monetary policy in advanced economies is being normalized and growth in emerging market economies is slowing down, with possible negative effects on commodity prices and exporters that are vulnerable to a fall in prices.

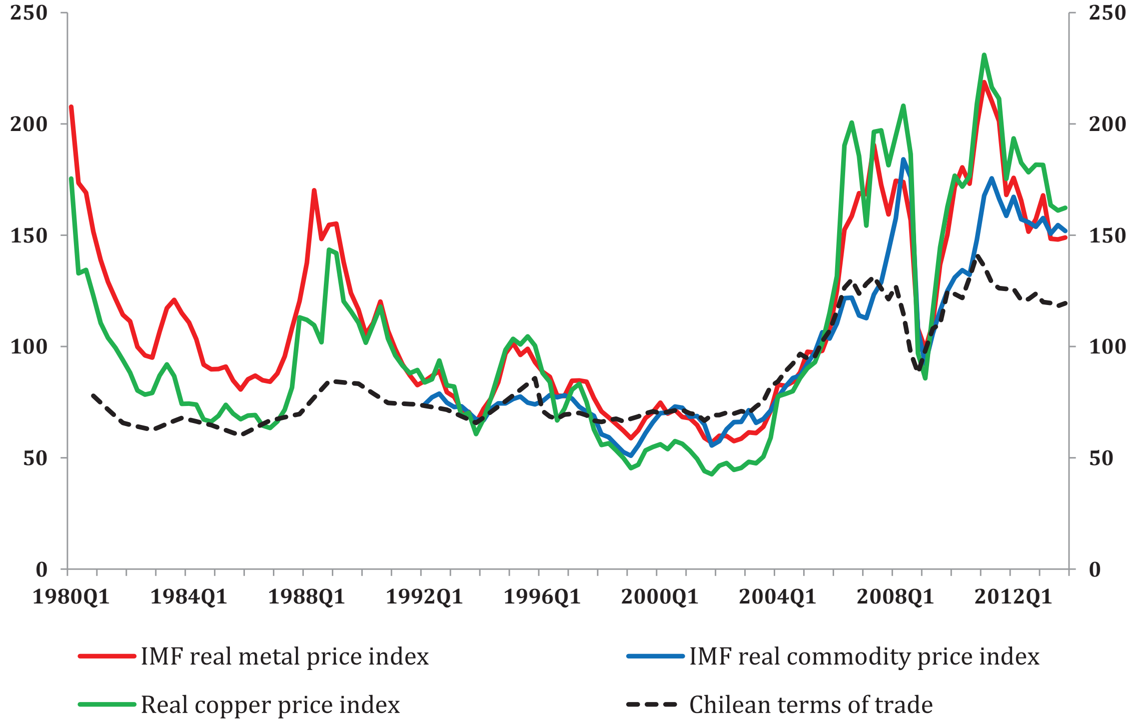
The macroeconomic effects of commodity price fluctuations have been widely studied in the literature, where two major strands can be distinguished.[2] The first one includes studies based on time series methods such as structural vector autoregressions (SVARs) that attempt to estimate the effects of exogenous movements in commodity prices on macroeconomic aggregates through short-run or long-run identification and/or sign restrictions.[3] Among those studies are, for instance, Bernanke, Gertler, and Watson (1997), Blanchard and Galí (2007), Kilian (2008, 2009), Kilian and Lewis (2011), Lombardi, Osbat, and Schnatz (2012), Baumeister and Peersman (2013), and Gubler and Hertweck (2013), and Filardo and Lombardi (2014). However, most of these studies have focused on the impact of oil price shocks in developed countries such as the US or Europe (all net commodity importers), whereas relatively few studies have examined the effects of commodity price shocks in economies that rely heavily on commodity exports (and

[1] See, for instance, IMF (2011, ch. 3; 2012, ch. 4).

[2] Other related studies are Cashin, Céspedes, and Sahay (2004), Raddatz (2007), Izquierdo, Romero, and Talvi (2008), Adler and Sosa (2011), De Gregorio and Labbé (2011), and Céspedes and Velasco (2012), among others.

[3] Sometimes in the literature commodity export price shocks are treated differently from ToT shocks. This distinction may or may not make sense depending on the size of the economy, importance of the commodity sector, comovement of import and export prices, etc. For our selection of countries and sample periods both definitions are fairly similar since the ToT for the countries considered are highly correlated with commodity prices.

Figure 1: Commodity price indexes and Chilean ToT (2005 = 100), 1980Q1-2013Q4.



Notes: The Chilean ToT series for the period since 1996 is obtained from the Central Bank of Chile. For the period before 1996 we use interpolated annual ToT data from Clio Lab, Pontifical Catholic University of Chile. Further details on data sources and definitions are provided in Appendix A.

in particular mineral exports) like many developing and emerging market countries. Only a few recent studies have analyzed this topic, like Camacho and Perez-Quiros (2014) who investigate the dynamic interactions between commodity prices and output growth of major Latin American commodity exporters using Markov-switching impulse response functions, or Gruss (2014) who uses Global VAR (GVAR) analysis to examine the impact of commodity price cycles on output growth in Latin America and the Caribbean. In addition, Knop and Vespignani (2014) use SVAR analysis to estimate the effects of commodity price shocks on different industries such as mining, construction, manufacturing, etc. in Australia.

The second major strand of the literature is based on dynamic stochastic general equilibrium (DSGE) models that allow to analyze in a structural micro-founded framework the different transmission channels and propagation mechanisms of commodity price shocks and to conduct policy experiments. Among these studies are, for instance, Kilian, Rebucci, and Spatafora (2009), Tober and Zimmermann (2009), Bodenstein, Erceg, and Guerrieri (2011), and Bodenstein, Guerrieri, and Kilian (2012). However, most of these studies also focus on the effects of commodity price shocks (and mainly oil shocks) in developed countries while the literature for developing and emerging commodity-exporting economies is less extensive. Some exceptions are, for example, Medina, Munro, and Soto (2008) who explore what factors explain current account developments in Chile and New Zealand, Desormeaux, García, and Soto (2010) who use a DSGE model to examine the transmission mechanism of commodity prices to inflation dynamics, Kumhof and Laxton (2010) who analyze Chile's structural surplus fiscal rule in the face of shocks to the world copper price, and Malakhovskaya and Minabutdinov (2014) who examine the effects of shocks to commodity export revenues in an estimated DSGE model for Russia. However, none of the above studies has analyzed the macro impact of commodity price shocks through their effects on investment in different sectors of the economy. A further examination to fill this gap is therefore interesting in view of recent sectoral investment dynamics in many commodity-exporting economies (see also Knop and Vespignani, 2014).

Hence, the objective of this paper is to analyze in a broad perspective the effects of commodity price shocks in commodity exporters, focusing on metals exporters such as Chile, where we highlight the propagation of those shocks through investment in mining and its macroeconomic spillover effects. This focus of the paper is motivated by the observed mining investment boom in most major commodity-exporting economies during the last decade, the impact of the latter on external savings balances and their policy implications.

To conduct our analysis we employ two different methodologies: SVAR analysis and a DSGE model. First, the SVAR approach is aimed at exploring broad cross-country patterns and dynamics in the data. Here we analyze questions such as: How do commodity prices interact in the first place with other key variables of the world economy such as output, inflation and interest rates? How do commodity price shocks affect domestic variables? Are the effects similar across countries? Does the persistence of commodity price shocks matter for their impact on macroeconomic variables such as investment? To facilitate this econometric exercise we analyze a group of small open economies as our identification approach relies on the exogeneity of commodity price fluctuations for commodity exporters.

Second, recognizing the usual difficulties that are involved with the identification of SVAR shocks, we use a DSGE model to add a different dimension to our analysis. This methodology not only allows to investigate the key propagation channels of commodity price shocks in a structural micro-founded way, but it is also useful to further explore several hypotheses that are raised by the SVAR results. For example, even though it may seem obvious that there is an endogenous response of mining investment to a commodity price shock, it is not clear whether a rise in commodity prices triggers a boom in investment in both mining and non-mining sectors or whether mining investment crowds out other aggregate demand components.[4] In addition, we may ask whether the persistence of commodity price shocks matters. Finally, the DSGE model is useful to conduct counterfactual policy experiments to answer questions such as: How

[4]For instance, at the sectoral level traditional exporters might suffer a loss of competitiveness if mining sectors compete with other sectors for resources. If this competition implies higher demand and inflation of non-tradable goods, there would be a real appreciation of the currency. The resulting reallocation is challenging for traditional export sectors, a phenomenon widely studied known as the Dutch disease.

is the response of the economy to commodity price shocks affected by different types of fiscal rules? Should monetary policy try to limit exchange rate fluctuations due to such shocks? For this purpose, we use a New Keynesian small open economy model estimated for Chile. The model is an extended version of the DSGE model developed by Medina and Soto (2007a), which we extend by an endogenous commodity production structure. In addition, we parameterize the block of external variables with the SVAR estimates for Chile. We then use the model to analyze the main propagation channels of a commodity price shock, to decompose historical fluctuations of investment and GDP, and to conduct two counterfactual experiments: alternative fiscal rules and response of monetary policy to exchange rate fluctuations.

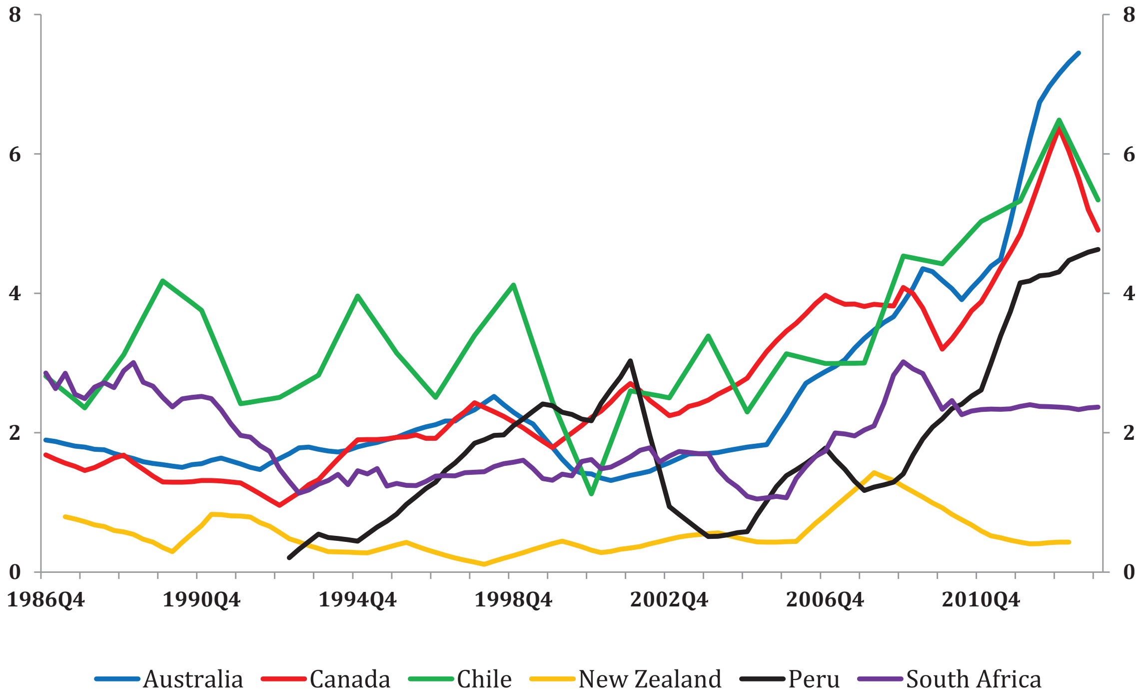
Our contribution to the literature is thus two-fold. First, we provide a study of the impact of commodity price shocks on sectoral investment in commodity-exporting economies based on an SVAR approach. Second, we augment an otherwise standard New Keynesian small open economy model with a commodity sector by an endogenous production structure in order to analyze the transmission channels and policy implications of commodity price shocks.

The main results from the SVAR analysis corroborate that commodity price shocks are an important source of business cycles in commodity-exporting economies. More in particular, we find that those shocks have significant effects on real GDP through their impact on investment, where investment in mining shows relatively large, lagged and persistent responses in most analyzed countries. We also find that local currencies appreciate and current account balances deteriorate in some countries as investment rises, inflation shows mixed responses depending on the size and persistence of the exchange rate effect, and interest rates rise in most countries. Furthermore, a stronger persistence of commodity price shocks generates a much larger expansion of mining investment that tends to spill over to non-mining sectors.

Most of these empirical findings are in line with the dynamics predicted by the DSGE model for Chile. In fact, according to the model, mining investment is an important propagation channel of commodity price shocks where there is a direct link between the duration of the price increases and their macroeconomic impact. Moreover, the model shows that an investment boom in mining can generate a relatively persistent current account deficit. From a policy perspective, our results further suggest that while different monetary and fiscal policy reactions have in general important implications for the response of the economy to commodity price shocks, they do not majorly affect investment decisions in the commodity sector that are mainly driven by sectoral productivity developments and, importantly, commodity prices.

The remainder of the paper is structured as follows. Section 2 discusses a number of stylized facts regarding the recent evolution of investment, real GDP growth and current account balances in selected commodity exporters. Section 3 presents the VAR analysis conducted for several commodity exporters. Section 4 describes the DSGE model for Chile while Section 5 documents the results of the model-based analysis. Finally, Section 6 concludes.

Figure 2: Investment in mining sectors (% of nominal GDP), 1986Q4-2013Q4.



2 Recent Evolution of Investment, GDP Growth and Current Account Balances in Commodity-Exporting Economies

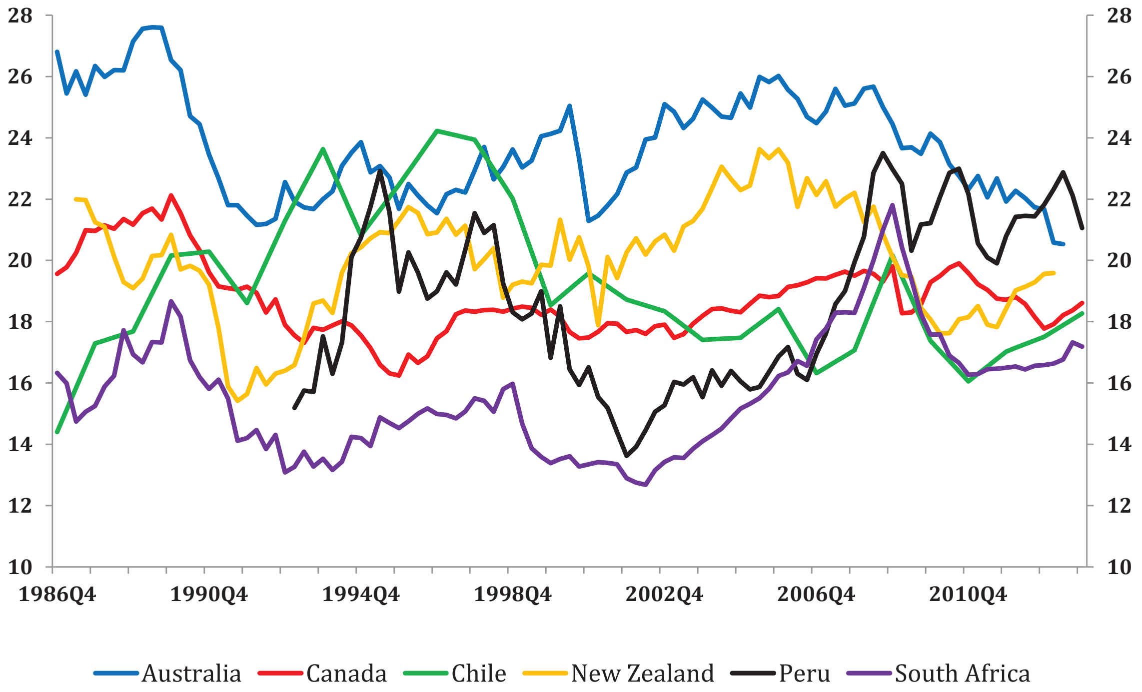
In this section we discuss a number of common patterns regarding the recent evolution of investment, GDP growth and current account balances in commodity-exporting economies.

