

Monetary Policy for Commodity Booms and Busts

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Abstract

Macroeconomic volatility in commodity-exporting economies is closely tied to fluctuations in international commodity prices. Commodity booms improve exporters' terms of trade and loosen their borrowing conditions, while busts lead to the reverse. This paper studies optimal monetary policy for commodity exporters in a small open economy framework that includes a key role for financial conditions. We incorporate the interaction between the commodity and financial cycles via a working capital constraint for commodity producers, which loosens as commodity prices increase. A rise in global commodity prices causes an inefficient reallocation toward the commodity sector, which expands and increases its demand for inputs. The real exchange rate appreciates, but because domestic firms do not internalize that the appreciation reduces the scale of the reallocation, they do not raise prices enough. An inefficient boom takes place, with inflation rising and output increasing relative to its welfare-maximizing level. Returning inflation to target is not sufficient to close the output gap, leaving the policymaker facing a stabilization trade-off. The optimal policy lets the exchange rate appreciate and raises interest rates, with a larger rate rise required the greater the loosening in borrowing conditions. The paper compares alternative

policy rules and discusses a key practical challenge for emerging and developing economies: how to transition to a stable path from initial conditions of high and persistent inflation.

I. Introduction

How should monetary policy in commodity-exporting economies react to booms and busts in commodity markets? Three broad observations have revived interest in this perennial question. First, the contribution of commodity price shocks to macroeconomic volatility has been growing over the past few decades.¹ Second, there is a strong relation between the commodity-price cycle and borrowing conditions in commodity-exporting economies: when commodity prices increase, borrowing terms in commodity-exporting economies improve.² Third, there has been an increase in the correlation across prices of different commodities and between commodity prices and other asset prices over the past two decades. This has coincided with a sharp increase in the number of positions in financial contracts in which commodities feature as the underlying asset, and has triggered a debate around the financialization of commodity markets.³ Collectively, these broad observations paint a picture of business cycles in commodity-exporting economies that appear increasingly driven by global commodity price shocks.

Motivated by this evidence, we study the optimal monetary policy response to commodity price fluctuations in a small open economy where financial conditions play an important role.⁴ Our economy is a net exporter of commodities and takes prices on world markets as given. A competitive commodity-exporting sector uses domestic goods as an intermediate input, so that commodity price variation impacts resource allocation across sectors in the economy. We link domestic financial conditions to the commodity cycle by introducing a borrowing constraint for commodity producers that loosens when commodity prices rise. This financial channel amplifies the impact of commodity price movements and increases their importance for monetary policy.

In the model, a positive commodity price shock leads to an inefficient boom that prevents policy from achieving full stabilization.

Specifically, a rise in commodity prices causes the commodity sector to expand, increasing its demand for domestic goods as inputs in production. The expansion is inefficient, as households do not benefit from the extra production in the commodity sector. The inefficiency is amplified by the relaxation of borrowing terms owing to higher commodity prices. Because intermediate inputs are domestically produced, higher input demand leads to an increase in the relative demand for domestic relative to foreign goods, putting upward pressure on domestic inflation and causing a real exchange rate appreciation. A stronger exchange rate, in turn, lowers household demand for domestic consumption relative to foreign (imported) consumption. Crucially, it also mitigates the initial inefficient reallocation toward the commodity sector. Domestic firms do not internalize this latter effect of the appreciation, so do not increase their prices in line with social benefits of doing so, instead increasing production by too much. Sticky prices exacerbate this effect. Importantly, there is no divine coincidence. Output rises above the efficient (welfare-maximizing) level, creating a stabilization trade-off: returning inflation to target is not enough to close the output gap. The optimal monetary policy response lets the exchange rate appreciate and raises interest rates, with the magnitude of the rate rise increasing in the strength of the financial channel.⁵

In addition to characterizing optimal monetary policy, we study the welfare implications of different simple monetary policy rules in the presence of these commodity cycles. From a welfare perspective, both a consumer price inflation (CPI) target and domestic inflation targeting rule imply dynamics closer to the optimal policy than an exchange rate peg, which performs poorly. The two inflation targets give rise to quantitatively similar welfare losses. While there has been much discussion in the literature and in policy circles over the best price index to target, our results suggest that the issue is of secondary importance relative to the gains obtained by achieving low and stable inflation for either price index.

We also briefly discuss the roles of exchange-rate management and fiscal policy in responding to commodity price shocks. We contrast the relatively poor performance of the exchange rate peg in our

model with the exchange-rate market interventions carried out by some central banks in practice. We provide some thoughts on what might explain these policy choices, even for countries that have officially adopted inflation targeting. On fiscal policy, for most of the paper we follow the literature by assuming that fiscal policy is unable to respond to the shocks arising in our model. (Or alternatively, that our model speaks to the part of the cycle that cannot be stabilized by fiscal policy). However, we do highlight that our model would suggest a possible stabilization role for fiscal policy in varying taxation.⁶

Finally we turn to a key practical issue facing monetary policymakers in emerging and developing-economy commodity exporters. Our model examines the appropriate policy response to commodity-price shocks starting from benign conditions of low inflation, passive fiscal policy and no in-built inflation inertia. But for emerging and developing economies with a history of high inflation those favorable conditions are less likely to hold. We discuss possible reasons why, before exploring the costs and benefits of different policy strategies commodity-exporting emerging economies have used to control inflation. To do so, we draw on the varied experiences of a selection of Latin American commodity exporters in the 1980s and 1990s.

Relation to the literature. Our paper is related to various strands of research. First, we stand in the tradition of studying monetary policy in open economies, building on the seminal work of Galí and Monacelli (2005). Other important contributions to this line of research include, but are not limited to, Benigno and Benigno (2003), Corsetti and Pesenti (2001, 2005), Faia and Monacelli (2008) De Paoli (2009) and Monacelli (2013).⁷ Corsetti, Dedola and Leduc (2010) provide a survey on some of the key studies. Second, we build on the literature that has examined the contribution of commodity price shocks to macroeconomic outcomes using structural models. For example, Shousha (2016), Fernández, González and Rodríguez (2018), Kohn et al. (2018) and Drechsel and Tenreyro (2018) all highlight the quantitative importance of commodity price shocks for emerging market business cycles. Third, the motivating facts we provide on financialization echoes the discussion in the literature that has studied this aspect of commodity markets in depth. Cheng and Xiong (2014) systematically review research findings

in this area. We make reference to other relevant work in the main text. Fourth, there are a few existing papers that have taken an approach similar to the one in this paper, that is, focus on monetary policy explicitly for commodity exporters.⁸ These studies include Romero (2008), Catao and Chang (2013), Hevia and Nicolini (2013), Bergholt (2014), Ferrero and Seneca (2018) and Wills (2019). The most closely related paper is Ferrero and Seneca (2018). We draw extensively on their modeling approach but deviate in four respects. First, we introduce a link between the commodity cycle and financial conditions. This, as we argue, is a realistic feature of the data that exacerbates the impact of commodity shocks and the inefficiencies they induce. Second, our analysis allows shocks to simultaneously move commodity prices and world output: this correlated disturbance can more realistically mimic the response of macroeconomic variables in the data. Third, we develop a variant of the model with incomplete asset markets, relaxing the perfect risk-sharing assumption that can lead to some of the less realistic model responses. Fourth, we embed our theoretical analysis into a broader discussion regarding practical implementation challenges.

Structure of the paper. Section II presents our three motivating observations: the increasing contribution of commodity price shocks to macroeconomic fluctuations, the link between commodity prices and borrowing conditions, and the discussion around the financialization of commodity markets. Section III presents the model. Section IV characterizes the equilibrium dynamics of the model and studies the conduct of monetary policy. Section V goes beyond the model framework and discusses practical policy considerations for emerging and developing economies. Section VI concludes.

II. Causes and Consequences of Commodity Booms and Busts

This section discusses three broad observations that motivate our study of optimal monetary policy in commodity-exporting economies. Section II.i discusses recent findings on the increasing quantitative importance of commodity price shocks for macroeconomic fluctuations in commodity-exporting economies. Section II.ii reviews the role of commodity prices in affecting borrowing conditions in these economies. Section II.iii summarizes several empirical patterns behind the debate around the financialization of commodity markets.

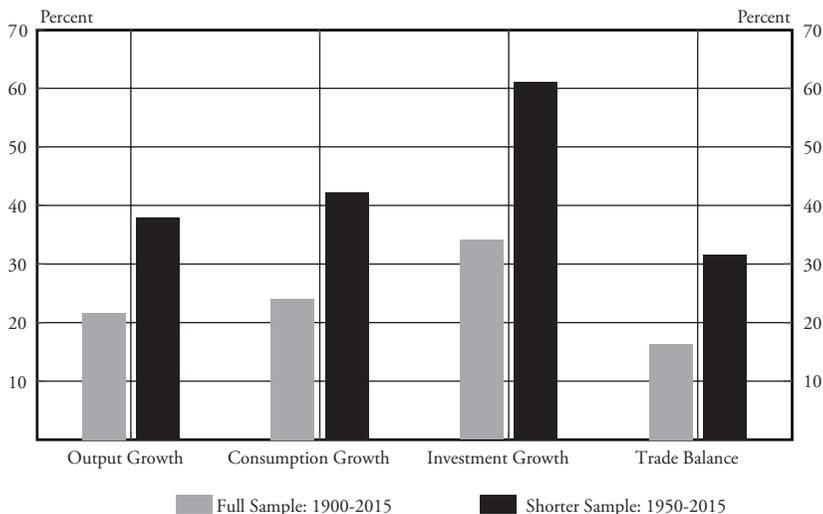
II.i. The Contribution of Commodity Price Shocks to Business Cycles

What is the quantitative role of commodity price shocks for macroeconomic fluctuations in economies that export commodities? We describe results from two different methods—structural macroeconomic models and structural vector autoregressions (SVARs)—and point out that both of these approaches have found an increasing importance of commodity price shocks for business cycles.

Evidence from structural macroeconomic models. A vast literature in international macroeconomics has applied structural models to decompose the fluctuations in macroeconomic aggregates into different underlying drivers.⁹ Chart 1 presents a result from Drechsel and Tenreyro (2018). This paper estimates a two-sector, small open economy model on annual data from Argentina spanning a period of over a century, and decomposes the variation in macroeconomic variables into different structural shocks. The chart reports the share in different observables that the estimated model attributes to commodity price shocks. A sizable fraction of output (21.67%), consumption (24.02%) and investment growth (34.11%), as well as the trade balance (16.33%) can be explained by commodity price shocks over the full sample 1900–2015 (as shown by the gray bars). Importantly, this contribution is much larger in a sample that only includes later decades (black bars). Post-1950, commodity price shocks explain 37.97% of the variance in output growth, 42.28% in consumption growth, and 61.11% and 31.56% in investment growth and the trade balance, respectively. The analysis in Drechsel and Tenreyro (2018) indicates that through the lens of an estimated structural model, the contribution of commodity price shocks to business cycles in Argentina—an economy in which the commodity net exports accounts for almost 9% of GDP—has been growing markedly over recent decades.

Evidence from SVARs and common patterns. Various studies have applied SVARs rather than fully specified structural models to quantify the extent to which macroeconomic fluctuations can be attributed to commodity price shocks, or more broadly, to shocks to the terms of trade. As highlighted by Schmitt-Grohé and Uribe

Chart 1
Contribution of Commodity Price Shocks to Macroeconomic Fluctuations in Argentina



Notes: Forecast error variance contribution of commodity price shocks in a structural model estimated with Bayesian methods using annual data from Argentina. The model is a two sector small open economy. The gray bars show the results for the full sample 1900-2015. The black bars are based on re-estimating the model on post-1950 data. For details on the methodology, see Drechsel and Tenreiro (2018).

(2018), the magnitude of this contribution has generally been found to be lower than in structural models, suggesting a disconnect between findings from these two alternative methods.^{10,11} In an important recent paper, Fernández, Schmitt-Grohé and Uribe (2017) propose an enriched SVAR framework which includes several different commodity prices that transmit world disturbances. Applying this methodology to a large collection of countries, the authors conclude that the share explained by commodity price shocks increases, thereby reducing the disconnect with the findings from structural models. Specifically, the contribution of world shocks to output fluctuations increases from 10% to around 33% when taking into account disaggregated commodity price series.

Crucially, irrespective of any remaining discrepancy in the *level* of the contribution of commodity price shocks to macroeconomic fluctuations, there is an increasing trend in their quantitative contribution. Consistent with the insight from the estimated structural model shown in Chart 1, the results of Fernández et al. (2017)

suggest that commodity price shocks explain more of the variation in macroeconomic variables in more recent decades. For example, the authors find that in a post-2000 sample they explain 79% of the variance of output on average across countries. While more work remains to be done on reconciling the results from structural models and SVARs regarding commodity and terms of trade shocks, the fact that both approaches point to a *growing* importance of these shocks warrants an ever stronger focus of research on the policy responses.