To begin with, mining investment has expanded at a higher rate than GDP (in terms of nominal ratios) in most major commodity-producing countries as Figure 2 shows. This increase in investment evolved to a certain extent in parallel with the commodity price boom after 2004, but with some lag. For example, in Australia, Canada, Chile and Peru investment in mining as a share of GDP more than doubled in the late 2000s with respect to the average observed in the nineties and early 2000s. The case of South Africa is somehow different because the increase in the ratio after the mid-2000s recovered figures observed in the eighties. Finally, New Zealand experienced a milder and shorter increase in mining investment.

Furthermore, Figure 3 illustrates the evolution of non-mining investment shares for our selection of commodity exporters. In the mid-2000s period, non-mining investment increased in several countries compared to its early 2000s volume, but much less than mining investment and relative to historical averages. Hence, most of the increase in total investment in those countries during the recent commodity cycle was due to higher investment in mining.

Higher investment in those countries has pushed aggregate demand and real GDP growth. Figure 4 compares the growth performance of our selection of countries with the world average

Figure 3: Investment in non-mining sectors (% of nominal GDP), 1986Q4-2013Q4.

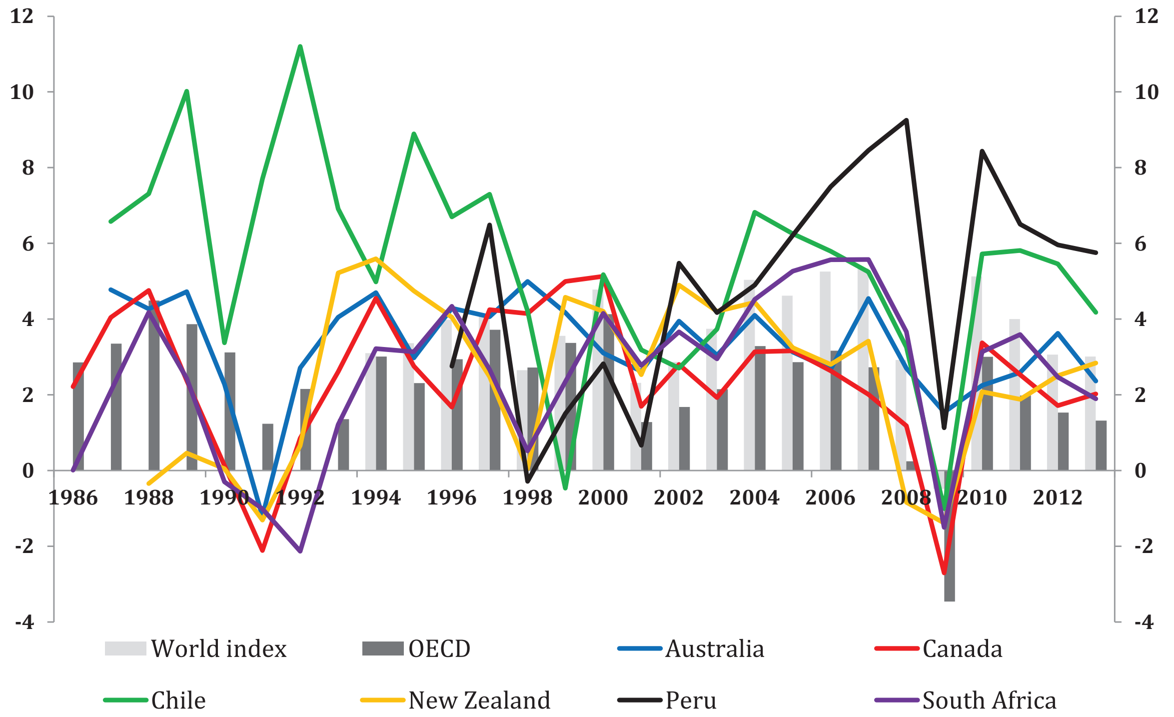


and with the average of OECD countries between 1986 and 2013. Notably, the annual real GDP growth rates of most of the selected countries since the mid-2000s were above the OECD average. Economic growth was especially high in Chile and Peru, who grew at a faster pace than the world and the OECD average. South Africa is located in the middle as it grew similarly as the world average. Finally, Australia, Canada and New Zealand performed slightly better than the OECD average, but worse than the world average. Differences in these countries' economic growth rates are driven by both structural and cyclical factors. One possible structural explanation hinges on the capital-deepening hypothesis according to which economic growth rates tend to reflect different stages of development (Chile and Peru are less developed than Australia, Canada and New Zealand). In addition, as Gruss (2014) suggests, the commodity price boom may have pushed real GDP growth of Latin American countries above trend.

Finally, Figure 5 shows that despite the high commodity prices, the current account balances of most commodity exporters have been in deficit. Some countries such as Australia, New Zealand and South Africa have been net international borrowers since the late nineties, but it seems surprising that these countries did not save at least part of the unprecedented rise in commodity income since the mid-2000s. The remaining countries and in particular Chile and Peru did have positive external savings balances during the mid-2000s period, but their current accounts also moved into deficit later on.[5] Are those current account deficits due to the invest-

[5]There are several hypotheses regarding underlying mechanisms that might explain such current account reversals. For instance, Fornero and Kirchner (2014) show that changes in agents' perceptions on the persistence of the commodity boom can explain the observed behavior of Chile's current account. Their argument is based on evidence of forecast revisions by professional forecasters and the panel of experts that determines the parameters

Figure 4: Real GDP growth (%, annual average), 1986-2013.



ment boom in those countries, and how is the latter related to the surge in commodity prices? How does the macroeconomic adjustment to commodity price shocks look like in commodity exporters such as Canada, Chile, Peru and New Zealand? Are the adjustments different or are they similar? To answer these questions, we now conduct a structural VAR analysis of the effects of commodity price shocks to explore the relevant propagation mechanisms in those countries.

3 Structural VAR Analysis

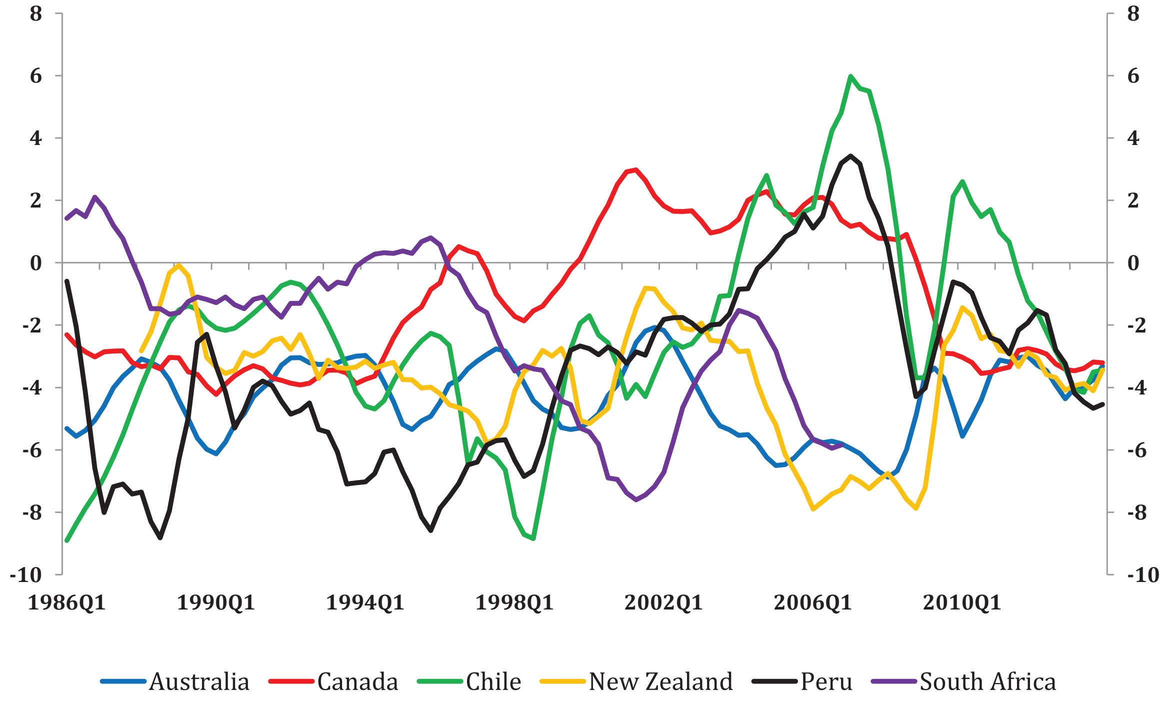
In this section we estimate VAR models for Australia, Canada, Chile, New Zealand, Peru and South Africa. These countries are commodity exporters that satisfy the small open economy assumption such that foreign variables may be regarded as exogenous. In addition, Table 1 reports the recent export shares of this selection of countries. It is noteworthy that Australia, Chile, Peru and South Africa are major exporters of industrial metals. In addition, exports of Canada and New Zealand are also concentrated in commodities, but not as much metals. Hence, these two countries are useful benchmarks to compare our results.

3.1 Data

Regarding the data, apart from an external block of variables we use official quarterly data for each country on GDP, mining and non-mining investment, inflation, interest rates, real exchange

of Chile's fiscal rule.

Figure 5: Current account balances (% of nominal GDP), 1986Q1-2013Q4.



Notes: Current account ratios of Australia, Chile, Peru and South Africa are four quarters moving averages.

rates and current account balances. The sample coverages include explicit or implicit inflation targeting monetary regimes. For Australia, the sample begins in 1993Q2 and ends in 2013Q2 due to restrictions of mining investment data. For Canada, the sample covers the period 1991Q3-2013Q4. For Chile, the considered period is 1996Q1-2013Q4. For New Zealand, the sample period is 1991Q1-2013Q4. For Peru, the sample spans the period from 1998Q1 to 2013Q4. Finally, for South Africa the sample period is 1995Q1-2014Q1. The foreign block of variables includes a measure of world GDP, foreign inflation and interest rates and a real commodity price index. Details of variable definitions, transformations and sources are provided in Appendix A. We apply homogeneous transformations to facilitate the comparison of shock sizes and their effects across countries.

3.2 Empirical model

The empirical model is a standard structural VAR with block exogeneity to account for the main characteristics of small open economies. Thereby, it is assumed that foreign variables do not respond to changes in domestic variables. This methodology allows an efficient estimation (compared to an unrestricted VAR) of the joint evolution of domestic and foreign variables.

Table 1: Top five products exported in 2013 in selected commodity exporters [1].

Australia	Iron ore & concentrates (26.7%) Coal (15.2%) Natural gas (5.6%) Gold (5.3%) Petroleum (4.5%)	Canada	Petroleum (21.4%) Motor vehicles & equipments (12.6%) Gold (3.6%) Aircrafts & equipment (2.3%) Natural gas (2.2%)
Chile	Copper (29.7%) Copper ores & concentrates (22.4%) Fruits (8.0%) Fish (5.0%) Pulp & waste paper (3.6%)	N. Zealand	Milk, cream & milk products (20.4%) Meat (11.4%) Rough wood (4.9%) Butter (4.6%) Petroleum (3.6%)
Peru	Copper ores & concentrates (17.0%) Gold (14.2%) Petroleum (10.0%) Ores & concentr. of base metals (8.7%) Copper (7.6%)	S. Africa [2]	Iron ore & concentrates (15.8%) Silver, platinum (7.4%) Ores & concentr. of base metals (6.5%) Coal (6.1%) Gold (5.3%)

Notes: [1] Source: UNCTAD Statistics, based on UN DESA and UN Comtrade; [2] Estimated values.

Following Hamilton (1994, p. 309), the reduced-form VAR can be written as follows:

$$\begin{pmatrix} \mathbf{y}_{1,t} \\ \mathbf{y}_{2,t} \end{pmatrix} = \begin{pmatrix} \mathbf{c}_1 \\ \mathbf{c}_2 \end{pmatrix} + \begin{pmatrix} \mathbf{A}'_1 & \mathbf{A}'_2 \\ \mathbf{B}'_1 & \mathbf{B}'_2 \end{pmatrix} \begin{pmatrix} \mathbf{x}_{1,t} \\ \mathbf{x}_{2,t} \end{pmatrix} + \mathbf{D} \begin{pmatrix} \mathbf{z}_{1,t} \\ \mathbf{z}_{2,t} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix},$$

where $\mathbf{y}_{1,t}$ and $\mathbf{y}_{2,t}$ are vectors of n_1 foreign variables and n_2 domestic variables, respectively. Accordingly, current outcomes are explained by previous developments measured by p lags in the variables $\mathbf{y}_{1,t-1}, ..., \mathbf{y}_{1,t-p}$ and similarly for $\mathbf{y}_2$. This lagged information is gathered in $\mathbf{x}_{1,t}$ and $\mathbf{x}_{2,t}$, of dimensions $n_1 p \times 1$ and $n_2 p \times 1$, respectively. In addition, the vector $\mathbf{z}_t$ includes deterministic terms such as time trends and constants. The unknown coefficients to be estimated are the elements of the vectors $\mathbf{c}_1$ and $\mathbf{c}_2$ and the matrices $\mathbf{A}'_1$, $\mathbf{A}'_2$, $\mathbf{B}'_1$, $\mathbf{B}'_2$ and $\mathbf{D}$. The errors $\varepsilon_{1,t}$ and $\varepsilon_{2,t}$ are of dimension $n_1 \times 1$ and $n_2 \times 1$, respectively. By definition, errors are expected to be zero on average and their variance-covariance matrix is positive definite.

The VAR is further restricted to reflect the small open economy assumption, namely we impose that $\mathbf{A}'_2 = \mathbf{0}$ such that $\mathbf{y}_1$ forms an exogenous block of variables (under the identification scheme that is described below). The resulting system of equations, subject to $\mathbf{A}'_2 = \mathbf{0}$, can be estimated by full information maximum likelihood. The implementation is standard and follows the algorithm described in Hamilton (1994, pp. 311-13).