II.ii. Commodity Price Shocks and Borrowing Conditions

A salient observation that has been emphasized in research on commodity-exporting economies is the relation between the commodity price cycle and borrowing conditions in the economy. In particular, the literature has typically highlighted the negative co-movement of interest rate spreads and commodity prices, a focus motivated by the fact that countercyclical interest rate movements have been found to be a key driver of emerging markets business cycles, as shown for example by Uribe and Yue (2006) and Neumeyer and Perri (2005). Bastourre et al. (2012), Shousha (2016) and Fernández et al. (2018) all find negative effects of commodity price increases on country risk premia in sovereign bond spreads for commodity-rich economies, with particularly strong effects in emerging economies. In Drechsel and Tenreyro (2018) we provide additional evidence by analyzing the correlation between various alternative measures of the real rate spread of Argentina and world commodity price movements, controlling for a variety of other macroeconomic variables.

The relation between commodity prices and borrowing conditions has been embedded in various structural economic models. While this is typically done in a reduced-form fashion, the relation is thought of as resulting from the effect of commodity prices on the country's repayment capacity to international creditors or from financial frictions faced by domestic firms.¹² In the model presented in this paper, we capture the same broad idea of a relation between commodity prices and borrowing conditions by introducing a working capital channel in the commodity sector.

II.iii. Does the Financialization of Commodity Markets Play a Role?

What is behind the growing importance of commodity price shocks for business cycles in commodity-exporting countries? There is an ongoing debate around the “financialization” of international commodity markets, which is seen as a potential explanation for the increased volatility in these markets. The term financialization broadly refers to the process by which commodities have developed as a distinct asset class (or investment style) for portfolio investors, such as large mutual funds. This, according to observers, has led to increased trading volumes in futures markets and may have contributed to larger volatility in commodity spot prices. The larger spot price volatility then passes through to fluctuations in economies that depend on commodity exports. Below we present some empirical patterns that show why the debate around commodity financialization has emerged. We also refer to the literature that has studied commodity financialization in depth.

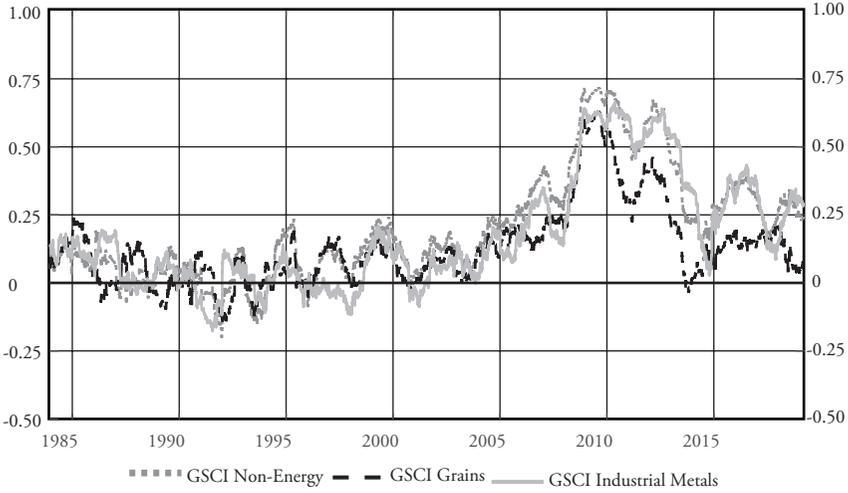
Stylized facts. We discuss three stylized facts that have emerged over the past one to two decades:

1. The correlation between prices of different commodities has increased
2. The correlation between commodity prices and other asset prices has increased
3. The number of transactions in commodity futures has sharply increased relative to commodity production, likely driven by a changing nature of investor types engaged in commodity markets

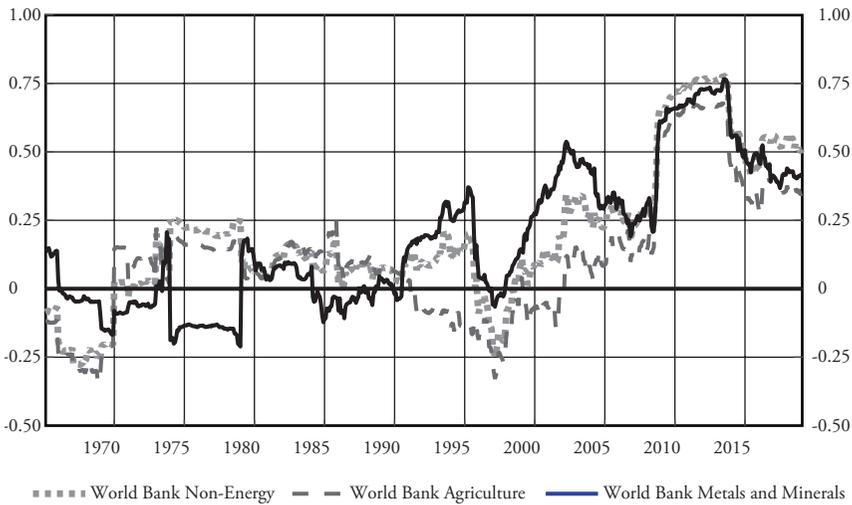
We discuss these facts in turn. Chart 2 focuses on the relation between prices of different types of commodities. Panel A displays rolling correlations of daily returns on commodity futures indices for different commodity categories. Specifically, we compute the 252-day rolling correlation with the GSCI Energy Index, for the analogous index for non-energy commodities, grains and industrial metals, respectively. Panel B carries out a similar exercise, but instead uses

Chart 2 Correlations Between Prices of Different Commodities

A. 252-Day Rolling Correlations with GSCI Energy



B. 60-Month Rolling Correlations with WB Energy



Notes: Panel A displays rolling correlations of daily returns on commodity futures. Specially, it displays the 252-day rolling correlation between GSCI Energy Index and the analogous index for non-energy commodities, grains and industrialmetals, respectively. Panel B shows rolling correlations of monthly returns on spot prices. These indices are retrieved from the World Bank Pink Sheet.

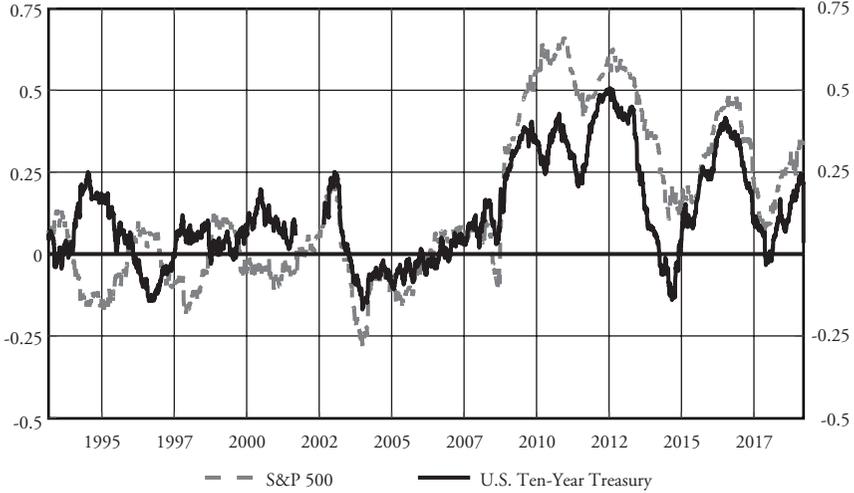
monthly spot price data provided by the World Bank. The latter data has the advantage that it is available for a longer time period, starting prior to the 1970s. Both panels show that while there is little correlation between prices of different commodity types prior to the 2000s, it markedly increases in the new millennium, spikes during the Great Recession and remains elevated thereafter. According to the financialization interpretation of these patterns, the increased correlation across commodities is driven by the growing importance of investors that seek exposure to a broad index of commodities. This investment behavior entails taking positions in different commodities simultaneously, which may render their prices positively correlated.

As shown in Chart 3, commodities have also become more correlated with other asset classes, in particular with equity and fixed income returns. Panel A displays 252-day rolling correlations between daily returns of the GSCI Commodity Index with U.S. equity returns (on the S&P 500) and U.S. sovereign bond returns (using 10-year Treasuries). Panel B presents a similar picture, but with a focus on emerging markets rather than the United States. Specifically, we compute the correlations with the MSCI EM Equity Index and an EM Sovereign Bond Index provided by Barclays. Both panels show that the correlation is more elevated in more recent decades. A stronger correlation between commodities and other asset prices is consistent with the view that as commodities become a distinct investment category, investors with time-varying risk appetites may unwind long positions in commodities if price drops in other asset markets induce them to reduce risk (see for example Cheng et al. 2014). If this view is relevant, financial markets are a key transmitter of shocks from other markets to commodities.

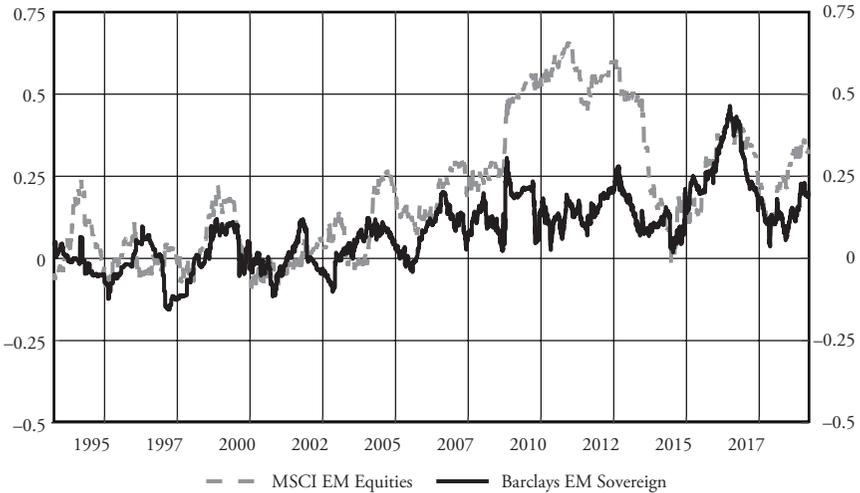
Finally, we present direct evidence on investors taking financial positions in commodities. Panel A of Chart 4 plots open interest, the total number of outstanding futures and option contracts. This data is provided by the U.S. Commodity Futures Trading Commission (CFTC) and represents a measure of financial market activity. We scale this by the level of physical commodity production to give an indication of the magnitude of financial market transactions in relation to the “real” volumes of commodity trade. It is clearly visible that this ratio has risen

Chart 3 Correlations Between Commodities and Other Asset Classes

A. 252-Day Rolling Correlations with GSCI Commodities

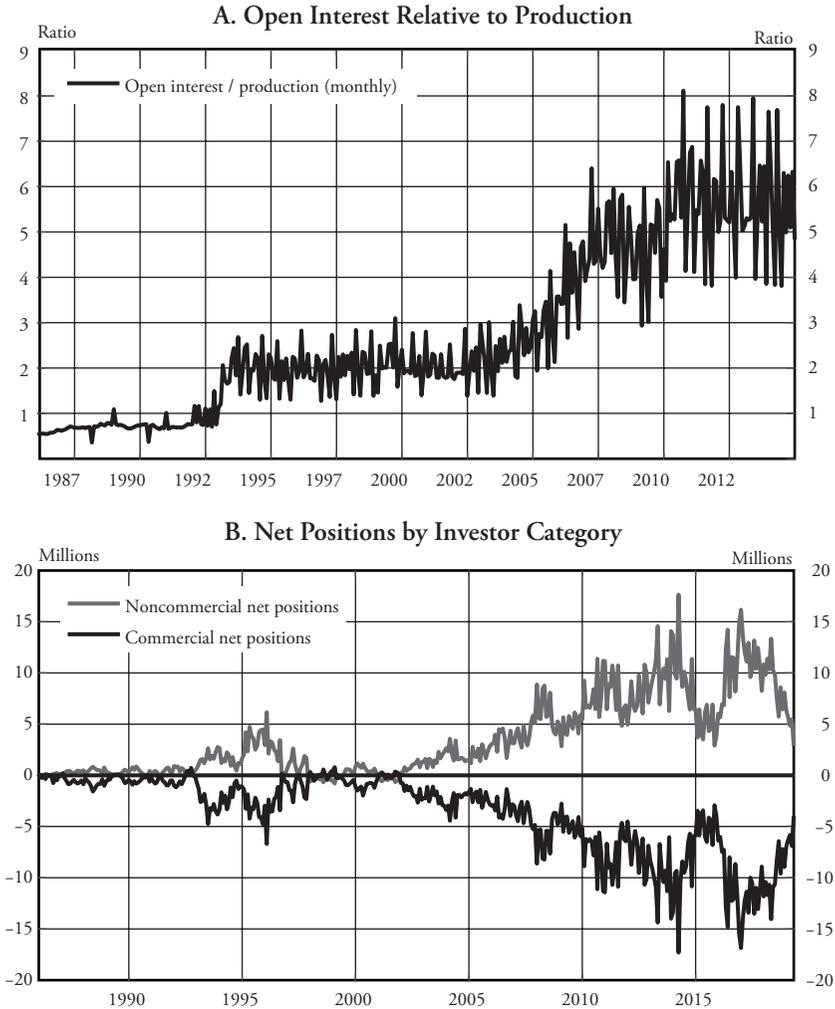


B. 252-Day Rolling Correlations with GSCI Commodities



Notes: Panel A displays 252-day rolling correlations between daily returns of the GSCI total commodity index with the S&P 500 and 10-year U.S. Treasuries. Panel B presents analogous correlations with the MSCI EM Equity Index and the Barclays EM Sovereign Bond Index.

Chart 4 Commodity Futures Positions Relative to Production and by Investor Type



Notes: Panel A shows open interest—the total number of outstanding futures/option contracts—scaled by the level commodity production. These are contracts that are entered into but have not been exercised. The aggregate of all long open interest is equal to the aggregate of all short open interest. Panel B show the according net positions by investor types. Commercial market-participants that seek to hedge-against price movements while non-commercial investors usually represent mutual funds or hedge funds that invest into commodity markets. The source of the data is the U.S. Commodity Futures Trading Commission (CFTC).

rapidly over the past two decades, increasing up to eightfold relative to the 1990s level. Panel B shows the net positions in futures contracts broken down by investor types. Commercial investors are producers who aim to hedge against price fluctuations, while noncommercial investors are usually mutual funds or hedge funds that seek exposure to commodities in their investment portfolios.¹³ The panel shows a rapid increase in financial positions on the long and short side. The increasing use of commodity futures contracts may of course simply improve risk-sharing (see for example Tang and Xiong 2012). If however, long investors' risk-bearing capacity is limited and they unwind their positions in response to shocks unrelated to commodity markets, this could lead to spillover effects from the global economy to commodity prices via financial markets.

Mixed evidence in the literature. If commodities are an investment style for globally active investors and their trading activity responds to a variety of shocks unrelated to commodities themselves, then commodity prices may transmit these shocks to individual commodity-exporting economies. The academic literature is still divided on the extent to which commodity financialization is indeed important for spot price volatility, and thus ultimately for fluctuations in commodity-driven economies. A systematic overview over this discussion is provided by Cheng and Xiong (2014). The authors contrast the simple hedging argument, by which financial transactions enhance risk sharing (see also Tang and Xiong 2012) with the view that the time-varying risk appetite of financial investors is a catalyst for spillovers between markets for different assets (see for example Cheng et al. 2014). Overall, Cheng and Xiong (2014) advocate the view that financialization has indeed fundamentally changed the working of commodity markets. Chari and Christiano (2017) provide an analysis that points against a link between financialization and commodity price volatility. They separately study commodities with and without futures markets and do not find any evidence that futures market trading alters behavior in spot prices. Another important caveat to exploring financialization channels empirically is that the Great Recession may have been a special event that confounds the analysis, one of the key findings of Hamilton and Wu (2015). Fernández et al. (2017), based on sample splits and counterfactual

exercises in their SVAR study, also do not find a particularly important role for financialization in explaining the increased importance of commodity price shocks. Taken together, more research remains to be done on this important issue.¹⁴

In our analysis of monetary policy, we do not take a strong stance on the degree to which financialization has contributed to rising commodity price volatility. However we do take the evidence, even if suggestive, as a motivation for a close look at the implication of global commodity price shocks for monetary policy. In our model we will formally capture the idea that commodity price fluctuations are driven by global shocks and that they are amplified through a link with broader financial conditions.

III. The Model

This section presents a model to study the conduct of monetary policy in the face of commodity price fluctuations. The core of the model consists of the NK-SOE framework proposed by Ferrero and Seneca (2018) (henceforth abbreviated FS). Their paper is one of relatively few contributions that focus explicitly on monetary policy for commodity exporters in a Galí and Monacelli (2005) (GM) framework and we draw extensively on their work. Similar to Drechsel and Tenreyro (2018) (DT), there is a separate competitive export sector that faces a price subject to exogenous shocks. This captures the idea that commodity prices are determined in world markets and taken as given by the small open economy. Importantly, and again in the spirit of DT, we also introduce a link between commodity price fluctuations and borrowing conditions into the FS framework.

III.i. Households

Households maximize expected lifetime utility

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \frac{N_t^{1+\phi}}{1+\phi} \right) \quad (1)$$

by choosing a sequence of consumption, labor supply and asset positions $\{C_t, N_t, D_{t+1}\}_{t=0}^{\infty}$, subject to the sequence of budget constraints

$$P_t C_t + \mathbb{E}_t(Q_{t,t+1} D_{t+1}) = W_t N_t + D_t + \Psi_t, \quad (2)$$

where $Q_{t,t+1}$ denotes the stochastic discount factor, W_t is the wage rate and Ψ_t is a rebate of profits. The parameters β , σ and ϕ capture the discount factor, the inverse intertemporal elasticity of substitution and the inverse Frisch elasticity, respectively. As is commonly assumed, households have access to a complete set of state-contingent securities on world markets, that is, there is perfect international risk sharing.¹⁵ Total consumption is a CES aggregate of domestic and foreign goods

$$C_t \equiv \left[(1-\alpha)^{\frac{1}{\eta}} C_{h,t}^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} C_{f,t}^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}. \quad (3)$$

$C_{h,t}$ is a bundle of consumption goods produced in the domestic economy (“home”), given by

$$C_{h,t} \equiv \left(\int_0^1 C_{h,t}(i)^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}}, \quad (4)$$

where ϵ is the elasticity of substitution, and $C_{f,t}$ is an analogous bundle of goods produced abroad (“foreign”). The price index for home goods is given by $P_{h,t} \equiv \left(\int_0^1 P_{h,t}(i)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}$. The parameter α captures a preference weight on $C_{f,t}$ and $1-\alpha$ is the “home bias” of the economy. Following GM and FS, we study the unit elasticity case where $\sigma = \eta = 1$. This gives log utility in consumption and

$$C_t \equiv \frac{C_{h,t}^{1-\alpha} C_{f,t}^{\alpha}}{\alpha^{\alpha} (1-\alpha)^{1-\alpha}}, \quad (5)$$

with the CPI given by

$$P_t \equiv P_{h,t}^{1-\alpha} P_{f,t}^{\alpha}. \quad (6)$$

Our focus on the unit elasticity case warrants a discussion, which also serves as a preview of some key ideas behind the model. Consider as a baseline the closed economy NK model with staggered

price setting. In this framework, a constant employment subsidy can offset the inefficiency arising from monopolistic competition, which leaves sticky prices as the only remaining distortion.¹⁶ In the absence of cost-push shocks, the monetary authority can achieve full stabilization by effectively keeping mark-ups at their efficient level and replicating the flexible price allocation. In the case of an open economy, there is an additional force at work that affects the choice of the monetary authority. Since domestic and foreign goods are not perfectly substitutable, monetary policy has an incentive to affect their relative price, that is, the terms of trade or real exchange rate, in a welfare enhancing way. In general, this means that deviations from the flexible price allocation can be optimal.¹⁷ In the absence of a commodity sector, the case $\sigma = \eta = 1$ gives rise to an employment subsidy that offsets simultaneously the distortions from monopolistic competition as well as the incentive to affect the terms of trade, and renders the flexible price allocation optimal, just like in the closed economy baseline. As shown by GM, this case admits a tractable second order approximation to the welfare of the representative household.¹⁸ In our approach, we stick to unit elasticities to leverage the latter advantage on a simple formulation of the policy objective. Importantly, however, the introduction of commodity trade will give rise to an incentive for the monetary authority to deviate from the flexible price allocation. As we will show, the commodity sector's demand for resources implies a wedge between the efficient and flexible price allocations outside the steady state, even with $\sigma = \eta = 1$.¹⁹ This gives rise to inefficient commodity booms and busts and results in a stabilization trade-off faced by the monetary authority.

The terms of trade is defined as the price of imports in terms of the price of domestic goods

$$\mathcal{T}_t \equiv \frac{P_{f,t}}{P_{h,t}}, \tag{7}$$

which gives the relations to relative prices $\mathcal{T}_t^{-\alpha} = P_{h,t} / P_t$ and $\mathcal{T}_t^{1-\alpha} = P_{f,t} / P_t$. We let asterisks indicate prices and quantities abroad and define \mathcal{E}_t as the nominal exchange rate. The law of one price requires that $P_{f,t} = \mathcal{E}_t P_{f,t}^*$. For simplicity we

assume that the economy does not export its domestic consumption goods abroad (i.e. $\alpha^* = 0$). The real exchange rate S_t is given by

$$S_t \equiv \frac{\mathcal{E}_t P_t^*}{P_t} = \frac{\mathcal{E}_t P_{f,t}^*}{P_t} = T_t^{1-\alpha}. \quad (8)$$

The demand functions for the home and foreign good bundles can be derived from the usual expenditure minimization problems as

$$C_{h,t} = (1-\alpha) \left(\frac{P_t}{P_{h,t}} \right) C_t = (1-\alpha) T_t^\alpha C_t \quad (9)$$

$$C_{f,t} = \alpha \left(\frac{P_t}{P_{f,t}} \right) C_t = \alpha T_t^{\alpha-1} C_t, \quad (10)$$

where the second equalities use the relation between the terms of trade and relative prices derived above. The demand for an individual home good is given by the familiar expression

$$C_{h,t}(i) = \left(\frac{P_{h,t}(i)}{P_{h,t}} \right)^{-\epsilon} C_{h,t}. \quad (11)$$

The household's optimality condition for labor gives the labor supply relation

$$N_t^\phi C_t = \frac{W_t}{P_t}. \quad (12)$$

The first order condition for D_{t+1} is given by the Euler equation

$$Q_{t,t+1} = \beta \frac{1}{\Pi_t} \frac{C_t}{C_{t+1}} \quad (13)$$

where $\Pi_t \equiv$ denotes gross CPI inflation. Perfect international risk sharing, a symmetric initial net asset position between countries, and the analogous Euler equation in the foreign country imply the risk-sharing condition

$$C_t = C_t^* S_t = Y_t^* T_t^{1-\alpha}, \quad (14)$$

where world consumption and output are denoted by C_t^* and Y_t^* , and world output will be subject to stochastic fluctuations. Perfect risk sharing implies that, given world output, consumption across countries is proportional to the real exchange rate. While this assumption is standard in models that follow the GM tradition, we will provide some further comments below.²⁰

III.ii. Domestic Good Sector

Firms produce with labor, paying the wage rate W_t , which they take as given. They are monopolistically competitive and prices are staggered following the setting of Calvo (1983). Technology of firm i is given by the CRS production function

$$Y_{h,t}(i) = A_{h,t} N_t(i). \tag{15}$$

Its first order condition is

$$\mathbb{E}_t \left[\sum_{\tau=0}^{\infty} \theta^\tau Q_{t,t+\tau} Y_{h,t,t+\tau}(i) \left(P_{h,t}(i) - \frac{1}{1+\zeta} \frac{\epsilon}{\epsilon-1} \frac{W_{t+\tau}}{A_{h,t+\tau}} \right) \right] = 0. \tag{16}$$

θ captures the probability of not being able to reset the price in a given period.²¹ ζ is a labor subsidy given by the government. In the absence of nominal rigidities prices are set as a markup $\mathcal{M} = \frac{\epsilon}{\epsilon-1}$ over marginal costs every period. The aggregate production function is given by

$$Y_{h,t} = \frac{A_{h,t} N_t}{\Delta_t}, \tag{17}$$

where $N_t = \int_0^1 N_t(i) di$ and Δ_t denotes the familiar domestic price dispersion term of NK models with Calvo pricing.