The exogenous foreign block is composed of: (1) an index of real world GDP (in logs), (2) annual US CPI inflation, (3) US federal funds nominal rate and (4) a real commodity price index (in logs).[6] Structural shocks are identified using a Cholesky decomposition of the variance-covariance matrix of the VAR residuals. Therefore, the ordering of the variables im-

[6] Due to parsimony reasons the oil price is not included in the external block of the VAR system. In the model of the following section, the oil price is thus assumed to follow an exogenous AR(1) process.

plies a recursive identification scheme with the first of the aforementioned variables being the most exogenous. In particular, we assume that US inflation and interest rates respond contemporaneously to exogenous changes in world GDP, while world GDP does not respond within a quarter to exogenous changes in inflation and interest rates. The interest rate is assumed to respond in the same quarter to exogenous changes in inflation, but not vice versa. This ordering of variables is fairly standard in monetary VARs. In addition, we order commodity prices after the remaining external variables to reflect the usage of commodities as financial assets that adjust instantaneously to news on the remaining foreign variables including foreign interest rates.[7] Hence, under this particular recursive identification scheme commodity price shocks could also be interpreted to capture signals on future changes in world demand for commodities that are associated with a delayed response of world GDP, inflation and interest rates.[8]

The endogenous domestic block includes seven key variables for each country: (1) real GDP (in logs), (2) nominal non-mining investment as a percentage of nominal GDP, (3) nominal mining investment as a percentage of nominal GDP, (4) the annual CPI inflation rate, (5) the annual nominal monetary policy rate, (6) the real exchange rate (in logs) and (7) the current account balance as a percentage of nominal GDP.

Regarding the lag length of the VARs, standard information criteria (Schwarz, Akaike and Hannan-Quinn) point towards one or two lags. However, for the sake of parsimony and to facilitate comparisons across countries we choose one lag for all reported estimations. Finally, we add a constant and a quadratic time trend as deterministic terms.

3.3 Cross-country comparison of SVAR results

Table 2 reports the impulse responses of foreign variables to an unexpected commodity price shock of 50%, which roughly corresponds to the observed average increase of real commodity prices in the mid-2000s period. In general, the SVAR estimates suggest that the increase in commodity prices is relatively persistent for all countries with a half-life of the commodity price responses ranging between two and three years for most countries (except Peru where the half-life of the shock is less than two years). The estimated shocks are coherent with a delayed expansion of world GDP that is statistically significant at conventional levels and persistent across countries. The peak effect on world GDP materializes after two to three years and ranges between 1.5% and 2.5%. Moreover, all estimations suggest a statistically significant rise in global inflation, which increases up to around one percent after a year. Higher output and inflation explain why interest rates increase consistently with flexible inflation targeting frameworks adopted by the Federal Reserve and other leading central banks around the world.

[7] We have tried alternative orderings (e.g. ordering commodity prices before interest rates to reflect the fact that these form part of the Fed's information set when monetary policy decisions are taken), but our main results that we highlight below were robust to those alternative orderings.

[8] This interpretation is in line with Frankel (2006, 2008b, 2008a) and Calvo (2008).

Table 2: Impulse responses to comm. price shocks (50%) from SVAR models, external variables.

	Log Real Foreign GDP						Annual Foreign Inflation					
Qrt.	Aus.	Can.	Chile	NZ	Peru	SA	Aus.	Can.	Chile	NZ	Peru	SA
t=0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
t=1	**0.7**	**0.5**	**0.8**	**0.5**	**0.9**	**0.9**	**0.5**	**0.4**	**0.3**	**0.4**	**0.6**	**0.5**
t=4	**1.9**	**1.5**	**1.6**	**1.5**	**1.8**	**2.3**	**1.2**	**0.9**	**0.7**	**1.0**	**1.2**	**1.2**
t=8	**2.2**	**1.9**	**1.3**	**1.8**	**1.2**	**2.4**	**1.2**	**1.0**	**0.6**	**0.9**	**0.8**	**1.1**
t=12	**1.9**	**1.7**	**0.7**	**1.6**	**0.4**	**1.6**	**0.9**	**0.8**	**0.3**	**0.7**	**0.2**	**0.8**
t=16	**1.4**	**1.4**	**0.3**	**1.2**	0.0	**0.9**	**0.6**	**0.6**	**0.1**	**0.5**	0.0	**0.4**
t=20	**1.0**	**1.0**	0.1	**0.8**	0.0	**0.4**	**0.4**	**0.4**	0.1	**0.3**	**0.0**	**0.2**

	Foreign Interest Rate						Log Real Commodity Price					
Qrt.	Aus.	Can.	Chile	NZ	Peru	SA	Aus.	Can.	Chile	NZ	Peru	SA
t=0	0.0	0.0	0.0	0.0	0.0	0.0	**50**	**50**	**50**	**50**	**50**	**50**
t=1	**0.4**	**0.5**	**0.5**	**0.5**	**0.5**	**0.5**	**51**	**50**	**50**	**49**	**50**	**55**
t=4	**1.1**	**1.3**	**0.9**	**1.4**	**1.1**	**1.1**	**48**	**45**	**41**	**41**	**35**	**57**
t=8	**1.2**	**1.5**	**0.6**	**1.4**	**0.7**	**1.0**	**37**	**34**	**24**	**28**	**13**	**42**
t=12	**1.0**	**1.1**	0.3	**1.0**	**0.3**	**0.6**	**25**	**23**	**12**	**17**	1	**26**
t=16	**0.6**	**0.6**	0.1	0.5	0.0	**0.2**	**17**	**16**	5	**10**	**-2**	**13**
t=20	**0.4**	**0.2**	0.0	0.1	0.0	0.0	**11**	**11**	2	**6**	**-1**	**6**

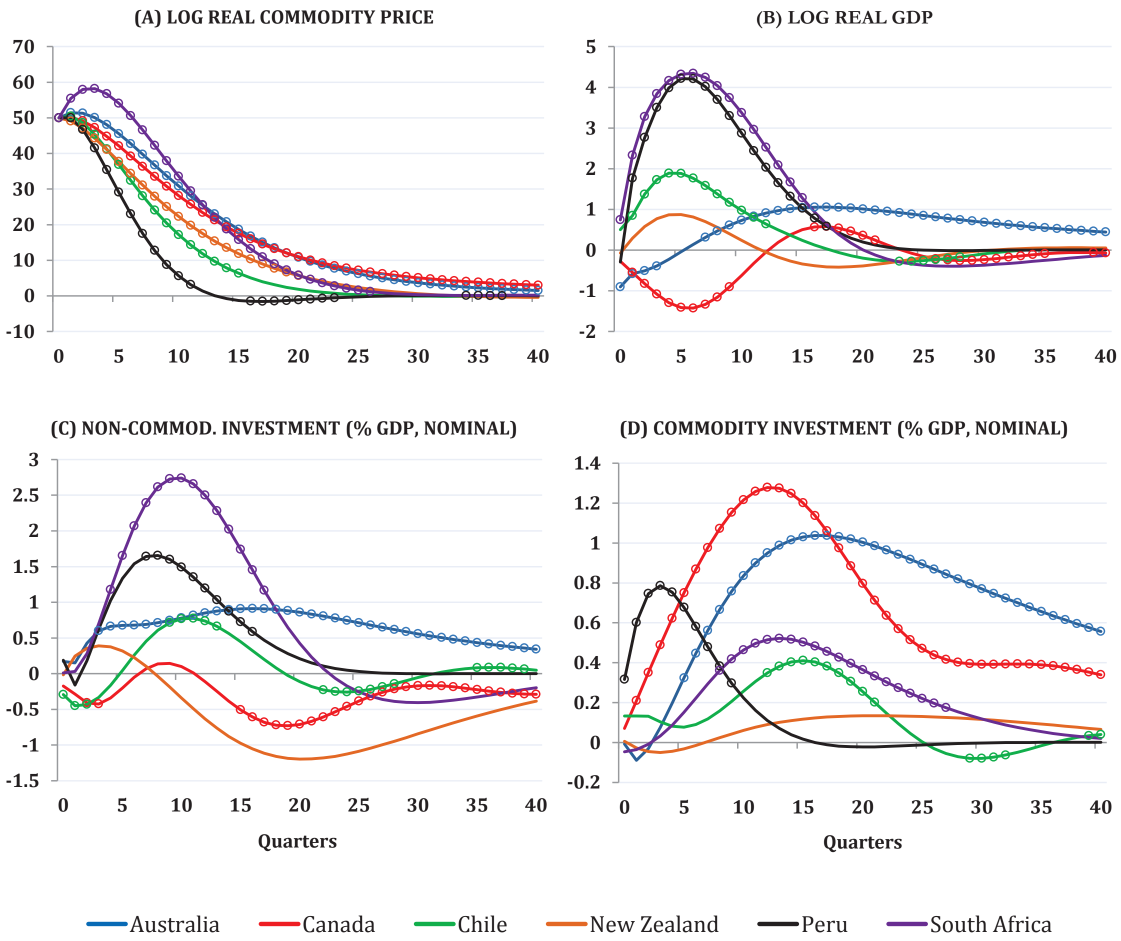
Note: Bold values are statistically significant at the 90% level of confidence.

Concerning the domestic effects of the commodity price shocks, Figure 6 shows the responses of real GDP and investment in mining and non-mining sectors (as a ratio of nominal GDP). The results show that the estimated commodity price shocks generate an expansion of real GDP in most countries that is partly driven by investment. On the one hand, investment in mining tends to react little on impact, but afterwards the responses are positive, relatively large and persistent for the majority of countries, pointing to an expansion of capacity that takes time to materialize. The effects of the commodity price are estimated to be stronger in countries with larger commodity sectors, i.e. Australia, Canada, Chile, Peru and South Africa, whereas they are not significant for New Zealand. In the case of Chile, the effects are smaller due to the lower persistence of the shock. In Peru, where the shock is also less persistent than in other countries, the effects are stronger initially but less persistent than on average.

On the other hand, non-mining investment shows more heterogeneous responses across countries. In the mining-exporting countries (Australia, Chile, Peru and South Africa), the increase in non-mining investment is larger than real GDP. One interpretation of this result is that mining investment induces more investment in construction while it boosts imports of machines and equipment. In contrast, in countries with a more diversified trade structure such as New Zealand and Canada, the reaction of non-mining investment is not significant or negative such that mining investment may crowd out other investment in those countries.

Figure 7 shows the responses of real exchange rates, inflation, interest rates and the current

Figure 6: Impulse responses from SVAR models, different countries.

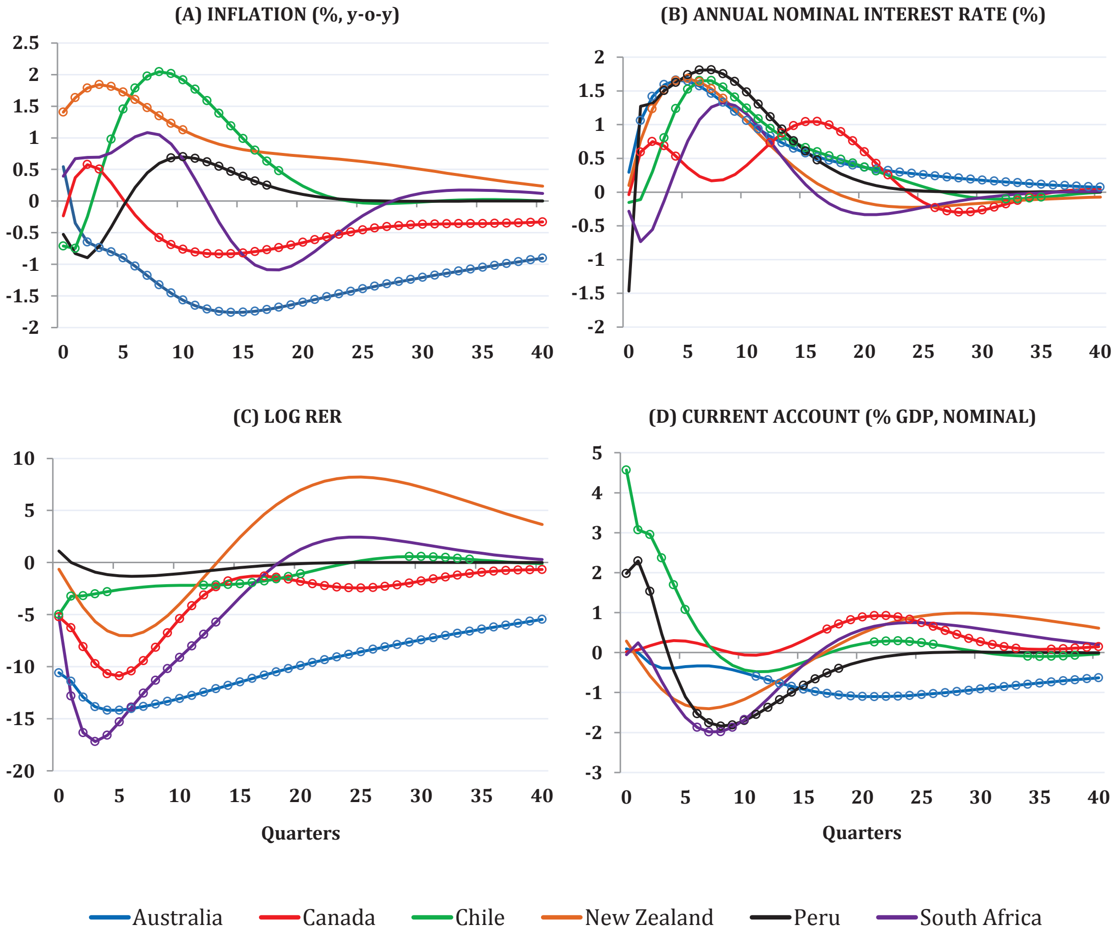


Notes: Shock is of size 50%. Circles indicate quarters in which the responses are statistically statistically significant at the 90% level of confidence.

account balances in the different countries. With the exception of Peru and New Zealand, all countries present a significant real appreciation of local currencies in the short run. These movements in real exchange rates are consistent with an upward adjustment in domestic absorption and demand due to the positive wealth effect associated with the shock. They also explain why inflation falls in some cases despite the increase in demand due to the pass-through effect of the real appreciation on consumer prices. In fact, the negative effects on inflation are stronger in countries with a more persistent real exchange rate appreciation (Australia and Canada). In addition, consistently with higher output and in some cases positive inflation, the estimated responses of monetary policy rates are significantly positive in all countries except South Africa.

Interestingly, current account balances move into deficit in several countries, while in some countries (Chile and Peru) we observe a reversal effect after initial surpluses (although this effect is not significant for Chile). The negative and delayed current account responses are evidently related to the hump-shaped dynamics of investment and in particular higher mining FDI.