III.iii. Commodity Sector

The commodity sector is competitive, taking prices as given. We assume that the dynamics in the international price of commodities $P_{c,t}^*$ are driven by developments in world markets and are thus taken as an exogenous variable by the small open economy. This assumption echoes the broader discussion provided in Section II and

in DT. For simplicity, commodities are not consumed by domestic households or firms but used solely for international trade.²² Firms in the commodity sector require a quantity $M_{h,t}$ of domestic goods as intermediate input, taking their price $P_{h,t}$ as given. The production function is

$$Y_{c,t} = A_{c,t} M_{h,t}^\nu, \quad (18)$$

where $0 < \nu < 1$ reflects the presence of decreasing returns in the sector. The assumption of decreasing returns allows us to pin down the sector size, which can be calibrated for the purpose of studying monetary policy. The use of domestic goods in commodity production reflects the idea that the flow of resources allocated to the production of commodities is a key channel for the transmission of commodity price shocks. This reallocation force will affect the efficient level of output, and in turn the output gap and domestic price pressures.

Profits from the commodity sector are rebated as a lump sum payment to the household. The real commodity price can be rewritten as a function of the real foreign currency commodity price:

$$\frac{P_{c,t}}{P_t} = \frac{\mathcal{E}_t P_{c,t}^*}{P_t} = \frac{P_{c,t}^*}{P_t^*} \mathcal{T}_t^{1-\alpha}. \quad (19)$$

Crucially, relative to FS, we also introduce a financial channel present in commodity production. In particular, commodity firms are subject to a working capital constraint, which requires them to pre-finance their input expenditures $P_{h,t} M_{h,t}$ with an intraperiod loan L_t . This loan is subject to a borrowing constraint which depends on commodity output $P_{c,t} Y_{c,t}$.²³ The presence of such a borrowing constraint reflects the idea that borrowing conditions are eased when commodity prices rise, a mechanism that DT emphasize. More specifically, DT provide empirical evidence of a negative relation between borrowing conditions (measured as credit spreads) and world commodity prices.²⁴ Formally,

$$P_{h,t} M_{h,t} = L_t \quad (20)$$

$$L_t \leq x_t P_{c,t} Y_{c,t}. \quad (21)$$

The variable χ_t captures the tightness of borrowing conditions and will be allowed to vary with the commodity cycle. We combine (20) and (21) to one inequality and denote the Lagrange multiplier on the resulting constraint as μ_t . Profit maximization gives

$$(1 + \chi_t \mu_t) P_{c,t} \nu A_{c,t} M_{h,t}^{\nu-1} = (1 + \mu_t) P_{h,t}. \quad (22)$$

The working capital constraint, when binding, gives a stronger response of input demand to commodity price shocks, since these shocks ease the access to funds for purchasing inputs from the rest of the economy. Rearranging (22), and using (19) as well as $P_{h,t} / P_t = T_t^{-\alpha}$ gives

$$M_{h,t} = \left(\frac{1 + \mu_t}{1 + \chi_t \mu_t} \nu \frac{P_{c,t}^*}{P_t^*} T_t A_{c,t} \right)^{\frac{1}{1-\nu}}. \quad (23)$$

If the constraint does not bind ($\mu_t = 0$), the input demand function (23) collapses to the analogous expression in the model of FS. If the constraint binds ($\mu_t > 0$), we have from (20) and (21) that

$$M_{h,t} = \left(\chi_t \frac{P_{c,t}^*}{P_t^*} T_t A_{c,t} \right)^{\frac{1}{1-\nu}}. \quad (24)$$

Combining (23) and (24) we can derive an expression of μ_t as a function of ν and χ_t , as well as a condition for the constraint to bind. Specifically, $\mu_t > 0$ if

$$\mu_t = \frac{\nu - \chi_t}{\chi_t(1 - \nu)} > 0 \quad (25)$$

$$\chi_t < \nu, \quad (26)$$

where the last line follows because $0 < \nu < 1$. Similar to DT, we want to capture the notion that the international commodity price cycle has an important influence on borrowing conditions, e.g. because lenders become more willing to lend in commodity price booms than in bust periods. We capture this in reduced form by assuming that the constraint tightness χ_t is an increasing function of the (U.S. dollar) commodity price $P_{c,t}^* / P_t^*$.²⁵ We specify

$$\chi_t = \bar{\chi} \left(\frac{P_{c,t}^*}{P_t^*} \right)^\chi, \quad (27)$$

where $\bar{\chi}$ and χ are constant parameters. $\bar{\chi}$ can be used to calibrate whether the borrowing constraint binds in steady state—by satisfying condition (26)—and drops out when the model is log-linearized to characterize policy. χ governs the elasticity of borrowing conditions to international commodity prices and will be a key parameter in our analysis. The input demand function becomes

$$M_{h,t} = \left(\bar{\chi} \left[\frac{P_{c,t}^*}{P_t^*} \right]^{1+\chi} \mathcal{T}_t A_{c,t} \right)^{\frac{1}{1-\nu}}. \quad (28)$$

The presence of the working capital constraint is thus an amplifier of the input demand response to commodity price shocks. In times of high commodity prices, more intermediate inputs can be financed and the effect on resource demand is stronger. In the absence of the financial channel, the elasticity of $M_{h,t}$ with respect to the price is $\frac{1}{1-\nu}$, but rises to $\frac{1+\chi}{1-\nu} > \frac{1}{1-\nu}$ when the constraint binds. The higher this elasticity, the stronger will be the transmission of changes in commodity prices to the rest of the economy and the more important will these changes be for policy considerations. The addition of the borrowing constraint thus highlights the broader applicability of the framework proposed by FS.^{26, 27}

III.iv. Market Clearing and Equilibrium

Domestic goods and foreign goods market clearing gives

$$C_{h,t} = Y_{h,t} - M_{h,t} \quad (29)$$

$$C_t^* = Y_t^*. \quad (30)$$

Given commodity prices $P_{c,t}^*$, monetary policy determining i_t , foreign output, inflation and interest rates $Y_t^*, \Pi_{f,t}^* = \Pi_t^*, i_t^*$, and an initial condition on price dispersion, the equilibrium is given by a sequence of quantities $\{C_{h,t}, C_{f,t}, C_t, N_t, D_{t+1}, Y_{h,t}, Y_{c,t}, M_{h,t}\}_{t=0}^\infty$ and

prices $\{Q_{t,t+1}, \Pi_{h,t}, \Pi_t, \mathcal{T}_t, \mathcal{S}_t, \mathcal{E}_t, \Delta_t\}_{t=0}^{\infty}$ so that agents maximize their objectives and markets clear.

III.v. Efficient and Natural Allocation

Planner problem. The efficient allocation is the solution of a planner problem, which maximizes household utility subject to the resource constraint in the domestic goods market, the risk-sharing condition and the optimal allocation of resources across sectors. We assume that the planner cannot undo the financial friction in the commodity market. Since μ_f is a function solely of exogenous variables (see equations (25) and (27)), the planner takes μ_f as given and the resulting derivations are analogous whether or not the constraint binds.²⁸ We focus on the situation where $\mu_f > 0$. Formally, using (9) and (14), the planner problem can be written as

$$\max_{T_t, N_t} \left\{ \ln(\mathcal{T}_t^{1-\alpha} Y_t^*) - \frac{N_t^{1+\phi}}{1+\phi} \right\} \tag{31}$$

subject to

$$A_{h,t} N_t = (1-\alpha) \mathcal{T}_t Y_t^* + M_{h,t} \tag{32}$$

and (28). The solution to this problem yields the condition

$$(1-\alpha) Y_{h,t}^e = (N_t^e)^{1+\phi} \left[C_{h,t}^e + \frac{1}{1-\nu} M_{h,t}^e \right], \tag{33}$$

where expressions for $Y_{h,t}$, $C_{h,t}$ and (28) have been used to re-write the first-order conditions, and where the superscript e denotes “efficient” allocations. It now becomes clear how the efficient allocation is affected by the presence of commodity trade. In the absence of the technological demand for domestic output $M_{h,t}$, the terms of trade would enter linearly in the resource constraint, due to the unit elasticity assumption $\sigma = \eta = 1$. This case would entail a constant efficient employment level and thus a constant efficient terms of trade. There would be a subsidy that could achieve these levels under flexible prices, and the efficient and natural levels of these variables would be equal. This does not hold when $M_{h,t}$ enters the resource constraint as a nonlinear function of the terms of trade. To illustrate

this, we can contrast condition (33) to its counterpart in GM, which is, $(N^e)^{1+\phi} = (1-\alpha)$ and note that the efficient allocation equals the one in GM up to a time-varying wedge W_t^e :

$$(N_t^e)^{1+\phi} = \frac{(1-\alpha)}{W_t^e}, \quad (34)$$

where

$$W_t^e = s_{c,t}^e + \frac{1}{1-\nu} s_{m,t}^e > 1, \quad (35)$$

and $s_{c,t}$ and $s_{m,t}$ denote the allocations of resources to home consumption and commodity production, respectively. It is evident from equation (34) that, unlike in GM, the efficient allocation is not constant and will vary, in particular with shocks to commodity prices. The time-varying demand for resources in the commodity sector and will affect the efficient allocation of resources across the economy by impacting $s_{c,t}^e$ and $s_{m,t}^e$. When this variation cannot be corrected by a subsidy, inefficient commodity booms and busts can arise.^{29, 30}

Efficient steady state, natural levels and subsidy. We characterize an efficient steady state with zero inflation and the terms of trade normalized to unity.³¹ Using perfect risk sharing (14), the input demand function (28) and the efficiency condition (34), we obtain

$$N_{ss}^e = \left[\frac{(1-\alpha)A_{h,ss}}{\left((1-\alpha)Y_{ss}^* + \frac{1}{1-\nu} \left(\bar{\chi} \left[\frac{P_{c,ss}^*}{P_{ss}^*} \right]^{1+\chi} A_{c,ss} \right)^{\frac{1}{1-\nu}} \right)} \right]^{\frac{1}{\phi}}. \quad (36)$$

All remaining steady state quantities and prices can be calculated from Ness.³² It is straightforward to calculate a steady state subsidy ζ that shuts off the inefficiency stemming from monopolistic competition in the domestic goods sector. We combine the firms' labor demand equation under flexible prices (the term inside the summation of equation (16))

with household labor supply given by (12), by substituting out the wage rate and using $T = 1$. This gives

$$(1 + \zeta) \frac{\epsilon - 1}{\epsilon} A_{h,ss} = (N_{ss}^n)^\phi C_{ss}^n, \quad (37)$$

where the superscript n indicates the “natural” level of variables, that is, the one prevailing under flexible prices. ζ can be adjusted to ensure that in steady state the natural allocations in (37) equal their efficient counterparts. Using the efficiency condition given by (34), the above relation can be rearranged to show that ζ in this case must fulfill

$$\zeta = \frac{\epsilon}{\epsilon - 1} \frac{S_{c,ss}^e}{W_{ss}} - 1. \quad (38)$$

Due to the presence of the wedge this subsidy is different from its analogue in GM, where ζ depends only on model primitives and not on endogenous variables. In GM the subsidy renders the natural allocation efficient even away from the steady state and the only remaining distortion arises from nominal rigidities. In the presence of the commodity sector, the time-varying nature of W_t prevents resources from being efficiently allocated across sectors via a constant subsidy *away from the steady state*. This highlights again how the commodity sector gives rise to variation in the efficient allocation over and above the presence of monopolistic competition and nominal rigidities.

III.vi. Log-Linearized Model and Monetary Policy Objective

Following the tradition of Clarida et al. (1999), we approximate the model with a log-linear system and a quadratic objective function for the policymaker. Variables are expressed in log deviations from the steady state, denoting $\hat{x}_t = \ln\left(\frac{X_t}{X_{ss}}\right)$. In doing so we leverage the advantage of the FS framework, which admits the approximation to such a linear-quadratic framework in the presence of an additional sector. Below we sketch out key results, Appendix A contains the full details.

Efficient and natural levels of output. In the appendix we derive expressions for the efficient and natural levels of domestic output and the trade balance in the log-linear system, $\hat{y}_{h,t}^e$, $\hat{\tau}_t^e \hat{y}_{h,t}^n$ and $\hat{\tau}_t^n$. As

noted in the discussion above, efficient and natural allocations differ in deviations from steady state due to the presence of the commodity sector and equate only in the special case $s_{m,ss} = 0$ and $W_{ss} = 1$. Using the expressions in the appendix, it can be shown that

$$\frac{\partial \hat{y}_{h,t}^e}{\partial \hat{p}_{c,t}^*} < 0 \quad (39)$$

$$\frac{\partial \hat{y}_{h,t}^n}{\partial \hat{p}_{c,t}^*} > 0. \quad (40)$$

We discuss the economic intuition behind the effect of commodity price shocks on efficient and natural allocations in detail when we characterize the model dynamics in Section IV.³³ Importantly, the elasticity χ increases the sensitivity of the economy's allocations to variation in $\hat{p}_{c,t}^*$.