Figure 7: Impulse responses from SVAR models, different countries (ct'd).

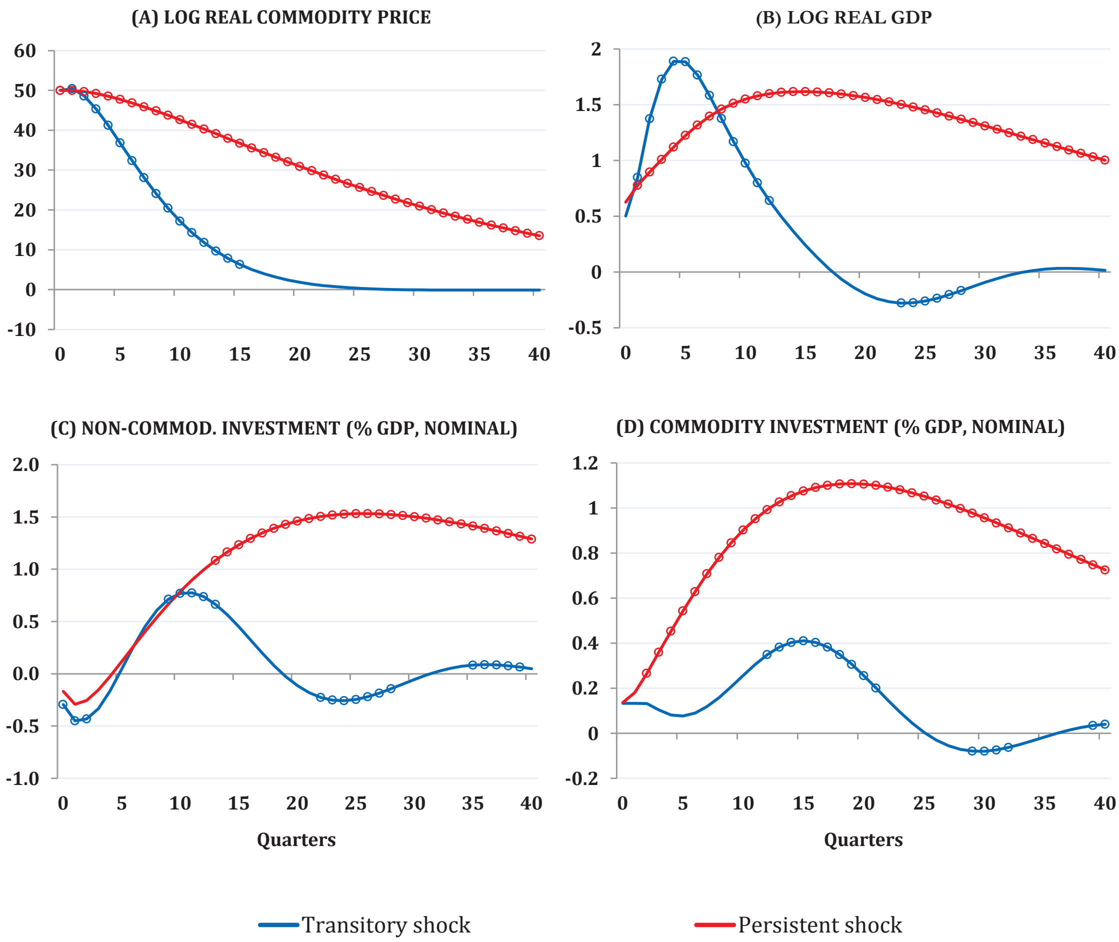


Notes: Shock is of size 50%. Circles indicate quarters in which the responses are statistically significant at the 90% level of confidence.

In summary, our main findings from the SVAR analysis across countries are as follows:

- The commodity price shocks estimated from the data are relatively persistent. All SVARs associate these shocks with expansionary effects on world GDP, inflation and interest rates.
- We observe delayed responses of domestic investment concentrated in mining sectors and expansion in aggregate output. However, non-mining investment may fall in countries with a more diversified trade structure.
- Across countries, local currencies appreciate in the short run and current account balances deteriorate in the medium term as investment rises.
- The responses of inflation are positive for some countries while they are negative in others where the exchange rate appreciation is relatively persistent. Interest rates rise in all countries consistently with a tightening response of monetary policy.

Figure 8: Impulse responses from alternative SVAR models for Chile.



Notes: Shock is of size 50%. Circles indicate quarters in which the responses are statistically significant at the 90% level of confidence.

3.4 The case of Chile with persistent and transitory shocks

In the analysis of the previous section we added time trends as controls to the estimated VARs to match long-run dynamics. In this section we implement an alternative exercise where we assume that the real price of copper is stationary in the long run. In other words, we maintain the assumption that the nominal copper price and the US CPI are cointegrated. This assumption is consistent with the finding that based on longer spans of data we reject the null hypothesis of a unit root in the real copper price.

Figure 8 shows that the estimated commodity price shock is significantly more persistent in this variant of the SVAR for Chile, where the half-life of the shock is more than six years. The impulse responses of investment in mining and non-mining sectors are very different from the previous transitory shock case. Under the more persistent shock, mining investment increases by more than one percentage point of GDP while under the transitory shock it reached less than

0.5 percentage points of GDP at maximum. The peak response of non-mining investment is also roughly double as big under the persistent shock compared to the transitory shock. Due to the aggregate demand push, GDP increases persistently over the ten years horizon considered. All these effects are statistically significant at the 90 percent level.

In summary, the persistence of commodity price shocks seems to matter for the responses of output and investment in commodity-exporting economies to such shocks. While transitory shocks do not seem to activate much investment in commodity sectors, persistent shocks tend to have larger effects. In the following section, we analyze in more detail the transmission mechanisms that can explain these dynamics based on a DSGE model, where some of the features of the model (such as time to build frictions) are motivated by the SVAR results.

4 The DSGE Model for Chile

In this section we describe an extended version of the DSGE model developed by Medina and Soto (2007a). The model of Medina and Soto (2007a) is a New Keynesian small open economy model with several standard elements[9] and some specific features of the Chilean economy such as a commodity-exporting sector that is owned in part by the government and in part by foreign agents, as well as a structural balance rule to describe fiscal policy in Chile. However, commodity production is assumed to be exogenous in the framework Medina and Soto (2007a). We drop this assumption and assume instead that commodity production is conducted in an endogenous way through capital with time to build in capital accumulation and investment adjustment costs, following Kydland and Prescott (1982) and Uribe and Yue (2006).[10] This extension is described in detail below while the description of the basic framework is relatively brief and we refer to Medina and Soto (2007a) for a more detailed discussion.[11] Finally, we assume that the dynamics of the relevant foreign variables are described by the external block of the structural VAR model for Chile from the previous section.

4.1 Households

There is a continuum of households indexed by $j \in [0, 1]$. A fraction λ of those households are non-Ricardian ones without access to the capital market. These households receive no profits and do not save, and thus consume entirely their disposable wage income. The remaining

[9] The standard ingredients (see, for instance, Adolfson, Laséen, Lindé, and Villani, 2008)) include a production structure with domestic and foreign tradable goods, sticky prices and wages with partial indexation to past inflation, incomplete exchange rate pass-through into import prices in the short run, adjustment costs in investment, and habit persistence in consumption. The model also includes a fraction of non-Ricardian households, oil in the consumption basket and as an input for domestic goods production, and food consumption.

[10] We include time to build *and* investment adjustment costs, as in Uribe and Yue (2006), to obtain more plausible investment and output dynamics in the commodity sector.

[11] A shock to the stock of capital is also added to the basic framework of Medina and Soto (2007a) to resemble the 2010 earthquake in Chile.

households are Ricardian ones that do have access to the capital market and make intertemporal consumption and savings decisions in a forward-looking manner.

Households of the Ricardian type maximize the present value of expected utility at time t:

$$\max E_t \sum_{i=0}^{\infty} \beta^i \zeta_{C,t+i} \left[\log(C_{t+i}^R(j) - hC_{t+i-1}^R) - \psi \frac{l_{t+i}(j)^{1+\sigma_L}}{1+\sigma_L} \right], \qquad j \in (1-\lambda, 1],$$

subject to the period-by-period budget constraint

$$P_{C,t}C_t^R(j) + E_t\{d_{t,t+1}D_{t+1}(j)\} + \frac{B_t(j)}{r_t} + \frac{\varepsilon_t B_{P,t}^*(j)}{r_t^* \Theta_t} = \\ W_t(j)l_t(j) + \Xi_t(j) - TAXN_t(j) + D_t(j) + B_{t-1}(j) + \varepsilon_t B_{P,t-1}^*(j),$$

where $C_t^R(j)$ is consumption of household j and C_t^R is aggregate consumption of Ricardian households, respectively, while $l_t(j)$ is household j's labor effort (in hours). The variable $\zeta_{C,t}$ is a preference shock to the households' subjective discount factor. Further, $P_{C,t}$ is the aggregate consumer price index (CPI), $W_t(j)$ is the nominal wage set by the household, $\Xi_t(j)$ collects payouts by firms, $TAXN_t(j)$ are lump-sum tax payments to the government, ε_t is the nominal exchange rate (units of domestic currency to buy one unit of foreign currency), and $d_{t,t+1}$ is the period t price of one-period domestic contingent bonds, $D_t(j)$, normalized by the probability of the occurrence of the state. The variable r_t denotes the gross interest rate on a non-contingent domestic bond denominated in domestic currency, $B_t(j)$, whereas r_t^* is the (exogenous) interest rate on a non-contingent foreign bond denominated in foreign currency, $B_{P,t}^*(j)$. The term $\Theta(\cdot)$ is a premium paid by domestic agents on top of the foreign interest rate.[12]

Following Erceg, Henderson, and Levin (2000), each household is a monopolistic supplier of a differentiated labor service. These labor services are bundled by a set of perfectly competitive labor packers that hire labor varieties and combine it into an aggregate labor service unit used as an input in production of domestic intermediate varieties. Cost minimization of labor packers yields the demand for each type of labor as a function of relative wages and aggregate labor demand by firms. There are wage rigidities in the spirit of Calvo (1983). In each period, a household faces a probability $(1-\phi_L)$ of being able to reoptimize its nominal wage. The households that can reoptimize at time t will maximize the expected discounted future stream of labor income net of the disutility from work, subject to the labor demand constraint. All those that cannot re-optimize at time t set their wages according to a weighted average of past CPI inflation and the inflation target set by the central bank. Once a household has set its wage, it must supply any quantity of labor service demanded at that wage.

[12] The premium is a function of the aggregate (private, $B_{P,t}^*$, plus government, $B_{G,t}^*$) net foreign bond position relative to nominal GDP ($BY_t = \varepsilon_t B_t^*/P_{Y,t}Y_t$), i.e. $\Theta_t = \bar{\Theta}\exp[-\varrho(BY_t - \overline{BY}) + \zeta_{\Theta,t}/\bar{\zeta}_\Theta - 1]$, where $\varrho > 0$ to ensure stationarity of net foreign bonds and where $\zeta_{\Theta,t}$ is a shock to the premium (throughout, bars indicate deterministic steady state values).

Households of the non-Ricardian type consume their disposable wage income each period:

$$P_{C,t}C_t^{NR}(j) = W_t l_t(j) - TAXN_t(j), \qquad j \in [0, \lambda].$$

For simplicity, it is assumed that non-Ricardian households set a wage equivalent to the average wage set by Ricardian households. As a consequence, the supply of labor by non-Ricardian households coincides with the average labor supply of Ricardian households.

The households' consumption bundle is a constant elasticity of substitution (CES) composite of a core consumption bundle, $C_{Z,t}(j)$, food consumption, $C_{A,t}(j)$, and oil consumption, $C_{O,t}(j)$. Core consumption is a CES composite of final domestic goods, $C_{H,t}(j)$, and imported goods, $C_{F,t}(j)$. Food consumption is a similar composite of domestic and imported goods but subject to an exogenous shock ($\zeta_{A,t}$) to capture deviations of food price inflation from core inflation. Households minimize the costs of the different bundles, which yields standard Dixit-Stiglitz type demand functions for the individual components as well as expressions for the headline CPI, food prices, and the core CPI excluding oil and food (given oil prices).

4.2 Domestic goods

In the domestic goods sector, there is a continuum of firms that produce differentiated varieties of intermediate tradable goods using labor, capital and oil as inputs. They have monopoly power over the varieties they produce and adjust prices infrequently. These firms sell their varieties to competitive assemblers that produce final domestic goods that are sold in the domestic and foreign market. Another set of competitive firms produces the capital goods used in intermediate goods production. All firms in this sector are owned by Ricardian households.

A representative capital goods producer rents capital goods to domestic intermediate goods producing firms. It decides how much capital to accumulate each period, assembling investment goods, I_t, with a CES technology that combines final domestic goods, $I_{H,t}$, and imported goods, $I_{F,t}$. The optimal composition of investment is determined through cost minimization. The firm may adjust investment to produce new capital goods, K_t, in each period but there are convex costs of adjusting investment, $\Phi(\cdot)$, following Christiano, Eichenbaum, and Evans (2005). The firm chooses the level of investment and its stock of capital to maximize the present value to households of expected profits (rental returns on capital net of the cost of investment):

$$\max E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i}[Z_{t+i} \exp(\zeta_{K,t+i}) K_{t+i-1} - P_{I,t+i} I_{t+i}],$$

subject to the law of motion of capital

$$K_t = (1 - \delta) \exp(\zeta_{K,t}) K_{t-1} + [1 - \Phi(I_t/I_{t-1})]\zeta_{I,t} I_t,$$

where $\Lambda_{t,t+i}$ is the stochastic discount factor for nominal payoffs from the Ricardian household's problem and Z_t is the rental price of capital.[13] The variable $\zeta_{I,t}$ is an investment-specific shock that alters the rate at which investment is transformed into productive capital (see Greenwood, Hercowitz, and Krusell, 2000), while $\zeta_{K,t}$ is an i.i.d. shock to the stock of capital that captures physical destruction of capital due to natural disasters such as an earthquake.

There is a large set of firms that use a CES technology to assemble final domestic goods from domestic intermediate varieties. A quantity $Y_{H,t}$ of those goods is sold domestically and a quantity $Y^*_{H,t}$ is sold abroad. The assemblers demand intermediate goods of variety z_H for domestic sale, $Y_{H,t}(z_H)$, and intermediate goods for foreign sale, $Y^*_{H,t}(z_H)$. Input cost minimization yields the typical Dixit-Stiglitz demand functions for each variety.