New Keynesian Phillips curve and IS curve. Linearizing the optimal price setting condition of domestic goods firms and using an expression for marginal costs in deviations from steady state, the New Keynesian Phillips curve (NKPC) can be derived as

$$\hat{\pi}_{h,t} = \xi(\hat{y}_{h,t} - \hat{y}_{h,t}^n) + \beta \mathbb{E}_t \hat{\pi}_{h,t+1} \quad (41)$$

where $\hat{\pi}_{h,t}$ denotes domestic good inflation, $\xi \equiv \frac{\kappa(1+\phi\mathcal{W}_{ss})}{\mathcal{W}_{ss}}$ and $\kappa = \frac{(1-\theta)(1-\beta\theta)}{\theta}$. The relevant output gap will reflect deviations from the *efficient* level, so that $\hat{x}_{h,t} \equiv \hat{y}_{h,t} - \hat{y}_{h,t}^e$. Re-expressing (41) in terms of $\hat{x}_{h,t}$ yields

$$\hat{\pi}_{h,t} = \xi \hat{x}_{h,t} + \beta \mathbb{E}_t \hat{\pi}_{h,t+1} + \xi(\hat{y}_{h,t}^e - \hat{y}_{h,t}^n). \quad (42)$$

The presence of the term $\xi(\hat{y}_{h,t}^e - \hat{y}_{h,t}^n)$ gives rise to a stabilization trade-off for monetary policy and moves in response to commodity prices shocks through their effect on the difference between the efficient and natural levels of output. Again, in the absence of commodities, natural and efficient levels would equate and the additional Phillips curve term would disappear. Note also the presence of the wedge W_{ss} in ξ , which gives a flatter slope of the NKPC. The IS curve is given by

$$\hat{x}_{h,t} = -\sigma_\alpha (i_t - \mathbb{E}_t \hat{\pi}_{t+1} - r_t^e) + \mathbb{E}_t \hat{x}_{h,t+1}, \quad (43)$$

with $\sigma_\alpha = \frac{1-\alpha}{\mathcal{W}_{ss}}$ and $r_t^e = \mathbb{E}_t \hat{c}_{t+1}^e - \hat{c}_t$. Again the presence of W_{ss} reduces the slope of the relation. The set of linear constraints that the monetary policymaker takes into account in an open economy setting is completed by the relation between domestic and CPI inflation, the link between the output gap and the terms of trade, and a condition for efficient consumption, which are given in the appendix.

Loss function. A key advantage of the FS framework is the fact that a tractable second order approximation of consumer welfare can be derived despite the fact that the “divine coincidence” of the closed economy benchmark does not hold in the presence of commodity trade. Formally, lifetime utility can be approximated using a second order expansion as a welfare function of the form

$$\mathbb{W} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t \quad (44)$$

with the period loss function given by

$$\mathcal{L}_t = -\frac{\Omega}{2} (\hat{\pi}_{h,t}^2 + \lambda_x \hat{x}_{h,t}^2), \quad (45)$$

where higher order terms and terms independent of policy have been dropped and where

$$\Omega = \frac{(1-\alpha)\epsilon}{\kappa \mathcal{W}_{ss}} \quad (46)$$

$$\lambda_x = \frac{\kappa}{\epsilon} \left(\frac{\lambda_\tau}{\mathcal{W}_{ss}^2} + \phi \right). \quad (47)$$

We have defined $\lambda_\tau = s_{c,ss} + \frac{s_{m,ss}}{(1-\nu)^2}$. Again note how the coefficients of the welfare function differ from the GM framework due to the presence of the wedge created by the commodity sector. We ment) in Section IV.

IV. Results: Monetary Policy with Commodity Price Shocks

This section characterizes the equilibrium dynamics of the model and studies the conduct of monetary policy. We begin by deriving optimal policy. We then discuss the calibration of the model's parameters and stochastic processes, before analyzing a variety of policy rules in comparison to optimal policy and highlighting in more detail the role of the financial channel. In doing so, we focus on the consequences of commodity price shocks under perfect risk sharing. But we also investigate the dynamics arising from shocks that raise commodity prices and world output simultaneously, as well as outlining the results under an alternative asset market structure.

Optimal policy. The optimal policy in the case of commitment is derived from maximizing the objective function (44) subject to the NKPC (42) by choosing a sequence for $\hat{x}_{h,t}$ and $\hat{\pi}_{h,t}$. The remaining variables, such as the interest rate, can be backed out from the additional linear constraints. Note that the loss function and constraints are similar to a standard GM setting with a trade-off inducing ("cost-push") term appearing in the NKPC. This additional term is $\xi(\hat{y}_{h,t}^p - \hat{y}_{h,t}^n)$, which can be shown to depend only on exogenous variables, including commodity price and world output shocks. Deriving optimal policy therefore yields the familiar expression

$$\hat{\pi}_{h,t} = -\frac{\lambda_x}{\xi}(\hat{x}_{h,t} - \hat{x}_{h,t-1}). \quad (48)$$

Due to the presence of the wedge between the natural and the efficient level of output, the policymaker trades off adjustments in domestic inflation and the output gap, and this trade-off is governed by the weight of output stabilization in the policy objective λ_x and the slope of the NKPC ξ .

Calibration. While several technology and preference parameters are shared with standard NK-SOE models and can be calibrated in line with the existing literature, the parameters capturing the role of the commodity sector allow the model to potentially be adapted to a variety of economies, which can differ in the quantitative importance of commodity trade to overall economic activity, the technology in the commodity sector, and the strength of the financial channel.

Table 1
Model Calibration

Parameter	Description	Value	Calibration target/source
$1-\alpha$	Home bias	0.6	Gali and Monacelli (2005)
ϕ	Inverse Frisch elasticity	3	Gali and Monacelli (2005)
β	Discount factor	0.996	Steady state interest rate $\approx 1.5\%$
$1-\theta$	Price re-set probability	0.25	Standard value for Calvo pricing
ϵ	Elasticity of substitution	6	Gives markup of 20%
$S_{m,ss}$	Share of output used in comm. prod.	0.15	Ferrero and Seneca (2018)
ν	Returns of scale in comm. prod.	0.38	Ferrero and Seneca (2018)
χ	Elast. borrowing limit to comm. price		Vary between 0, 0.5 and 2

Specifically, these parameters are the share of resource demand from the commodity sector in domestic output $s_{m,ss}$, the curvature in commodity production technology ν and the elasticity of the tightness of the working capital constraint to the commodity price cycle χ . We proceed by calibrating the model in line with FS and varying the strength of the link between commodity prices and domestic borrowing conditions captured by χ .³⁴ Table 1 summarizes our calibration.

Stochastic processes. We assume that international commodity prices as well as world output follow log-linear AR(1) processes with normal innovations, persistence parameters $\{\rho_{pc}, \rho_{y^*}\}$ and standard deviations $\{\sigma_{pc}, \sigma_{y^*}\}$, that is,

$$\hat{p}_{c,t}^* = \rho_{pc} \hat{p}_{c,t-1}^* + \epsilon_t^{pc} \tag{49}$$

$$\hat{y}_t^* = \rho_{y^*} \hat{y}_{t-1}^* + \epsilon_t^{y^*}. \tag{50}$$

We set the persistence of both processes to 0.9 and the standard deviations of commodity price shocks and world output shocks to 10% and 3.33%, respectively. The assumption that the standard deviation of commodity price shocks is three times as large as those of world output shocks captures the empirical observation that commodity prices are much more volatile than global economic activity. We study the policy response to shocks that hit the commodity price process, as well as to shocks that increase ϵ_t^{pc} and $\epsilon_t^{y^*}$ simultaneously. As we will explain in more detail below, the idea of considering such

a correlated shock is to model commodity booms which go alongside a global economic expansion.³⁵

Alternative policy rules. In addition to optimal policy, we compare a set of different monetary rules. Specifically, we consider a CPI target, a domestic inflation target and a nominal exchange rate peg. Formally,

$$\dot{i}_t = \phi_{cpi} \hat{\pi}_t \quad (51)$$

$$\dot{i}_t = \phi_h \hat{\pi}_{h,t} \quad (52)$$

$$\Delta \hat{e}_t = 0, \quad (53)$$

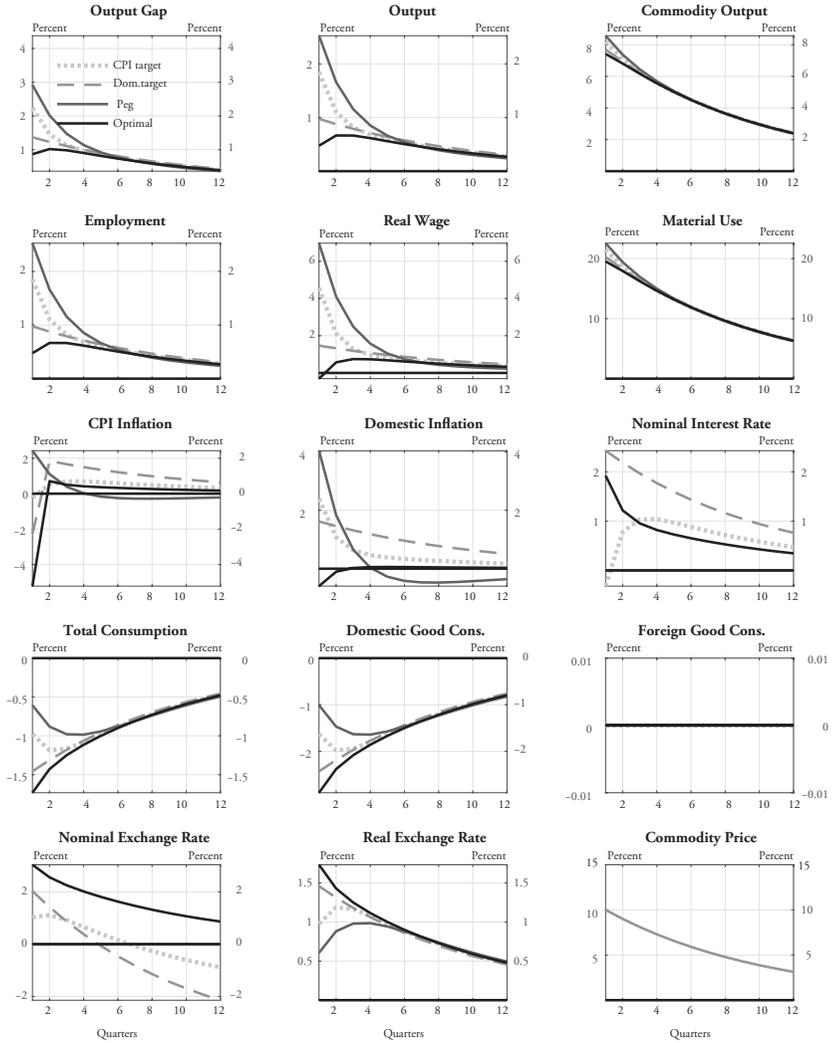
where we set $\phi_{cpi} = \phi_h = 1:5$. We compare the dynamics of the model under these alternative rules with those arising under optimal policy.

Monetary policy for commodity price shocks. Chart 5 plots the impulse response functions (IRFs) to a one standard deviation positive commodity price shock, setting $\chi = 0.5$.³⁶ Specifically, the chart compares the dynamics of key model variables across different policies. As the responses show, independent of the policy rule in place, a rise in commodity prices leads to an expansion in the economy, with an increase in output and factor inputs in both sectors (labor and intermediate goods, respectively).

The output gap in goods production increases and inflationary pressures in the domestic economy arise. Nominal and real exchange rates appreciate. Before turning in more detail to the comparison between alternative policies, let us build the economic intuition behind these forces.

The transmission of the commodity price shock works as follows. From profit maximization in the commodity sector, higher commodity prices result in more commodity production and higher demand for intermediate inputs. Given risk sharing, the extra revenues from commodity production are not associated with any increase in consumption, so the reallocation of labor effort toward the commodity sector is welfare-reducing. The demand for resources from the commodity sector also puts pressure on the price of domestic goods (relative to foreign

Chart 5 IRFs to Commodity Price Shock Under Different Policy Rules



Notes: IRFs to a 10% positive commodity price shock under alternative policy rules. The results are generated under the calibration shown in Table 1, setting $\chi = 0.5$. Inflation and interest rates are shown in annualized percent. The nominal and real exchange rates are plotted as \hat{e}_t^{-1} and \hat{s}_t^{-1} so that an increase corresponds to an appreciation.

goods), triggering an appreciation of the real exchange rate ($\hat{\tau}_t$ falls). A stronger exchange rate (terms of trade) lowers domestic consumption demand from households since in the presence of perfect risk sharing and without global output shocks, household consumption of home goods moves directly with terms of trade. The reallocation means that a greater proportion of labor effort is now used producing commodity inputs, which brings a smaller consumption benefit, so the efficient level of output and employment actually fall.

Importantly, the real exchange rate movement reduces commodity producers' input demand by an even greater amount than it does consumption, so helps offset the initial reallocation towards commodity input production. Firms do not internalize this effect, and raise prices by too little (and quantities by too much) relative to the social benefit of doing so. This is the case even if prices were fully flexible, so the natural level of output rises. Given that there are impediments to raising prices for some firms and the adjustment then goes through quantities, the domestic firm sector overproduces even more. Output rises by more than its natural level, and by much more than its efficient level, which has fallen. The output gap and domestic inflation rise, and the economy "overheats" in an inefficient expansion and reallocation of resources, triggered by the commodity price shock.³⁷

In the face of these pressures, optimal policy implies an increase the nominal interest rate to lean against the inefficient boom. Since full stabilization is not attainable, changes in the output gap are traded off with changes in inflation and the dynamics entail movements in both variables. Returning inflation to target is not enough to close the output gap. At the optimum, the output gap remains positive and domestic inflation undershoots the target. The chart shows that the model dynamics are different across the alternative policies. As expected, the targeting rules imply larger variation in the output gap and domestic inflation than the optimal policy. The exchange rate peg clearly implies the largest volatility in key variables such as output, employment and domestic inflation. Importantly, with the exception of the peg, policy generally prescribes to hike nominal rates in the face of the commodity price boom. To further buttress

these observations, the standard deviations of key model variables across the different rules, as well as a numerical welfare comparison are shown in Table 2. We compute welfare the same way as GM and FS, by computing the implied approximate consumer utility for $\beta \rightarrow 1$, expressed in percent of steady state consumption. We show all welfare calculations relative to a benchmark case in which no shocks hit the economy and the deviations in all variables remain at 0. We also break down the welfare loss into the individual contribution of the variance in inflation and the output gap. The table confirms the intuition conveyed by the IRFs. CPI inflation targeting performs relatively well, followed closely by the domestic inflation target, while the exchange rate peg clearly performs the worst.³⁸ In line with the findings of GM, higher implied exchange rate volatility is generally associated with lower variation in inflation and the output gap, and therefore lower welfare losses.³⁹ Taken together, commodity price shocks have welfare consequences that can be mitigated by appropriate conduct of monetary policy. As these welfare differences appear relatively small compared with some of the anecdotal evidence on the disruptive effects of commodity cycles in emerging markets, Section V will turn to some practical considerations.

The financial channel. We now compare the model dynamics for different strengths of the financial channel by showing the results for $\chi \in \{0, 0.5, 2\}$, focusing on the domestic inflation target only.⁴⁰ The IRFs are shown in Chart 6. Comparing the responses across the calibrated values for χ , it is clearly visible that the presence of the financial channel greatly intensifies the economy's responses to commodity price shocks. While the qualitative transmission of the shock is similar, the fact that the working capital constraint gets looser due to the rise in prices for higher values of χ acts as an amplifier of the transmission of the shock. When the borrowing constraint faced by commodity producers is more sensitive to the commodity price cycle, the effect of commodity price shocks on resource demand from the commodity sector and the commodity sector's is stronger. Accordingly, the rise in rates prescribed by domestic inflation targeting is much more elevated for larger values of this key parameter. The stronger the financial channel that accompanies a commodity boom, the more aggressive is the rate hike that is warranted by the inflation target.⁴¹

Table 2
Implied Standard Deviations and Numerical Welfare
Calculations Across Policies

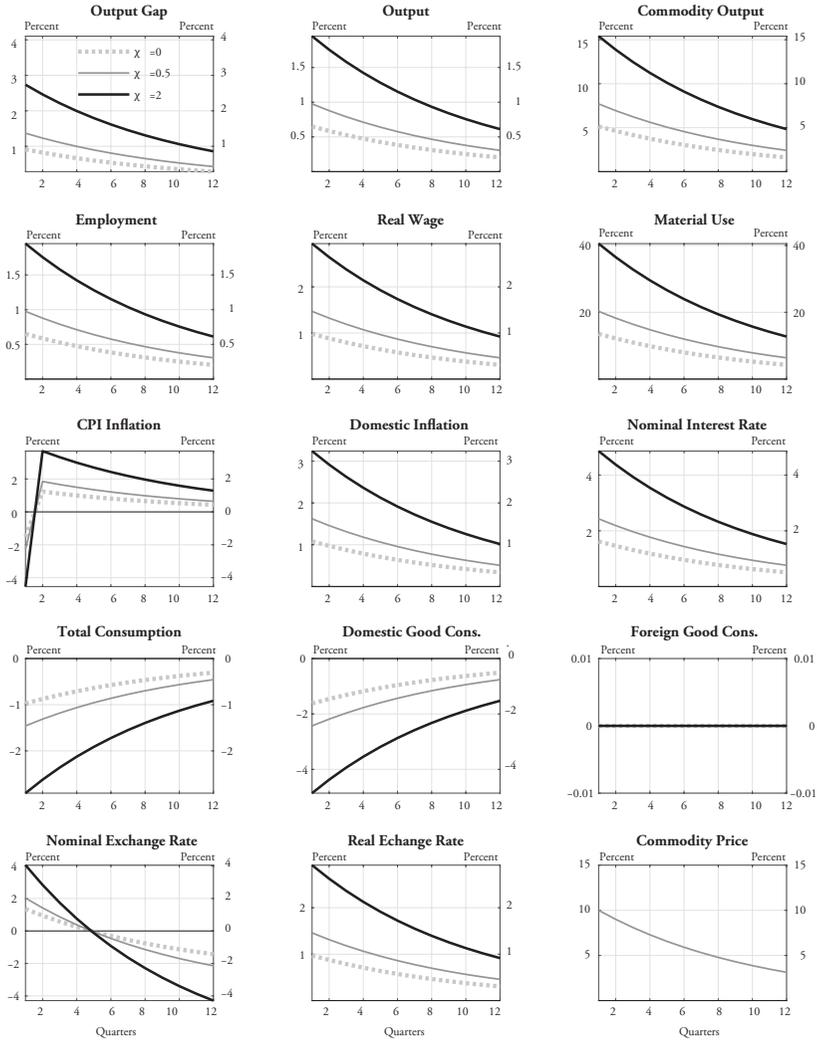
A. Implied Standard Deviations (percentage)				
	CPI inf. target	Dom. inf. target	Nominal peg	Optimal policy
Output Gap	3.62	3.14	4.43	2.66
Domestic Output	2.75	2.24	3.59	1.77
Commodity Output	17.90	17.67	18.28	17.40
Domestic Inflation	0.72	0.93	1.17	0.16
CPI Inflation	0.47	1.20	0.70	1.34
Nominal Interest Rate	0.70	1.39	0.00	0.77
Terms of Trade	5.27	5.57	4.82	6.04
Commodity Price	22.94	22.94	22.94	22.94

B. Contribution to Welfare Losses Relative to no Shocks (percentage of SS consumption)				
	CPI inf. target	Dom. inf. target	Nominal peg	Optimal policy
Var(domestic inflation)	0.1019	0.1708	0.2730	0.0048
Var(output gap)	0.1458	0.1093	0.2174	0.0788
Total	0.2476	0.2801	0.4903	0.0836

Global activity, risk sharing and the response of consumption.

We also characterize the dynamics of the model under different policies in response to shocks that *simultaneously move world output and commodity prices*. The motivation for this exercise is twofold. First, in reality it is likely that a commodity price boom is accompanied by stronger economic activity in the world economy. As shown for example by Kilian (2009) in the context of oil, commodity prices are mainly driven by global demand shocks, which move commodity prices and real economic activity simultaneously in the same direction. Our framework can encompass such correlated shocks and we explore the consequences for policy. Second, the consumption response to the pure commodity price shock in Charts 5 and 6 appears counterfactual in light of empirical studies. As highlighted for example in DT, consumption typically responds positively to commodity price shocks. The negative consumption response shown above is a direct consequence of perfect international risk sharing embedded in the NK-SOE core of the model. Equation (14) shows that in the absence of other global shocks, consumption simply moves directly

Chart 6
IRFs to Commodity Price Shock for Varying Strength
of the Financial Channel



Notes: IRFs to a 10% positive commodity price shock. The light dotted, medium dashed and dark solid lines show the responses of key variables for χ equal to 0, 0.5 and 2, respectively. The results are generated under the calibration shown in Table 1 with a domestic inflation targeting rule and $\varphi_b = 1.5$. Inflation and interest rates are shown in annualized percent. The nominal and real exchange rates are plotted as \hat{e}_t^{-1} and \hat{s}_t^{-1} so that an increase corresponds to an appreciation.

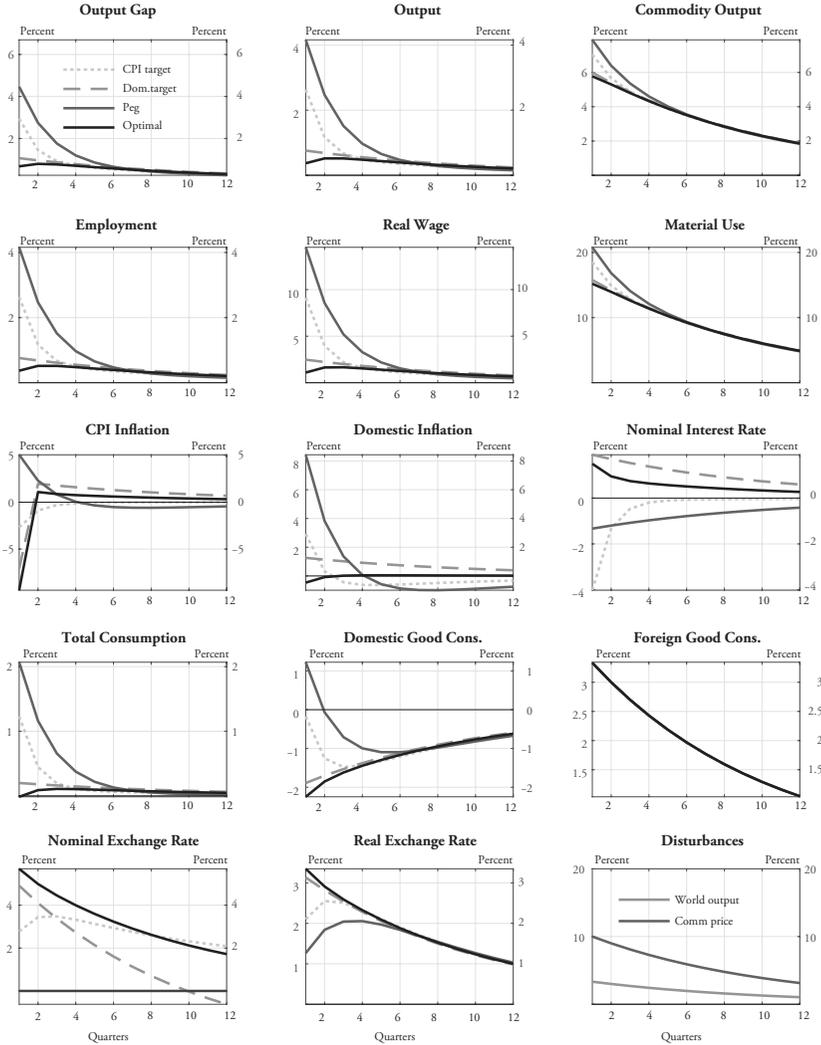
with the terms of trade. By the same token, the response of foreign consumption to pure commodity price shocks is completely flat.⁴² As these characteristics of the model seem rather stark, we want to allow for additional consumption movements to mitigate the strong influence of the risk sharing assumption on policy considerations.

Chart 7 presents IRFs to a shock which again raises commodity prices by 10% on impact, but also simultaneously increases world output by one third of this magnitude. The persistence of the two exogenous variables is the same. It is visible that most of the responses qualitatively similar to Chart 6, but the response of (total) consumption is positive, in line with empirical findings and confirming our intuition that relaxing the role of risk sharing helps making the model dynamics more realistic. It also highlights that our framework is applicable to commodity price in a context of global demand fluctuations. Interestingly, the CPI target as well as the exchange rate peg now prescribe a reduction in the nominal interest rate.