Intermediate goods producers decide on the most efficient combination of labor, capital and oil (i.e. to minimize input costs given factor prices). The available technology is as follows:

$$\mathbf{Y}_{H,t}(z_H) = a_{H,t}\left[{\alpha_H}^{1/\omega_H} V_{H,t}(z_H)^{1-1/\omega H} + (1-\alpha_H)^{1/\omega_H} O_{H,t}(z_H)^{1-1/\omega H}\right]^{\frac{\omega_H}{\omega_H - 1}},$$

where $V_{H,t}$ denotes value added produced out of labor and capital, while $O_{H,t}(z_H)$ is the amount of oil used as intermediate input and $a_{H,t}$ represents a stationary productivity shock common to all firms.[14] Value added is generated through a Cobb-Douglas function:

$$V_{H,t}(z_H) = [T_t l_t(z_H)]^{\eta_H} [\exp(\zeta_{K,t}) K_{t-1}(z_H)]^{1-\eta_H},$$

where $l_t(z_H)$ is the amount of labor utilized, T_t is a stochastic trend in labor productivity, and $K_{t-1}(z_H)$ is the amount of capital rented at the beginning of period t.[15]

The intermediate producers have monopoly power and set their prices separately in the domestic market, $P_{H,t}(z_H)$, and the foreign market, $P^*_{H,t}(z_H)$, maximizing profits subject to the corresponding demand constraints. Prices are set in a staggered way, following Calvo (1983). In every period, the probability that a firm receives a signal for optimally adjusting its price for the domestic market is $1 - \phi_{H_D}$, and the probability of optimally adjusting its price for the foreign market is $1 - \phi_{H_F}$. If a firm does not receive a signal, it updates its price according to a weighted average of past changes of aggregate producer prices ($P_{H,t}$ or $P^*_{H,t}$) and steady state domestic or foreign CPI inflation. Let $MC_{H,t}$ denote the marginal cost of producing variety z_H. When a firm can reoptimize its price for the domestic market or foreign market, it solves

$$\max E_t \sum_{i=0}^{\infty} \phi^i_{H_D} \Lambda_{t,t+i} [\Gamma^i_{H_D,t} P_{H,t}(z_H) - MC_{H,t+i}] Y_{H,t+i}(z_H),$$

[13]The stochastic discount factor satisfies $\Lambda_{t,t+i} = \beta^i(\zeta_{C,t+i}/\zeta_{C,t})(C^R_t - hC^R_{t-1})/(C^R_{t+i} - hC^R_{t+i-1})(P_{C,t}/P_{C,t+i})$. Further, the function $\Phi(\cdot)$ satisfies $\Phi(1+g_Y) = \Phi'(1+g_Y) = 0$ and $\Phi''(1+g_Y) = \mu_S > 0$, where g_Y is the steady state (balanced) growth rate of the economy.

[14]By market clearing, it holds that $\mathbf{Y}_{H,t}(z_H) = Y_{H,t}(z_H) + Y^*_{H,t}(z_H)$.

[15]The productivity trend evolves according to the process $T_t/T_{t-1} = \zeta_{T,t} = (1+g_Y)^{1-\rho_T} \zeta^{\rho_T}_{T,t-1} \exp(\varepsilon_{T,t})$.

subject to the final domestic goods producer's demand $Y_{H,t}(z_H) = [P_{H,t}(z_H)/P_{H,t}]^{-\epsilon_H} \mathrm{Y}_{H,t}$. Analogously, when a firm can reoptimize its price for the foreign market, it solves

$$\max E_t \sum_{i=0}^{\infty} \phi_{H_F}^i \Lambda_{t,t+i} [\Gamma_{H_F,t}^i \varepsilon_{t+i} P_{H,t}^*(z_H) - MC_{H,t+i}] Y_{H,t+i}^*(z_H),$$

subject to the demand constraint $Y_{H,t}^*(z_H) = [P_{H,t}^*(z_H)/P_{H,t}^*]^{-\epsilon_H} Y_{H,t}^*$.[16]

4.3 Imported goods

In the imported goods sector, there is a continuum of retail firms that repackage a homogeneous good bought from abroad into differentiated imported varieties through a brand naming technology. Those firms have monopoly power in the domestic retailing of their particular variety and set prices infrequently. They sell their varieties to competitive assemblers that produce final imported goods that are bought by households and firms. As in the case of the domestic goods sector, all firms in the imported goods sector are owned by Ricardian households.

There is a large set of firms that use a CES technology to assemble final imported goods, $Y_{F,t}$, from imported varieties. Demand for a particular imported variety, $Y_{F,t}(z_F)$, is determined through minimization of costs, which yields the Dixit-Stiglitz demand functions for each variety.

Imported goods retailers buy a homogeneous good from abroad at the price $P_{F,t}^*$, which is then differentiated into a particular variety and sold domestically to assemblers of final imported goods. It takes one unit of the homogenous foreign good to produce a unit of retail output. Each importing firm has monopoly power, and adjusts the domestic price of its variety in a staggered way, following Calvo (1983). Each period, a firm optimally adjusts its price with probability $1 - \phi_F$. If a firm does not receive a signal, it updates its price according to a weighted average of past changes of aggregate producer prices ($P_{F,t}$) and steady state CPI inflation. When a firm can reoptimize its price, it solves

$$\max E_t \sum_{i=0}^{\infty} \phi_F^i \Lambda_{t,t+i} [\Gamma_{F,t}^i P_{F,t}(z_F) - \varepsilon_{t+i} P_{F,t+i}^*] Y_{F,t+i}(z_F),$$

subject to the final imported goods producer's demand $Y_{F,t}(z_H) = [P_{F,t}(z_F)/P_{F,t}]^{-\epsilon_F} \mathrm{Y}_{F,t}$. [17]

4.4 Commodity goods

We extend the model of Medina and Soto (2007a) by endogenizing commodity production. As in Medina and Soto (2007a), there is a representative firm in the commodity sector (S) that

[16] For $i > 1$, the passive price updating rules are $\Gamma_{H_D,t}^i = \Gamma_{H_D,t}^{i-1} \pi_{H,t+i-1}^{\chi_{H_D}} \bar{\pi}^{1-\chi_{H_D}}$ for domestically sold goods and $\Gamma_{H_F,t}^i = \Gamma_{H_F,t}^{i-1} \pi_{H,t+i-1}^{*\chi_{H_F}} \bar{\pi}^{*1-\chi_{H_F}}$ for goods sold abroad, where $\pi_{H,t} = P_{H,t}/P_{H,t-1}$, $\pi_{H,t}^* = P_{H,t}^*/P_{H,t-1}^*$ and $\bar{\pi}^*$ denotes steady state foreign CPI inflation. For $i = 0$, we have $\Gamma_{H_D,t}^0 = \Gamma_{H_F,t}^0 = 1$.

[17] The passive price updating rule is $\Gamma_{F,t}^i = \Gamma_{F,t}^{i-1} \pi_{F,t+i-1}^{\chi_F} \bar{\pi}^{1-\chi_F}$ for $i > 1$ and $\Gamma_{F,t}^0 = 1$ for $i = 1$.

produces a homogeneous commodity good. The entire production is exported. A fraction χ of the assets of that firm is owned by the government and the remaining fraction is owned by foreign investors. The revenue generated in the commodity sector is shared accordingly, but the government levies taxes on the profits that accrue to foreign investors.

4.4.1 Production technology

The firm in sector S uses capital specific to that sector, $K_{S,t}$, to produce commodity goods, $Y_{S,t}$. Production evolves along the balanced growth path of the economy, but we admit transitory deviations from that growth path due to sectoral technology shocks, $a_{S,t}$. Specifically, commodity production satisfies

$$Y_{S,t} = a_{S,t} F^S(T_t, K_{S,t-1}). \tag{1}$$

The function $F^S(\cdot)$ is homogeneous of degree one in its arguments and has diminishing returns to capital additions. While we focus on capital-intensive commodity production and abstract from other inputs such as labor for simplicity, the shock $A_{S,t}$ can be interpreted to capture any variations in such additional inputs.[18] We also allow for a fixed transfer to households to capture eventual labor remunerations or other fixed costs (see below).

4.4.2 Profits and cash flow

Let $P^*_{S,t}$ denote the international price of the commodity good and let $P_{S,t} = \varepsilon_t P^*_{S,t}$ be its domestic price, which the firm takes as given. Gross profits of the firm are given by

$$\Pi_{S,t} = P_{S,t} Y_{S,t} - P_{C,t} T_t \kappa_S,$$

where $P_{C,t} T_t \kappa_S$ is a fixed cost of production that grows at the same rate as nominal output. We assume that this fixed cost is a lump-sum transfer to Ricardian households. The cash flow of the firm is $CF_{S,t} = \Pi_{S,t} - P_{I_S,t} I_{S,t}$, where $P_{I_S,t} I_{S,t}$ is the firm's investment. The objective of the firm is to maximize the present real value of its expected cash flow:

$$\max E_t \sum_{i=0}^{\infty} \Lambda_{t,t+i}(S) \frac{CF_{S,t+i}}{P_{C,t+i}},$$

where $\Lambda_{t,t+i}(S)$ denotes the stochastic discount factor relevant to the firm. This discount factor is taken to be identical to the one of the households, i.e. $\Lambda_{t,t+i}(S) = \Lambda_{t,t+i}$.[19]

[18] For instance, we could take the Cobb-Douglas production function $Y_{S,t} = \tilde{F}^S(T_t l_S, T_t F_{S,t}, K_{S,t-1}) = (T_t l_S)^{\eta_{l_S}} (T_t F_{S,t})^{\eta_{F_S}} K_{S,t-1}^{1-\eta_{l_S}-\eta_{F_S}}$, where l_S would be a fixed input of labor and $F_{S,t}$ would capture variations in other factors such as the mineral content of land. Defining $\eta_S = \eta_{l_S} + \eta_{F_S}$, we obtain $Y_{S,t} = a_{S,t} T_t^{\eta_S} K_{S,t-1}^{1-\eta_S}$, which is a representation of (1) with $a_{S,t} = l_S^{\eta_{l_S}} F_{S,t}^{\eta_{F_S}}$ and with $F^S(T_t, K_{S,t-1}) = T_t^{\eta_S} K_{S,t-1}^{1-\eta_S}$. Under those assumptions, total factor productivity $a_{S,t}$ is a function of labor and other factors subsumed in $F_{S,t}$.

[19] The relation $\Lambda_{t,t+i}(S) = \Lambda_{t,t+i}$ holds, as we assume, if the government has a stochastic discount factor equivalent to the one of the households and if foreign investors have access to domestic currency bonds.

4.4.3 Law of motion of capital

Notice that the definition of profits does not have any importance for firm's optimality; however, it is a key determinant of the tax base, which is needed to characterize the Chilean fiscal rule (see next section for details). The stock of capital in sector S is augmented through investment projects, $X_{S,t}$. Following Uribe and Yue (2006), there are adjustment costs in investment and *time to build* in the installation of capital à la Kydland and Prescott (1982). In particular, the firm can start new investment projects in each period but at a cost that is convex: the larger the change in investment the larger the implied cost. In addition, new investment projects take $n \geq 1$ periods to mature. Collecting these assumptions results in the following law of motion of capital:

$$K_{S,t} = (1-\delta_S)K_{S,t-1} + [1-\Phi_S(X_{S,t-n+1}/X_{S,t-n})]X_{S,t-n+1}. \tag{2}$$

The function $\Phi_S(\cdot)$ is analogous to the Christiano, Eichenbaum, and Evans (2005) style flow adjustment cost function from the law of motion of capital used in the domestic goods sector, and satisfies $\Phi_S(1+g_Y) = \Phi'_S(1+g_Y) = 0$ and $\Phi'_S(1+g_Y) = \mu_{I_S} > 0$. A similar specification of the law of motion of capital is employed in Uribe and Yue (2006). The effective flow of investment in period t is given by

$$I_{S,t} = \sum_{j=0}^{n-1} \varphi_j X_{S,t-j}, \tag{3}$$

where φ_j denotes the fraction of projects initiated in period $t-j$ that is financed in period t, with $\sum_{j=0}^{n-1} \varphi_j = 1$. We will assume that $\varphi_0 = \varphi_1 = \ldots = \varphi_{n-1}$, as in Kydland and Prescott (1982) i.e. the cost of a project is spread equally over the horizon of its installation. In the extreme when $n = 1$, we obtain the familiar law of motion $K_{S,t} = (1-\delta_S)K_{S,t-1} + [1-\Phi_S(I_{S,t}/I_{S,t-1})]I_{S,t}$.

4.4.4 Capital-investment choice

The firm's first-order optimality conditions are as follows:

$$K_{S,t} \; : \; \frac{Q_{S,t}}{P_{C,t}} = E_t\left\{\Lambda_{t,t+1}\left[\frac{Q_{S,t+1}}{P_{C,t+1}}(1-\delta_S) + \frac{P_{S,t+1}A_{S,t+1}F^S_{K_S}(T_{t+1}, K_{S,t})}{P_{C,t+1}}\right]\right\},$$

$$\begin{aligned} X_{S,t} \; : \; & \varphi_0 \frac{P_{I_S,t}}{P_{C,t}} + \varphi_1 E_t\left\{\Lambda_{t,t+1}\frac{P_{I_S,t+1}}{P_{C,t+1}}\right\} + \cdots + \varphi_{n-1}E_t\left\{\Lambda_{t,t+n-1}\frac{P_{I_S,t+n-1}}{P_{C,t+n-1}}\right\} \\ & = E_t\left\{\begin{array}{c} \Lambda_{t,t+n-1}\frac{Q_{S,t+n-1}}{P_{C,t+n-1}}[1-\Phi_S(X_{S,t}/X_{S,t-1}) - \Phi'_S(X_{S,t}/X_{S,t-1})X_{S,t}/X_{S,t-1}] \\ +\Lambda_{t,t+n}\frac{Q_{S,t+n}}{P_{C,t+n}}\Phi'_S(X_{S,t+1}/X_{S,t})(X_{S,t+1}/X_{S,t})^2 \end{array}\right\}, \end{aligned}$$

where $F^S_{K_S}(\cdot)$ is the derivative of the production function in (1) with respect to capital. These two conditions jointly determine the evolution of investment projects and the mark-to-market value of capital, $Q_{S,t}$, in sector S. The law of motion (2) determines the evolution of the stock of capital and (3) determines the effective flow of investment in this sector.