Financial autarky model. As an alternative way of examining the robustness of the risk sharing assumption, in appendix B we also relax it directly, by assuming incomplete markets across countries. We replace perfect risk sharing with the opposite extreme of financial autarky—no international trade in financial assets—which implies a zero trade balance each period.⁴³

The transmission of a commodity price shock under financial autarky in our model turns out to be qualitatively very similar to the transmission of the correlated shock to world output and commodity prices shown in Chart 7. With a moderate severity of the financial friction, there is an inefficient boom and optimal policy prescribes a small tightening in monetary policy. Again, the key difference relative to a commodity price shock under perfect risk sharing is that consumption now increases, driven by a large increase in foreign good consumption, funded by higher commodity income. Although it has a different source, the rise in consumption has a similar effect as when driven by higher global output under risk sharing. In reality, it is likely both channels play at least some role in explaining the observed correlations between consumption and commodity prices in the data.

Chart 7 IRFs to Correlated Commodity and Global Activity Shock Under Different Policy Rules



Notes: IRFs to a correlated shock which raises world output by 3.33% and commodity prices by 10%. The results are generated under the calibration shown in Table 1 setting $\chi = 0.5$. Inflation and interest rates are shown in annualized percent. The nominal and real exchange rates are plotted as \hat{e}_t^1 and \hat{s}_t^1 so that an increase corresponds to an appreciation.

There are a few interesting differences in the transmission of shocks under financial autarky. First, the financial friction plays an additional role under autarky, as it is the source of the inefficient boom rather than purely an amplifier. Chart B1 shows the impulse responses for different levels of severity of the financial friction. With no financial friction, the real exchange rate appreciation completely offsets the effect of the commodity price rise on output and there is no inefficient reallocation. As the severity increases, commodity output and input demand now over-respond due to the initial price rise, but also due to the endogenous loosening in borrowing conditions. As under risk sharing, this causes an inefficient reallocation of production toward the commodity sector. The channel highlights how financial volatility may be an additional source of inefficient sectoral reallocation for commodity exporters.⁴⁴

Second, although the results are qualitatively similar, the quantitative sizes of some of the responses are much larger. In particular large real exchange-rate appreciations occur. Under optimal policy, these result in a sharp fall in CPI of around 20% at an annualized rate, shown in Chart B2. These volatile responses may partly reflect the fact that financial autarky is also an extreme assumption, and so these results are more stylized and less realistic than those using a correlated increase in global demand and commodity prices. As a result, the prescribed interest rate policy differs markedly across different rules. A small tightening is required under optimal policy and a domestic inflation targeting rule. While under a CPI inflation target or an exchange rate peg, a large loosening takes place. The exchange rate peg again performs poorly, resulting not only in above-target domestic inflation and a large positive output gap, but also CPI inflation above 10% at an annualized rate. Although the movements in CPI inflation are very short-lived, they highlight some of the tensions CPI inflation targeters might face due to exchange-rate volatility.

Some remarks on the role of exchange rate smoothing. Our model implies a relatively poor performance of the exchange rate peg, a finding that is reasonably common in the NK-SOE literature.⁴⁵ The financial channel we introduce increases the quantitative importance of commodity price shocks in this framework and generally warrants

larger rate cuts in commodity booms. Nevertheless our model does not fundamentally change the broad conclusion that there is not much need for exchange rate smoothing. This general dictum of inflation targeting and freely floating exchange rates has been officially adapted by many central banks around the world. The reduction in the pass-through from exchange rate movements to inflation may be a consequence of this broader change in policy style (see for example Jasova et al. 2016). In practice, however, exchange rate interventions are still relatively common. A recent policy speech by Carstens (2019) provides a comprehensive review of this tension.⁴⁶ Especially emerging market central banks in Asia and Latin America frequently intervene in currency markets by trading international reserves, and use a variety of other measures to limit the volatility of their exchange rate. In combination with an official pure inflation target these frequent interventions are sometimes referred to as “dirty floats.” In light of the theory, how can they be rationalized?

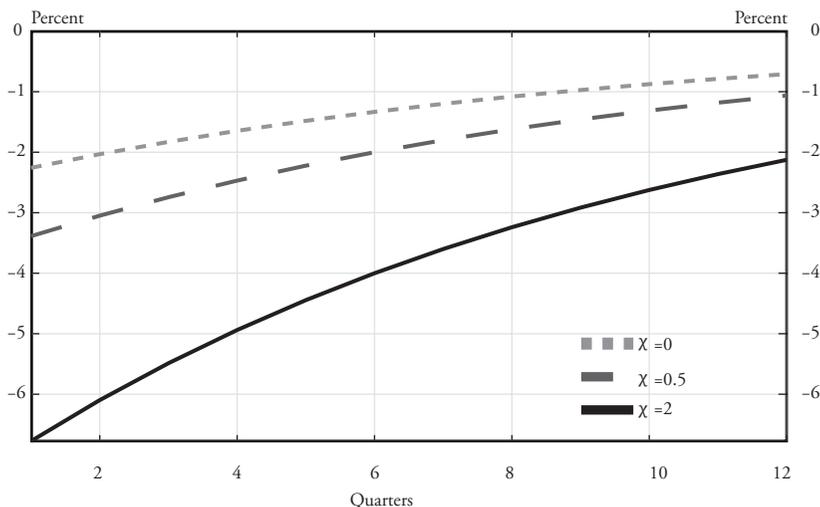
Policymakers in practice may respond to several trade-offs. One relevant mechanism are other kinds of financial frictions that fundamentally change the policy trade-offs. For example, important parts of the economy may face currency mismatches in their balance sheets. If firms’ revenues are denominated in local currencies but their liabilities in foreign currencies, a depreciation, despite other positive effects, exacerbates this mismatch and leads to financial distress in the corporate sector. This is highlighted for example by Chui et al. (2016). Our model abstracts from such mismatches and focuses on studying persistent commodity price shock. While trying to smooth exchange rate fluctuations in response to such shocks is futile, that practice appears more defensible in the face of short-lived shocks. Formalizing additional trade-offs theoretically in light of monetary policy questions, as done for example by Chang and Velasco (2006), is a promising avenue for research. In particular, studying them jointly with the persistent commodity price fluctuations we consider in our model should be a key issue on the research agenda. Finally, it would be interesting to extend a framework like ours to study capital controls, which would interact with exchange rate policy. See in particular the work on optimal capital controls by Farhi and Werning (2012, 2014).

A role for fiscal policy? The inefficiency of the commodity price boom in our model arises from the fact—discussed in detail in Section III.v.—that a constant employment subsidy cannot offset the distortion arising from the terms of trade externally. While our focus is on monetary policy, it may be conceivable that a well-coordinated fiscal policy is able to respond to commodity price shocks in a time-varying manner. This notion is emphasized in an important paper by Hevia and Nicolini (2013). To explore this idea in our model, we compute the optimal time-varying employment subsidy in a commodity price boom. Specifically, we compute the log deviation in $1 + \zeta$ from linearizing (37), that is, $\phi \hat{n}_t^e + \hat{c}_t^e - \hat{a}_{h,t}$ and then trace the response of this expression in response to a 10% commodity price shock for different values of χ . The results are shown in Chart 8.⁴⁷ The chart shows that the fiscal authority should cut the labor subsidy in the face of a commodity price boom. Importantly, this response is again more aggressive when a stronger financial channel amplifies the transmission of the commodity price shock.

The relevance of this prescription of course result depends on the case of interest. In emerging and developing economies, where commodity exports are often of key importance, there may be very tight constraints on fiscal policy. In fact, part of the problem in these economies may be the highly pro-cyclical nature of fiscal policy, which could even act as an amplifier on commodity price cycles.⁴⁸ For the most part of this paper we have therefore followed the NK tradition of focusing on the situation where fiscal policy is thought of as passive but monetary policy can react to economic conditions. That said, the role of fiscal policy in the face of commodity price shocks is an important area of research and we refer the reader to Hevia and Nicolini (2013), who provide a host of additional insights.

Take-aways. Our results highlight that commodity price fluctuations, in the presence of an amplification via a financial channel, pose a challenge for monetary policy. Specifically, the analysis conveys that monetary policy, even when carried out optimally, cannot fully stabilize the inefficient macroeconomic fluctuations stemming from the distortionary effects of commodity trade on domestic resource allocation. Optimal policy prescribes to hike rates in the face of a commodity price

Chart 8
Response of Employment Subsidy to Commodity Price Shock



Notes: IRFs of the required employment subsidy to a 10% positive commodity price shock for χ equal to 0, 0.5 and 2, respectively. The results are generated under the calibration shown in Table 1.

boom. While we also show how studying commodity price increases that are accompanied by strong global activity makes some of the model dynamics more appealing in light of empirical observations, there are important remaining limitations in applying our framework to the experiences of some emerging and developing economies. We provide a discussion on these in the following section.

V. Practical Policy Considerations for Emerging and Developing Economies

The results in the previous section shows how commodity price shocks introduce inefficient fluctuations that monetary policy cannot fully offset. But appropriate policy is nonetheless able to stabilize the economy and the price level in a short time period, once the shock has dissipated. In Section V.i. we detail that many emerging economies, in contrast, have suffered bouts of chronic inflation lasting several years. Since the mechanisms we study are especially applicable to emerging and developing economies, we discuss some channels not present in our model that might explain these experiences.⁴⁹ In particular, in Section V.ii., we examine *policy credibility*

and in Section V.iii. we explore the role of intrinsic *inflation inertia*. In Section V.iv. we then examine some case studies of attempts to disinflate in commodity-exporting emerging markets. These highlight some of the costs and benefits of different policy prescriptions for addressing chronic inflation. Finally, in Section V.v. we draw together the lessons from these case studies and discuss how the policy recommendations might depend on the stage of the commodity cycle.

V.i. Chronic Inflation and the Costs of Disinflation

Many emerging and developing economies, including several commodity exporters, suffer from what the literature has defined as chronic inflation (Pazos 1972). Precise definitions vary, but chronic inflation is generally taken to mean long periods of persistently high (but not explosive) inflation.⁵⁰ Our model, in line with much of the NK literature, is characterized around a zero inflation steady state, a reasonable abstraction for a typical low-inflation economy. Crucially, after a shock to our model economy, domestic inflation (the relevant policy variable) returns to target rapidly—within a single quarter under optimal policy following a persistent commodity-price shock. This seems at odds with the experience of the many economies that have experienced prolonged periods of very high inflation—often lasting several years.

How might initial conditions of high and persistent inflation affect the policy recommendations in the previous section? The answer partly depends on which features of these economies, not explicitly captured in our model, help explain their experiences. While now largely a developing or emerging country phenomenon, persistently high rates of inflation were the pre-eminent policy issue in advanced economies in the 1970s. So the question contains many parallels with historic monetary policy debates in advanced economies.⁵¹ At the time, one set of theories posited different forms of intrinsic inertia in the inflation process, which implied large real costs of disinflations.⁵² Rational expectations theories, supported by the historical evidence in Sargent (1982), asserted that inflation persistence stemmed largely from the behavior of monetary and fiscal policy.

While monetary models have become ever-more sophisticated over the past 40 years, the broad sets of theories that might explain persistent high inflation remain similar.⁵³ On the one hand, with rational expectations having become the dominant methodology, many models would pinpoint a lack of policy credibility: broadly defined to mean a widely believed and commonly understood commitment to lower inflation (e.g. Erceg and Levin 2003; Ascari and Ropele 2007; Sbordone 2007). On the other hand, in order to fit the observed persistence of inflation in the data, many estimated DSGE models now incorporate ad hoc sources of intrinsic inflation inertia (Galí and Gertler 1999; Christiano et al. 2005; Smets and Wouters 2007).⁵⁴ We next explore these different explanations in turn.

V.ii. Policy Credibility

There is a large literature, stemming from Barro and Gordon (1983), exploring the interaction between central banks' reputations and the credibility of their policy commitments. In particular, Backus and Driffill (1985a, b) and Barro (1986) highlight that when there is uncertainty about the government's preferences, uncommitted policymakers will have an incentive to masquerade as committed ones. Committed policymakers may have to earn their reputation at some cost to the real economy before a disinflation can be successful. If the degree of uncertainty is high and agents are relatively slow to learn, this cost could be significant.⁵⁵

These credibility issues are likely to be particularly stark in emerging and developing economies with histories of high inflation. Aizenman (2005) argues that credibility cannot be imposed given those initial conditions, and needs to be learned. If the learning process is based on past experience, then a history of chronic inflation may lead to a prohibitively slow and costly disinflation.⁵⁶ Even full commitment by the current authority may not be enough to establish credibility, since there is no way to commit all future possible monetary authorities.⁵⁷ A small possibility that a future government may renege on the anti-inflationary commitment could prevent agents coordinating on the desired low-inflation equilibrium.