4.4.5 Composition of investment

The investment good that is required to build the stock of capital in sector S is a CES bundle of final domestic goods, $I_{H,t}(S)$, and imported goods, $I_{F,t}(S)$:

$$I_{S,t} = \left[\gamma_{I_S}^{1/\eta_{I_S}} I_{H,t}(S)^{1-1/\eta_{I_S}} + (1-\gamma_{I_S})^{1/\eta_{I_S}} I_{F,t}(S)^{1-1/\eta_{I_S}} \right]^{\frac{\eta_{I_S}}{\eta_{I_S}-1}}. \tag{4}$$

The optimal composition of investment is determined through cost minimization. In each period, given the effective flow of investment, the firm minimizes $P_{I_S,t}I_{S,t} = P_{H,t}I_{H,t}(S) + P_{F,t}I_{F,t}(S)$ subject to (4), which yields the following demands for investment inputs originating in sector S:

$$I_{H,t}(S) = \gamma_{I_S}(P_{H,t}/P_{I_S,t})^{-\eta_{I_S}} I_{S,t}, \qquad I_{F,t}(S) = (1-\gamma_{I_S})(P_{F,t}/P_{I_S,t})^{-\eta_{I_S}} I_{S,t}.$$

4.5 Fiscal policy

A share χ of the cash flow that is generated in sector S goes directly to the government, and the government also levies taxes at a fixed rate τ_S on the profits–net of depreciation–that accrue to foreign investors. The budget constraint of the government is therefore as follows:

$$P_{G,t}G_t + \frac{\varepsilon_t B^*_{G,t}}{r^*_t \Theta_t} = \varepsilon_t B^*_{G,t-1} + \tau_t P_{Y,t}Y_t + \chi CF_{S,t} + \tau_S(1-\chi)(\Pi_{S,t} - \delta_S Q_{S,t}K_{S,t-1}),$$

where $P_{G,t}G_t$ denotes nominal government consumption expenditure, $B^*_{G,t}$ is the government net foreign asset position, and τ_t are lump-sum taxes from households net of transfers (as a share of nominal GDP, $P_{Y,t}Y_t$). Note that the government net asset position is assumed to be completely denominated in foreign currency, as in Medina and Soto (2007a). In addition, government consumption is characterized by complete home bias, i.e. $G_t = G_{H,t}$ and $P_{G,t} = P_{H,t}$.

Government expenditure follows a structural balance fiscal rule analogous to the one described in Medina and Soto (2007a):

$$\frac{P_{G,t}G_t}{P_{Y,t}Y_t} = \left[\begin{array}{l} \left(1 - \frac{1}{r^*_{t-1}\Theta_{t-1}}\right) \frac{\varepsilon_t B^*_{G,t-1}}{P_{Y,t}Y_t} + \tau_t \frac{P_{Y,t}\bar{Y}}{P_{Y,t}Y_t} + \chi \frac{CF_{S,t}}{P_{Y,t}Y_t} \\ +\tau_S(1-\chi)\frac{\Pi_{S,t} - \delta_S Q_{S,t}K_{S,t-1}}{P_{Y,t}Y_t} - \frac{VC_t}{P_{Y,t}Y_t} - \bar{s}_B \end{array} \right] \frac{P_{G,t}\zeta_{G,t}T_t}{P_{Y,t}Y_t},$$

where $VC_t = [\chi + \tau_S(1-\chi)]\varepsilon_t(P^*_t - \tilde{P}^*_t)Y_{S,t}$ is the cyclical adjustment of the rule that depends crucially on the difference between the effective commodity price, P^*_t, and the long-run reference price, $\tilde{P}^*_t$, which is calculated as the forecast of the effective commodity price averaged over a 10 years horizon. In addition, $\bar{Y}$ stands for potential real GDP, which for simplicity is taken to be equal to steady state output, and the parameter $\bar{s}_B$ is the structural balance target. The variable $\zeta_{G,t}$ is a shock capturing deviations of government expenditure from the fiscal rule.

4.6 Monetary policy

Monetary policy is conducted through a simple Taylor-type feedback rule for the nominal interest rate, which is a slightly modified version of the one presented in Medina and Soto (2007a). In particular, while the latter assume that the central bank responds entirely to deviations of core CPI inflation from target and of output growth from potential growth, we allow for a partial response to headline CPI inflation to capture possible concerns by the central bank on oil and food price inflation. Hence, the monetary policy rule is specified as follows:

$$\frac{r_t}{\bar{r}} = \left(\frac{r_{t-1}}{\bar{r}}\right)^{\psi_r} \left[\left(\frac{\pi_{Z,t}}{\bar{\pi}}\right)^{\psi_\pi \psi_{\pi Z}} \left(\frac{\pi_t}{\bar{\pi}}\right)^{\psi_\pi (1-\psi_{\pi Z})} \left(\frac{Y_t/Y_{t-1}}{T_t/T_{t-1}}\right)^{\psi_Y}\right]^{1-\psi_r} \exp(\zeta_{m,t}),$$

where $\pi_{Z,t}$ and π_t are core and headline CPI inflation, respectively, Y_t is real GDP, and $\zeta_{m,t}$ is an i.i.d. shock that captures deviations of the interest rate from the monetary policy rule.

4.7 Rest of the world

Foreign agents demand the commodity good and the final domestic good. They supply oil and the homogeneous good that is bought by importing firms. Foreign demand for the commodity good is assumed to be completely elastic at its international price, $P^*_{S,t}$. Likewise, foreign supply of oil is assumed to be completely elastic at any given price, $P^*_{O,t}$. The real exchange rate is defined as the domestic currency price of a foreign price index, $\varepsilon_t P^*_t$, relative to the domestic CPI. The domestic economy is assumed to be small relative to the rest of the world. As a consequence, the price of the homogeneous foreign good, $P^*_{F,t}$, coincides with the foreign price index. Foreign demand for the final domestic good depends on its relative price abroad, $P^*_{H,t}/P^*_t$, and foreign aggregate demand, Y^*_t , according to the demand function $Y^*_{H,t} = \zeta^*(P^*_{H,t}/P^*_t)^{-\eta^*} Y^*_t$.

4.8 Aggregate equilibrium

The market clearing condition for each variety of domestic goods is

$$\mathbf{Y}_{H,t}(z_H) = [P_{H,t}(z_H)/P_{H,t}]^{-\epsilon_H} Y_{H,t} + [P^*_{H,t}(z_H)/P^*_{H,t}]^{-\epsilon_H} Y^*_{H,t},$$

where $Y_{H,t} = C_{H,t} + I_{H,t} + I_{H,t}(S) + G_{H,t}$. In the labor market, labor demand by intermediate goods producers equals labor supply: $\int_0^1 l_t(z_H)dz_H = l_t$, where the aggregate labor service unit is given by

$$l_t = \left[\int_0^1 l_t(j)^{1-1/\varepsilon_L} dj\right]^{\frac{\varepsilon_L - 1}{\varepsilon_L}}.$$

Nominal GDP satisfies $P_{Y,t}Y_t = P_{C,t}C_t + P_{I,t}I_t + P_{I_S,t}I_{S,t} + P_{G,t}G_t + P_{X,t}X_t - P_{M,t}M_t$, where $P_{X,t}X_t = \varepsilon_t(P^*_{H,t}Y^*_{H,t} + P^*_{S,t}Y_{S,t})$ and $P_{M,t}M_t = \varepsilon_t[P^*_{F,t}Y_{F,t} + P^*_{O,t}(C_{O,t} + O_{H,t})]$ are nominal exports and imports, respectively, with $Y_{F,t} = C_{F,t} + I_{F,t} + I_{F,t}(S)$. Real GDP is defined as

$Y_t = C_t + I_t + I_{S,t} + G_t + X_t - M_t$. Substituting out aggregate profits in the budget constraint of the households and combining the latter with the budget constraint of the government yields the following expression for the evolution of aggregate net foreign bonds:

$$\frac{\varepsilon_t B_t^*}{r_t^* \Theta_t} = P_{X,t} X_t - P_{M,t} M_t + \varepsilon_t B_{t-1}^* - (1-\chi) CF_{S,t} + \tau_S (1-\chi)(\Pi_{S,t} - \delta_S Q_{S,t} K_{S,t-1}).$$

The terms on the right-hand side are net exports, net interest receipts minus the cash flow from the commodity sector that accrues to foreign investors, and transfers from foreigners due to taxes on profits net of the mark-to-market value of capital depreciation in the commodity sector. Finally, the current account balance is equivalent to the quarter-on-quarter change in the international investment position of the country (relative to nominal GDP):

$$CAY_t = \frac{1}{P_{Y,t} Y_t} \left[\frac{\varepsilon_t B_t^*}{r_t^* \Theta_t} - \frac{\varepsilon_t B_{t-1}^*}{r_{t-1}^* \Theta_{t-1}} \right] - (1-\chi) \frac{Q_{S,t}(K_{S,t} - K_{S,t-1})}{P_{Y,t} Y_t}.$$

4.9 Exogenous processes and foreign VAR

There are fifteen exogenous variables in the model: preferences ($\zeta_{C,t}$), neutral technology ($a_{H,t}$), productivity growth ($\zeta_{T,t}$), investment-specific technology ($\zeta_{I,t}$), capital destruction ($\zeta_{K,t}$), commodity-specific technology ($a_{S,t}$), fiscal policy ($\zeta_{G,t}$), monetary policy ($\zeta_{m,t}$), stationary foreign demand ($y_t^* = Y_t^*/T_t$), foreign inflation ($\pi_t^* = P_t^*/P_{t-1}^*$), food prices ($\zeta_{A,t}$), real commodity price ($p_{S,t}^* = P_{S,t}^*/P_t^*$), real oil price ($p_{O,t}^* = P_{O,t}^*/P_t^*$), foreign interest rate (r_t^*), and the country premium ($\zeta_{\Theta,t}$). The domestic exogenous variables are assumed to follow autoregressive processes of order one in logs, AR(1), except the monetary policy shock and the capital destruction shock, which are i.i.d. processes in levels. The foreign variables are assumed to be determined by the external block of the structural VAR model from Section 3.[20]

5 Analysis with the DSGE Model

We now use the model from the previous section to analyze the impact of commodity price shocks in Chile. In particular, we highlight how the effects of those shocks on the main macroeconomic variables are amplified through the endogenous response of investment in the commodity sector and discuss the role of the persistence of those shocks. We also compute historical decompositions of investment and real GDP growth in terms of the different structural shocks of the model to examine the importance of commodity price shocks relative to other types of shocks for observed macroeconomic dynamics. Finally, we conduct some counterfactual policy exercises to analyze the effectiveness of alternative macroeconomic policy frameworks in mitigating the impact of commodity price shocks in a commodity-exporting economy such as Chile.

[20] As the real oil price does not enter the foreign VAR, it is assumed to follow an AR(1) process.

5.1 Parameterization

The model is parameterized following Fornero and Kirchner (2014), who combine calibration and Bayesian estimation of the structural parameters of the model. In addition, the parameters of the foreign SVAR are assigned using the estimation results from the previous section where we take the persistent case as a benchmark (see Section 3.4). Tables 3 and 4 summarize our choice of parameters, where we use the posterior mode estimates from Fornero and Kirchner (2014). For space reasons we only discuss the key parameters related to the commodity sector and refer to Fornero and Kirchner (2014) for a more detailed discussion.

Among the calibrated parameters, the share of government ownership in the commodity sector (χ) is set to 0.31, consistent with the average share of production of the state-owned copper mining company (Codelco) relative to total copper production since 2001. The tax rate on foreign profits (τ_S) is set to 0.35, which is the flat rate tax on foreign companies in Chile. The fixed costs in production parameter (κ_S) is chosen to match a labor share in total value added of about 14%, according to recent data. The elasticity of production with respect to capital ($1-\eta_S$) is set to 0.31, in order to obtain a share of physical capital to quarterly output in the commodity sector of 12. This number is in line with available data on the value of financial assets over total sales of Codelco. The quarterly depreciation rate of capital in the commodity sector (δ) is approximately 3%, chosen to match an average investment-to-output ratio in Chile's mining sector of about 4% from 2001-2012. The home bias in investment in the commodity sector is set to 0.59, consistent with available data on the share of construction in total investment in the mining sector. The horizon of time to build is set to $n = 6$ quarters, consistent with the average duration of investment projects by private mining companies according to data from a regular survey of the Chilean Corporation of Capital Goods (CBC). Following Kydland and Prescott (1982), the financing profile of projects (ϕ_j) is set to $1/n$.

In addition, the estimated parameters in Table 4 reflect a relatively high degree of investment adjustment costs in the commodity sector relative to other sectors, in addition to the time to build structure in this sector. Hence, investment in the commodity sector tends to respond relatively sluggishly to commodity price shocks and other types of shocks. The estimates also indicate some degree of complementarity between domestic and foreign inputs for investment in that sector, which tends to enhance the spillover effects from the commodity sector to the rest of the economy. We now proceed to analyze the effects of different types of commodity price shocks on the main macroeconomic variables.

5.2 Effects of persistent and transitory commodity price shocks

Figure 9 shows the impulse responses of selected variables to a commodity price shocks of size 50% as in the SVARs from Section 3. We distinguish two types of persistences of the shock: a

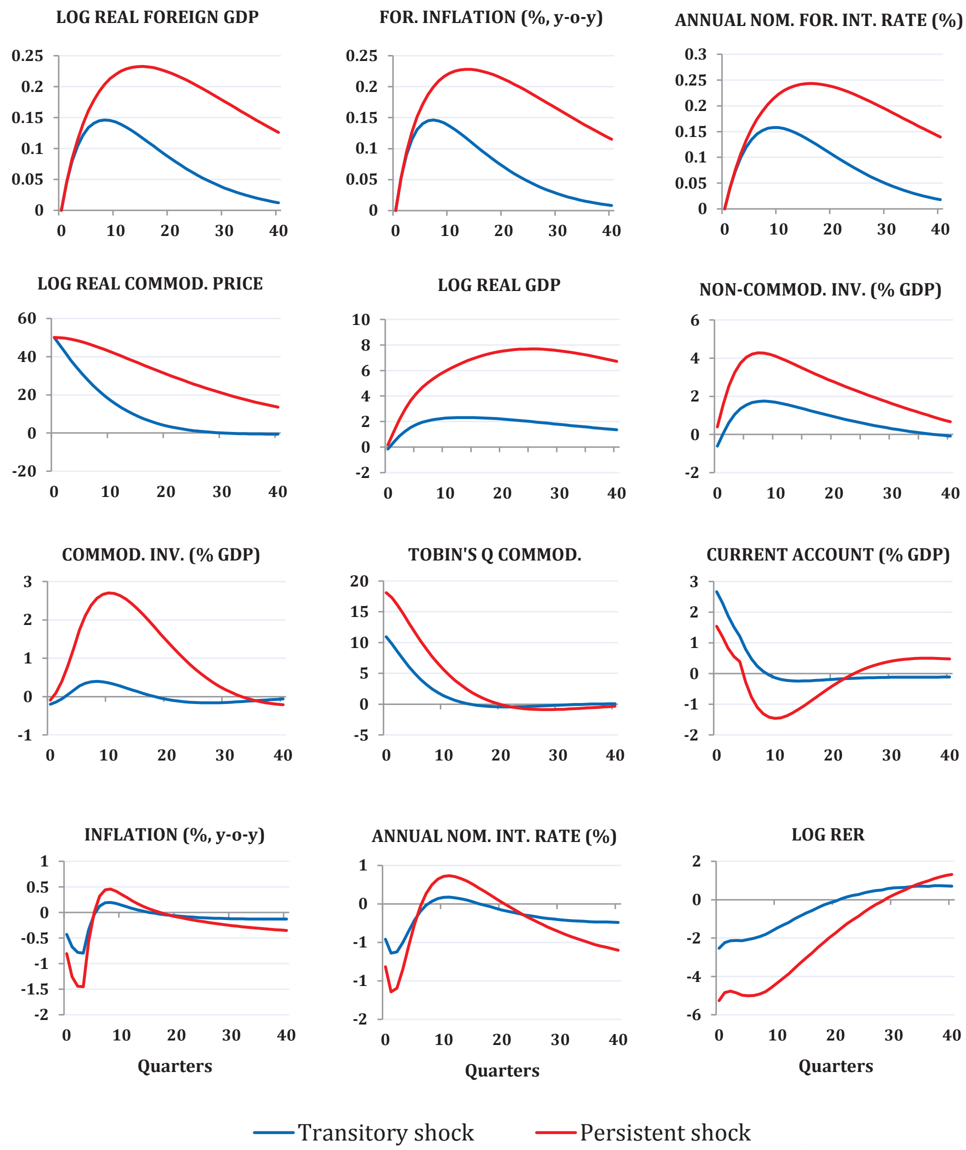
Table 3: Calibrated parameters (Fornero and Kirchner, 2014).

Parameter	Value	Description
Steady state values		
g_Y	2.5%	Balanced growth path (net rate, annual basis)
$\bar{\pi}$	3%	St. state inflation target (net rate, annual basis)
$\bar{\pi}^*$	3%	St. state foreign inflation rate (net rate, annual basis)
$\bar{r}^*$	4.5%	St. state foreign interest rate (net rate, annual basis)
$\bar{\Theta}$	1.3%	St. state country premium (net rate, annual basis)
$\bar{s}_B$	0%	St. state structural fiscal balance target
$\bar{g}$	0.055	St. state government consumption (stationary level)
$\bar{a}_S$	0.081	St. state productivity in commodity sector
$\bar{y}^*$	1	St. state foreign demand (stationary level)
$\bar{p}_O$	1	St. state real international price of oil (dom. currency)
$\bar{p}_S$	1	St. state real international commodity price (dom. currency)
Non-Ricardian households		
λ	0.5	Share of non-Ricardian households
Ricardian households		
β	0.999	Subjective discount factor (quarterly basis)
σ_L	1	Inverse Frisch elasticity of labor supply
ψ	15.622	Disutility of labor parameter
α_a	0.19	Share of food consumption in total consumption
α_o	0.03	Share of oil consumption in total consumption
α_c	0.78	Share of core consumption in total consumption
γ_c	0.74	Share of domestic goods in core and food consumption
Non-commodity sectors		
δ	0.01	Depreciation rate (quarterly basis), sector H
α_H	0.99	Share of non-oil inputs in production, sector H
η_H	0.66	Share of labor in Cobb-Douglas value added, sector H
ϵ_L	11	Elast. of substitution among labor varieties, sector H
ϵ_H	11	Elast. of substitution among domestic varieties, sector H
ϵ_F	11	Elast. of substitution among imported varieties, sector F
γ_I	0.64	Share of domestic goods in investment, sector H
Commodity sector		
χ	0.31	Government ownership of assets, sector S
τ_S	0.35	Tax rate on foreign profits, sector S
κ_S	0.009	Fixed cost of production, sector S
$1-\eta_S$	0.314	Capital elasticity of production, sector S
δ_S	0.032	Depreciation rate (quarterly basis), sector S
γ_{IS}	0.59	Share of domestic goods in investment, sector S
n	6	Periods of time to build (quarters), sector S
ϕ_j	0.167	Financing profile of investment projects, sector S
Foreign economy		
ζ^*	0.101	Import share of foreign economy
Exogenous processes		
$\rho_{p_O^*}$	0.893	AR(1) coef., international oil price shock (ML)
$\sigma_{p_O^*}$	0.1393	Innov. s.d., international oil price shock (ML)
σ_{z_k}	0.0044	Innov. s.d., capital destruction shock

Table 4: Estimated parameters (Fornero and Kirchner, 2014).

Parameter	Description	Prior			Posterior				
		dist.	mean	s.d.	mean	mode	s.d.	5%	95%
Households									
h	Habit formation	B	0.7	0.1	0.893	0.862	0.0284	0.8468	0.9389
ω_C	EoS oil and core cons.	IG	1	Inf	0.389	0.385	0.1091	0.2237	0.5512
η_C	EoS H and F core cons.	IG	1	Inf	1.477	1.575	0.7059	0.3414	2.4797
Wages									
ϕ_L	Calvo prob. wages	B	0.75	0.1	0.966	0.975	0.0128	0.9471	0.9874
ξ_L	Indexation wages	B	0.5	0.2	0.785	0.710	0.1191	0.6102	0.9672
Prices									
ϕ_{H_D}	Calvo prob. dom. prices	B	0.75	0.1	0.630	0.626	0.0595	0.5355	0.7272
ϕ_{H_F}	Calvo prob. exp. prices	B	0.75	0.1	0.901	0.890	0.0451	0.8381	0.9689
ϕ_F	Calvo prob. imp. prices	B	0.75	0.1	0.507	0.504	0.0501	0.4236	0.5882
ξ_{H_D}	Indexation dom. prices	B	0.5	0.2	0.260	0.268	0.1406	0.0401	0.4654
ξ_{H_F}	Indexation exp. prices	B	0.5	0.2	0.430	0.346	0.1919	0.1124	0.7379
ξ_F	Indexation imp. prices	B	0.5	0.2	0.414	0.399	0.1475	0.1701	0.6568
Production									
ω_H	EoS oil, other inputs	IG	1	Inf	0.393	0.460	0.1264	0.2124	0.5648
Investment									
η_I	EoS H and F inv., non-S	IG	1	Inf	1.345	0.497	0.9417	0.2511	2.8218
η_{I_S}	EoS H and F inv., S	IG	1	Inf	0.868	0.695	0.6367	0.2340	1.6080
μ_S	Inv. adjustm. cost, non-S	G	2	0.5	1.844	1.533	0.4220	1.1542	2.5062
μ_{I_S}	Inv. adjustm. cost, S	G	3	0.5	2.864	3.078	0.5169	2.0249	3.7079
For. economy									
η_F	Price elast. for. demand	IG	1	Inf	0.273	0.239	0.0549	0.1891	0.3559
ϱ	Country prem. debt elast.	IG	0.01	Inf	0.008	0.009	0.0016	0.0051	0.0104
Mon. policy									
ψ_r	Interest rate smoothing	B	0.75	0.1	0.818	0.828	0.0233	0.7797	0.8556
ψ_Y	Int. feedb. GDP growth	N	0.125	0.05	0.101	0.116	0.0439	0.0302	0.1735
ψ_π	Int. feedb. inflation	N	1.5	0.1	1.700	1.733	0.0793	1.5702	1.8314
ψ_{π_Z}	Feedb. weight core infl.	B	0.5	0.2	0.740	0.656	0.1282	0.5456	0.9442
AR(1) coef.									
ρ_{a_H}	Neutral technology shock	B	0.75	0.1	0.783	0.785	0.0865	0.6452	0.9243
ρ_{ζ_T}	Productivity growth shock	B	0.75	0.1	0.768	0.718	0.0601	0.6755	0.8680
ρ_{ζ_C}	Preference shock	B	0.75	0.1	0.757	0.715	0.0732	0.6423	0.8764
ρ_{ζ_I}	Inv.-specif. techn. shock	B	0.75	0.1	0.619	0.627	0.0724	0.5034	0.7404
ρ_{ζ_G}	Fiscal policy shock	B	0.75	0.1	0.870	0.878	0.0390	0.8084	0.9338
ρ_{ζ_Θ}	Country premium shock	B	0.75	0.1	0.955	0.958	0.0198	0.9269	0.9854
ρ_{ζ_A}	Food price shock	B	0.75	0.1	0.781	0.0825	0.806	0.6566	0.9175
ρ_{a_S}	Comm.-specif. techn. sh.	B	0.75	0.1	0.959	0.960	0.0173	0.9324	0.9855
Innov. s.d.									
u_{a_H}	Neutral technology shock	IG	0.005	Inf	0.008	0.008	0.0016	0.0051	0.0103
u_{ζ_T}	Productivity growth shock	IG	0.005	Inf	0.011	0.012	0.0024	0.0070	0.0149
u_{ζ_C}	Preference shock	IG	0.005	Inf	0.047	0.036	0.0131	0.0271	0.0668
u_{ζ_I}	Inv.-specif. techn. shock	IG	0.005	Inf	0.047	0.040	0.0115	0.0292	0.0649
u_{ζ_G}	Fiscal policy shock	IG	0.005	Inf	0.038	0.036	0.0046	0.0304	0.0452
u_{ζ_m}	Monetary policy shock	IG	0.005	Inf	0.002	0.002	0.0002	0.0014	0.0020
u_{ζ_Θ}	Country premium shock	IG	0.005	Inf	0.001	0.001	0.0001	0.0008	0.0012
u_{ζ_A}	Food price shock	IG	0.005	Inf	0.014	0.013	0.0033	0.0082	0.0189
u_{a_S}	Comm.-specif. techn. sh.	IG	0.005	Inf	0.034	0.034	0.0035	0.0287	0.0401

Figure 9: Impulse responses to commodity price shocks (50%) with different persistences.



more persistent case where the foreign block is taken from the estimated VAR model for Chile from Section 3.4 (where the real copper price is not detrended) and a less persistent case where the persistence of the copper price in the foreign VAR is adjusted so that the half-life of the shock matches the half-life of the real copper price in the VAR where all variables including the copper price are detrended using quadratic trends.

The results show that in both cases the shock generates an expansion of real GDP and investment in all sectors, a real exchange rate appreciation, lower inflation in the short run and higher inflation after some periods, with the associated interest rate response. However, the expansion of investment and GDP is significantly stronger when the shock is persistent. In this case, there is a strong incentive to invest in the commodity sector, as indicated by the persistent rise in the sectoral Tobin's q, such that commodity investment increases by more than 2% above its steady state level with positive spillover effects on investment in other sector and on real GDP. However, when the shock is transitory, the relatively short-lived increase in the expected Tobin's q is not sufficient to generate a significant response of investment in the commodity sector, since it would take too long relative to the duration of the shock (and it would be too costly) to install the additional productive capacity due to the time to build frictions. Another difference between the two cases is that the transitory shock is associated with a current account surplus, while the persistent shock is followed by a relatively sizable current account deficit already after a few quarters. As shown in Fornero and Kirchner (2014), these differences in the response of the current account balance are mainly due to the endogenous response of investment in the commodity sector and its effects on the economy's net international investment position.

Overall, the predictions of the model are therefore in line with the empirical results from Section 3. However, an advantage of using a DSGE model is that we can decompose the dynamics of macroeconomic variables such as investment and GDP growth according to the different structural shocks that drive economic dynamics, as we do next.

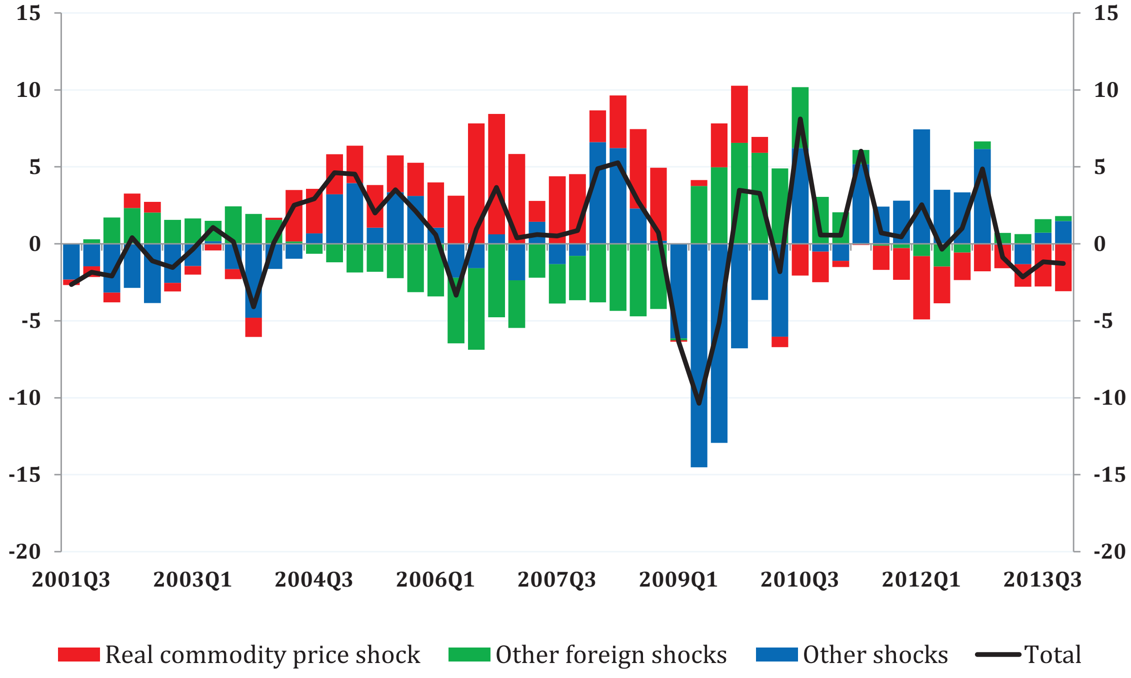
5.3 Historical decomposition of investment and GDP growth

Figure 10 shows the historical decomposition of real investment growth in Chile over the period 2001Q3-2013Q4, where the contributions of commodity price shocks and other foreign shocks are separated from the contributions of other shocks.[21] According to the results, most of the above-average growth of investment in Chile between 2004 and 2010 is explained by commodity price shocks while other foreign shocks (e.g. relatively high foreign interest rates until 2008) had a negative influence on investment growth until the global financial crisis and a positive influence afterwards (e.g. due to better external financing conditions for emerging economies). However, the investment boom seems to have come to an end after 2012 mainly due to lower commodity prices. Hence, these results suggest that commodity price fluctuations have been a significant driving force of the investment cycle in Chile over the last decade, in line with the empirical findings presented in the previous section and the impulse responses of Figure 9.

In terms of real GDP growth, Figure 11 shows that commodity price shocks have been an equally important determinant. In fact, the effects of the commodity price surge before the financial crisis and the quick rebound of commodity prices after the crisis have counteracted

[21] To compute the historical decompositions, we used as observed variables real GDP (Y_t), real copper output as a proxy for commodity production ($Y_{S,t}$), private non-durable consumption (C_t), total investment ($I_t + I_{S,t}$), government consumption (G_t), CPI inflation ($\pi_{C,t}$), the inflation rate of a price index excluding food and energy prices as a proxy for core inflation ($\pi_{Z,t}$), the short-term central bank target rate (r_t), the real exchange rate (rer_t), the current account balance-to-GDP ratio (CAY_t), the foreign variables from the VAR for Chile ($Y_{F,t}$, π_t^*, r_t^* and $P_{S,t}^*/P_t^*$), the J.P. Morgan Emerging Market Bond Index (EMBI) spread for Chile as a proxy for the country premium (Θ_t) and the real price of West Texas Intermediate crude oil ($P_{O,t}^*/P_t^*$). Real GDP, private consumption, investment, and government consumption are measured as quarterly growth rates. The inflation and interest rates are in quarterly terms. Finally, copper output, the real exchange rate and the real oil price are transformed into natural logarithms. Copper output and foreign output are detrended using linear trends while the remaining variables are demeaned using their average sample values.

Figure 10: Historical decomposition of real investm. growth in Chile (%, q-o-q), 2001Q3-2013Q4.



Notes: The zero line means that the investment growth rate equals the sample average.

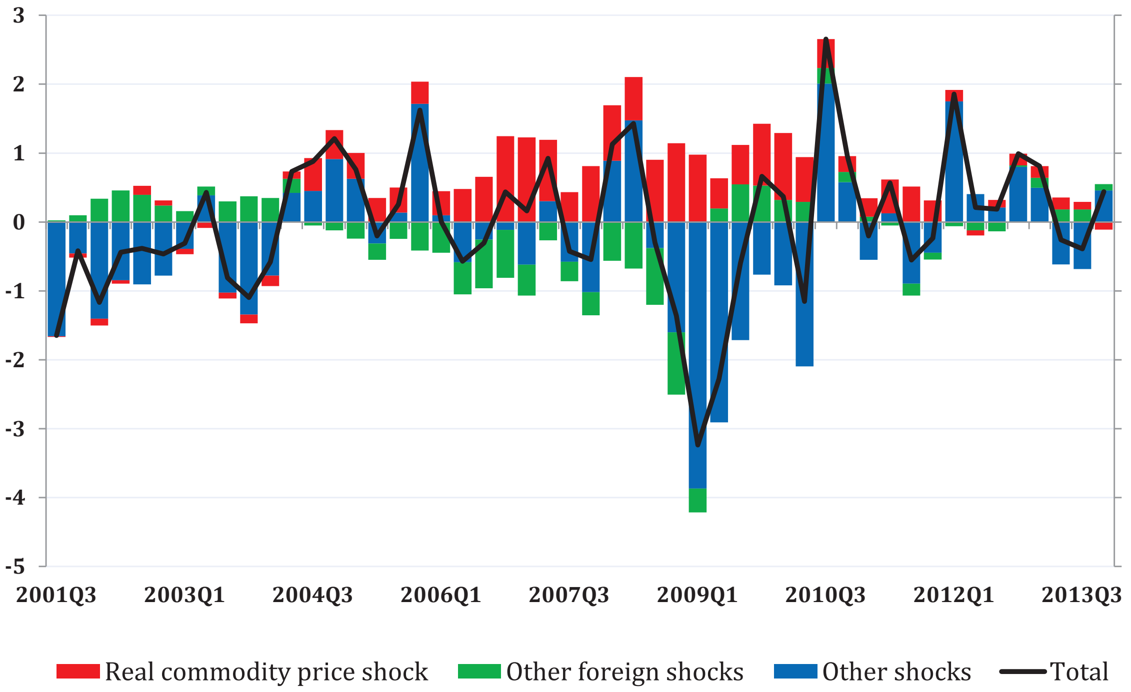
the impact of the recession and accelerated the recovery of the Chilean economy. However, the effects of the commodity price boom on GDP growth have by now diminished due to the end of the investment cycle. Overall, our model therefore points towards an important role of commodity price fluctuations for business cycles in Chile and similar commodity-exporting economies. Given these findings, we now analyze some policy implications of our model.

5.4 Counterfactual policy analysis

What are the implications of alternative types of monetary and fiscal policies for the effects of commodity price shocks? For instance, on the monetary side it is sometimes argued that a (strong) exchange rate appreciation may be responsible for current account imbalances by reducing the demand for exports and stimulating the demand for imports, which may be a motivation for monetary authorities in commodity-exporting countries to try to limit exchange rate fluctuations. On the fiscal side, a rules-based fiscal framework seems important in order to reduce spending pressures due to higher commodity income for the government, and it is therefore interesting to analyze the consequences of alternative fiscal rules.

Thus, in Figure 12 we compare the responses to a persistent commodity price shock under the benchmark set of macroeconomic policies (i.e. a flexible inflation targeting regime with a floating exchange rate, and a structural balance fiscal rule) with the case where the monetary authority adjusts the interest rate in order to stabilize the real exchange rate (i.e. $rer_t = \overline{rer}$

Figure 11: Historical decomposition of real GDP growth in Chile (%, q-o-q), 2001Q3-2013Q4.



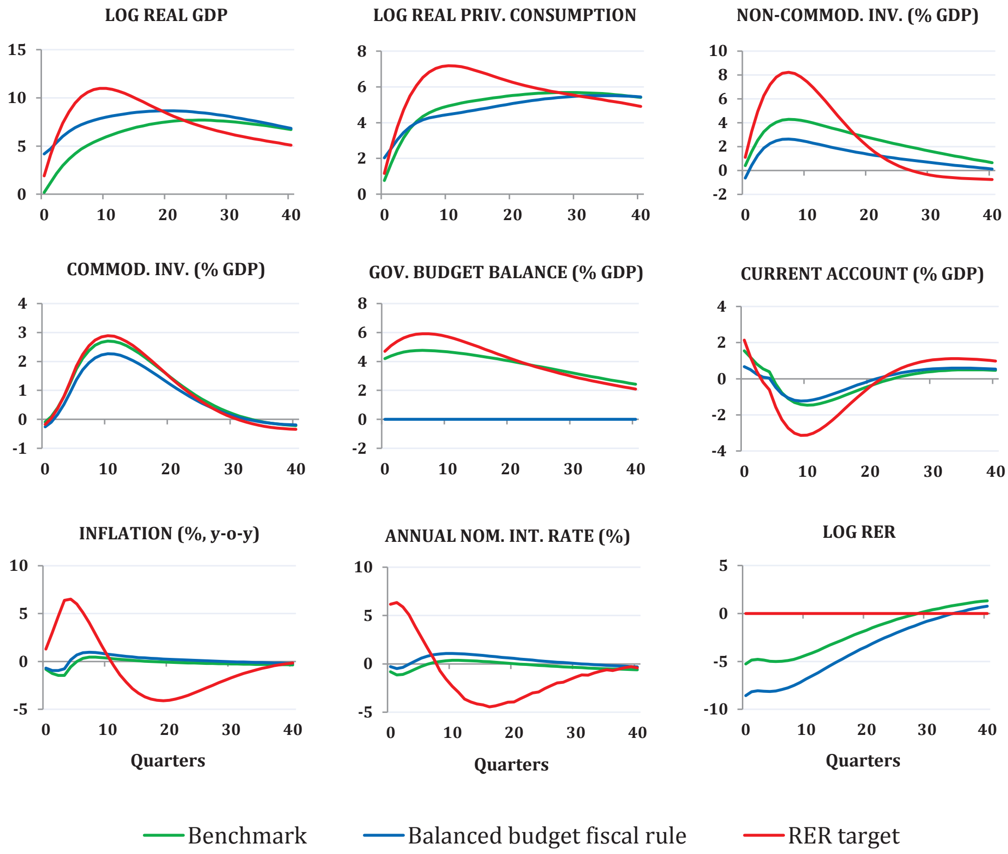
Notes: The zero line means that the GDP growth rate equals the sample average.

for all t) and the case where the government adheres to a balanced budget rule.[22] The results show that under the real exchange rate target, the central bank needs to generate a reduction in the real interest rate in order to keep the real exchange rate unchanged, but this generates higher inflation that would imply an additional real appreciation and the central bank therefore raises the nominal interest rate initially before cutting it. However, the negative real interest rate response generates a larger expansion of the economy and a larger peak current account deficit than under an inflation targeting policy with a flexible exchange rate.

On the fiscal side, in comparison to a structural balance rule, a balanced budget policy implies a larger expansion of real GDP, higher inflation, a stronger interest rate response, a larger real appreciation and, initially, a somewhat larger expansion of private consumption due to the response of consumption by non-Ricardian households to higher labor income. However, consumption by Ricardian households and investment is crowded out, which explains why the current account response hardly changes although government savings do not change. Interestingly, while non-commodity GDP and investment are quite sensitive to the monetary and fiscal policy responses to the shock, the responses of real GDP and investment in the commodity sector are much less sensitive to the different policy responses. The reason is that commodity investment and production are primarily driven by of the international commodity

[22]We assume that government consumption is the fiscal instrument that adjusts to keep the government balance unchanged.

Figure 12: Impulse responses to a persistent commodity price shock under different policies.



price, while the alternative policies–through different real interest rate and real exchange rate responses–mainly affect the economy-wide stochastic discount factor and the conversion of the international commodity price into domestic currency terms, but those indirect effects are less relevant for investment decisions in this sector. Therefore, these exercises show that while different monetary and fiscal policy reactions have in general important implications for the response of the economy to commodity price shocks, they do not majorly affect investment decisions in the commodity sector according to our model.

6 Conclusions

In this paper we have analyzed the impact of terms of trade shocks (i.e. commodity price shocks) in commodity-exporting economies. In particular, we have examined common patterns of macroeconomic responses in major commodity exporters based on SVAR analysis and we have complemented this analysis using a DSGE model with a commodity sector for Chile.

The main results are as follows. First, depending on the share of commodity exports, a commodity price increase generates expansionary effects in the economy, in line with previous studies. Part of this expansion is due to positive and delayed effects on investment in commodity sectors that may cause spillovers to non-commodity investment. Second, the persistence of commodity price shocks is crucial to understand those dynamics: when the shock is persistent, the response of investment, real GDP and other quantities are magnified and might lead to a current account deficit. Third, according to historical decompositions of fundamental shocks for Chile, the copper price boom after the mid-2000s was a key driver in real investment and real GDP growth. Finally, our structural DSGE model provides additional policy insights. One main finding is that the implications of commodity price fluctuations for monetary policy are not trivial since they depend on the persistence of shocks, their impact on private consumption and investment, the fiscal policy response, real exchange rate pass-through to prices, and so on. Moreover, the policy exercises that we have conducted show that changes in monetary and fiscal policy rules have small impacts on investment decisions in the commodity sector, which are mainly driven by sectorial productivity developments and commodity prices.

Our results thus complement previous studies that have analyzed the macroeconomic impacts of commodity price fluctuations for business cycles and inflation dynamics in commodity exporters (see e.g. Medina, Munro, and Soto, 2008; Desormeaux, García, and Soto, 2010), the role of sectoral investment (see e.g. Knop and Vespignani, 2014) and the role of macroeconomic policy (see e.g. Medina and Soto, 2007b, 2014; Kumhof and Laxton, 2010; Frankel, 2011). From a general perspective, our findings reaffirm the conclusions from previous studies that flexible inflation targeting frameworks, flexible exchange rates and fiscal rules are essential to limit the macroeconomic impact of commodity price volatility in commodity-exporting countries.

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A Data Appendix

Since we study the particular case of mining investment, for Chile we use the real copper price as a proxy for a commodity price shock. For the remaining countries (Australia, Canada, New Zealand, Peru and South Africa) we use the real IMF metal price index. Alternative estimations were made for every country using different commodity price indexes (see Table 5) and the results were relatively robust. Commodity investment is measured as nominal gross fixed capital formation in mining as a percentage of nominal GDP. Tables 5 and 6 contain a detailed summary of the different variables and data sources for each country.

Following conventional data adjustments, a number of additional transformations were made. For missing observations of commodity/mining investment, due to a change in the periodicity of the data, we used standard linear interpolations to transform annual into quarterly data. Real GDP, real exchange rates and commodity price indexes were transformed into natural logarithms. We used the US CPI to deflate commodity price indexes that were available in nominal US dollar terms from their sources. Real GDP, investment and current account balances were seasonally adjusted using the Census X-12 procedure when they were not available in seasonally adjusted form from the original source.

Table 5: Data sources and transformations for each country, foreign blocks.

Series	Country	Proxy	Source
Log real foreign GDP (SA)	All	World real GDP index (SA)	CB of Chile
Foreign inflation (annual % change)	All	Annual % change of US CPI	FRED
Foreign interest rate	All	US federal funds rate	FRED
Log real commodity price index (deflated with US CPI, 2005 = 100) [1]	Australia	**IMF metal price index**	IMF
		RBA commodity price index	RBA
		RBA bulk price index	RBA
	Canada	**IMF metal price index**	IMF
		Local metal price index	Bank of Canada
		Local commodity price index	Bank of Canada
	Chile	**Real copper price**	Cochilco
		IMF metal price index	IMF
	N. Zealand	**IMF metal price index**	IMF
		Local commodity price index	ANZ Bank NZ
	Peru	**IMF metal price index**	IMF
		Local commodity price index	CRB of Peru
		Real copper price	Cochilco
	S. Africa	**IMF metal price index**	IMF
		Real gold price	IFS

Notes: [1] Bold letters indicate the indexes used in the estimations.

Table 6: Data sources and transformations for each country, domestic blocks.

Series	Country	Source
Log real GDP (SA)	Australia	Australian Bureau of Statistics
	Canada	Statistics Canada
	Chile	Central Bank of Chile
	N. Zealand	Reserve Bank of New Zealand
	Peru	IFS
	S. Africa	South African Reserve Bank
Nom. commodity investment (% of nom. GDP) [1]	Australia [2]	Australian Bureau of Statistics
	Canada [2]	UN STATS
	Chile [2]	Central Bank of Chile
	N. Zealand [2]	Reserve Bank of New Zealand
	Peru [2]	UN STATS
	S. Africa	South African Reserve Bank
Inflation (annual % change of local CPI)	Australia	Reserve Bank of Australia
	Canada	OECD
	Chile	Central Bank of Chile
	N. Zealand	Reserve Bank of New Zealand
	Peru	Central Reserve Bank of Peru
	S. Africa	OECD
Monetary policy rate	Australia	Reserve Bank of Australia
	Canada	IFS
	Chile	Central Bank of Chile
	N. Zealand [3]	Reserve Bank of New Zealand
	Peru [4]	Central Reserve Bank of Peru
	S. Africa	OECD
Log real exch. rate (increase means depreciation)	Australia [5]	Reserve Bank of Australia
	Canada	IFS
	Chile	Central Bank of Chile
	N. Zealand [6]	Reserve Bank of New Zealand
	Peru	Central Reserve Bank of Peru
	S. Africa	South African Reserve Bank
Current account (% of nominal GDP)	Australia	Reserve Bank of Australia
	Canada	Statistics Canada
	Chile	Central Bank of Chile
	N. Zealand	Reserve Bank of New Zealand
	Peru	Central Reserve Bank of Peru
	S. Africa	South African Reserve Bank

Notes: [1] Measured as nominal gross fixed capital formation in mining, where nominal non-mining investment was computed by subtracting nominal mining investment from nominal total investment; [2] Linear interpolation of annual data; [3] Interbank rate from 1991Q1-1999Q1; [4] Interbank rate from 1996Q1-2000Q4 and overnight rate from 2001Q1-2003Q4; [5] Inverse of trade-weighted index, May 1970 = 100; [6] Inverse of trade-weighted index, long-run average = 100.