An alternative possibility is that the lack of success in some developing and emerging economies at tackling chronic inflation is purely down to a failure to commit to doing so by policymakers. For example, some authors have suggested that inflation only appears persistent in the data when one does not account for changes in the monetary policy regime or rule.⁵⁸ Many estimated New Keynesian models aim to circumvent this issue by first removing a time-varying trend in inflation from the raw data (e.g. Christiano et al. 2005; Smets and Wouters 2007). The theoretical literature has also made progress in modeling these inflation trends explicitly, as surveyed by Ascari and Sbordone (2014).⁵⁹ But these models are designed primarily to analyze moderate non-zero trend inflation rates rather than the persistently high inflation rates experienced in many developing and emerging economies.⁶⁰ Moreover, they also suggest significant welfare costs of high trend inflation, with negligible offsetting benefits. If chronic inflation were solely due to inaction by policymakers, the models would lead us to question why, given the clear net benefits of disinflating.

V.iii. Inflation Inertia and Indexation

Historically, the literature has appealed to price and wage indexation as a key source of inflation inertia that leads to costly disinflation. Indexation is particularly likely to be prevalent in economies that have a history of high inflation, including many emerging economies, since it offers protection against some of the costs of inflation. This highlights how the degree of indexation is not a truly structural parameter, and will depend on the monetary regime.

Modern DSGE models used in the literature and in central banks nonetheless introduce various sources of intrinsic inflation inertia to better match the observed persistence in the inflation data.⁶¹ Galí and Gertler (1999) assume that a proportion of firms set prices according to a backward-looking rule of thumb. Christiano et al. (2005) assume that firms and workers who are not able to re-optimize their prices or wages are able to index them based on the previous period's inflation rate. Either setup leads to a reduced-form Phillips curve with a lagged inflation term and more inertial inflation dynamics.

Introducing these sources of inertia to modern, forward-looking models is not typically enough, on its own, to explain the chronic inflation seen in emerging economies. Wage indexation or other backward looking components generate hump shaped dynamics, but the models remain strongly mean reverting.⁶² This is because even with full indexation, the resulting hybrid Phillips curve still places as much weight on future inflation as on lagged inflation. Those firms who do re-optimize prices and wages still do so based on their rational expectations of future inflation. This forward-looking behavior, combined with expectations of a stabilizing monetary policy in future, is generally enough to quickly stabilize inflation.

To explain chronic inflation in emerging economies purely via intrinsic persistence is likely to require larger deviations from full information rational expectations. Various forms of bounded rationality also can introduce more inertia into the inflation process. But in many of these frameworks, departures from rationality are more likely when the costs of doing so are small. In economies with persistently high rates of inflation, we might expect agents to behave in ways that more closely approximate the rational benchmark.

The reality probably contains elements of each of these different explanations of high and persistent inflation. Given our current state of knowledge, a robust approach to disinflation might involve policies designed both to maximize credibility and to reduce intrinsic persistence. We next turn to some specific examples of emerging economies' experiences to explore how they have set out to achieve these aims.

V.iv. Case Studies

As illustrative examples of the severity of practical issues missing in our formal analysis, we describe four attempts to reduce inflation in particular commodity-exporting emerging economies. Specifically, We discuss disinflation policies implemented by: Argentina's 1985 *Austral Plan*; Mexico's 1987 *Pacto*; Argentina's 1991 *Convertibility Plan*; and Chile's 1991 introduction of an inflation target. Our descriptions draw on a range of more detailed analyses of each of the individual episodes, as well as comprehensive summaries of all of

these experiences (and others) in Latin American countries by Mishkin and Savastano (2001) and Frenkel and Rapetti (2010).

Argentina, 1985: The Austral Plan

In the aftermath of Argentina's military dictatorship, its economy was left with extremely high inflation, a large debt burden and sluggish economic growth. The *Austral Plan*, a comprehensive monetary-fiscal reform, was introduced in 1985 by the Alfonsín government.⁶³ The package of policies, which was encouraged by the IMF, involved a currency reform in which the peso was replaced by the austral, a large devaluation followed by a nominal exchange rate peg, but also various "incomes policies": measures such as wage and price freezes. These measures were intended to tackle the inertia in inflation from indexation and other coordination issues. Policymakers were worried that traditional fiscal and monetary measures by themselves were not sufficient and chose a drastic incomes policy approach to generate a disinflationary shock.

Initially, the plan was successful at reducing inflation—it fell rapidly, although remained at high levels. At the same time, real wages stayed relatively stable and the fiscal situation improved. The initial stabilization reversed when, with inflation remaining elevated, pressure started to rebuild for nominal wage increases and fiscal policy. Ultimately, the *Austral Plan* failed as policymakers gave in to pressure from unions and political opponents. Inflation accelerated again, leading to the introduction of the *Primavera Plan*, which placed less emphasis on fiscal restraint. Over the next few years, Argentina went through a cycle of increasingly drastic high inflations, followed by renewed and then aborted stabilization plans.

Mexico, 1987: Pacto

Chronic inflation had been a feature of the Mexican economy, an oil exporter, since the oil price shocks of the 1970s. With the currency pegged to the dollar, the Mexican government had responded to the increases in oil revenues and accompanying terms of trade improvement with highly expansionary fiscal policies. A turnaround in the external environment, including higher U.S. interest rates and a dol-

lar appreciation, led to a run on the currency and a government default in 1982 (van Wijnbergen 1990; Dornbusch and Werner 1994). High rates of inflation ensued for the rest of the decade and were accelerated by the oil price collapse in 1986, leading to an annual inflation rate of around 150% in 1987.

In response, the Mexican authorities launched the *Economic Solidarity Pact*, or *Pacto* in December 1987.⁶⁴ The plan initially involved a consensus agreement between government, unions and firms to impose short-term wage and price freezes, alongside tighter fiscal policy. The exchange-rate component of the plan evolved over time. The initial *Pacto* did not intend to use the currency as an explicit nominal anchor, but a fixed exchange-rate with the dollar was quickly introduced in 1988. This was changed to a crawling peg in 1989, and then an exchange-rate band from 1991.

In terms of inflation stabilization, the plan was highly successful.⁶⁵ Inflation fell rapidly to around 20% by 1990, and then gradually to single digits by 1993. Although the real exchange rate appreciated, the gradual moves toward greater flexibility allowed authorities to limit the appreciation more than with a hard peg. Mexico also benefited from supportive external events, in the form of moves toward trade liberalization; low international interest rates; and especially the 1989 *Brady Plan* to restructure its external debt, which led to sharply lower sovereign risk premia (van Wijnbergen 1990; Dornbusch and Werner 1994).

The success period came to a dramatic end with the *Peso Crisis* in 1994. Rising U.S. interest rates and pressure on the currency led to a decision to devalue, followed by an outright run and a decision to float the currency days later. A further depreciation upon floating precipitated an extremely damaging banking crisis and recession. Explanations of the causes abound, but tend to agree that despite the flexibility afforded by the exchange-rate regime, the currency had nonetheless become overvalued, partly as a result of vast capital inflows into the newly liberalized financial system.⁶⁶ As to why the devaluation led to a worsening in the crisis, the literature has variously pointed toward the role of dollar-denominated debt and of herding by investors triggering capital flight.

Argentina, 1991: The Convertibility Plan

After progressively worse bouts of inflation, the collapse of further stabilization plans and a soaring fiscal deficit tipped Argentina twice into outright hyperinflation, with annual inflation rates reaching the thousands in 1989 and 1990. Orthodox fiscal and monetary measures twice brought inflation back down temporarily, but when threatened by a third hyperinflation episode, the new Menem administration launched the *Convertibility Plan* in 1991.

As described in Canavese (1992), Cavallo and Cottani (1997) and elsewhere, the plan had multiple elements. Most visibly, a new currency, the peso, replaced the austral at a fixed exchange rate of parity with the U.S. dollar. A currency board system was established by law. To address inflation inertia, price indexation was abolished and contracts rewritten in dollars. It was also accompanied with a number of supply-side measures to liberalize trade and capital flows and a large-scale privatization program. Importantly, the plan managed to achieve greater consensus with labor unions than previous attempts (Bambaci et al. 2002).

The plan was an immediate success. Inflation fell rapidly to around 25% in 1992, and to single digits for the remainder of the decade. Although inflation was stabilized relatively quickly, the real exchange rate appreciated. Fiscal policy did not run large deficits, although nor did it generate surpluses over the decade. Consumption also grew robustly alongside the real exchange rate appreciation, leading to current account deficits and growing external debt.

The large stock of external debt, much of it denominated in dollars, coupled with the appreciation of the real exchange rate, left Argentina vulnerable to any reversals that required a sharp real depreciation. Beginning in 1998, this vulnerability was realized, triggered first by a sudden reversal of capital flows following the Russian crisis, and then amplified by a sharp fall in commodity prices. In turn, lower commodity income worsened tax revenues, leading to a fiscal tightening and recession. They also led to a devaluation of the Brazilian currency, further increasing the pressure on the Argentinian

exchange-rate peg to devalue. The series of events culminated in the dramatic currency and financial crisis of 2001-02.

Chile, 1990: Inflation Targeting

The disinflation experience of Chile serves as a counterpoint to the previous three examples, both in terms of context and implementation. Having experienced annual inflation rates well above 100% in the 1970s, inflation was stabilized at rates below 30% throughout the 1980s. It was against this relatively favorable backdrop that the central bank was made independent in 1989, and became an early adopter of inflation targeting in 1990, with inflation standing at around 25%. (Albeit that the regime did not initially include some of the aspects now commonplace among inflation-targeting central banks, as argued by Mishkin and Savastano 2001).⁶⁷

The inflation target was initially a range set slightly below the prevailing rate of inflation. It was accompanied by a (looser) target for the current account deficit, to be achieved via a combination of a wide crawling exchange rate band and selective capital controls. The inflation objective was itself seen as a means to tackle widespread indexation in contracts, by giving price and wage setters a clear and transparent target for price increases (Morandé 2002).

Under the regime, Chile achieved a slow reduction in inflation during the 1990s, reaching 5% by 1998. The inflation target was reduced further each year. This was done in gradual steps, which served to limit output costs given the degree of indexation. A more flexible exchange rate regime than the previous examples allowed Chile to maintain a relatively stable real exchange rate over the period. The range target was adapted to a point target after 1996, and the currency allowed to float freely from 1999.

V.v. Lessons from the Case Studies

What can we learn from these historical episodes in Latin America? We should be cautious in inferring too much from a small number of cases, each of which took place under very different domestic and international backdrops, and each incorporated a diverse array of policy decisions. Nonetheless, we would argue that these examples

are indicative of two general prescriptions that are absent from our model but are relevant for high-inflation emerging and developing economies.

- Exchange-rate pegs are a double-edged sword. They can bring greater policy credibility to a disinflation, but can create major risks if the currency becomes overvalued. It seems that while a credible and sustainable fiscal policy is necessary, it is not a sufficient condition for a successful disinflation.
- Heterodox policies that reduce inflation inertia may make disinflations less costly, but only if they can be designed in a way that is consistent with authorities' monetary and fiscal policies.

We now discuss the costs and benefits of these policy tools in turn, highlighting as we do the insights from our model as to how the commodity cycle might impact the success of the disinflation.

Advantages of exchange-rate based disinflations. Since many developing and emerging economies do not have a history of credible anti-inflation policies, an oft-cited advantage of committing to an exchange-rate peg is that authorities can “borrow” credibility from low-inflation economies. Mechanisms that make it costlier to renege on the commitment are likely to increase its credibility, with Argentina's adoption of a currency board a quintessential example. Clear and highly visible commitments, such as introducing a new currency, may also help coordinate beliefs.

Exchange rate pegs can also help reduce inflation expectations. In our model, the welfare optimal policy allows the exchange rate to fluctuate as it only aims to stabilize domestic prices. In response to a negative commodity-price shock, the exchange-rate depreciation leads to a sharp rise in CPI inflation. By contrast, an exchange rate peg leads to a smaller initial impact. If policy is not fully credible, as is more likely in chronic-inflation economies, such a rise in CPI inflation may increase inflation expectations, in turn feeding into higher domestic price inflation. The effect, missing from our model, may help explain why some emerging-economy commodity

exporters find it optimal to lean aggressively against exchange-rate fluctuations (Calvo and Reinhart 2002).

The experience of Chile shows that a *credible* inflation target can also help to bring down inflation expectations, but for countries with much higher initial inflation, an exchange rate peg may have two short-run advantages. First, the exchange rate is immediately observable, which can help achieve a faster disinflation if agents do not fully trust that the new policy will be implemented. With intrinsic inertia in inflation, any reduction in inflation will take some time, which may increase skepticism in the policy. Second, the costs of an exchange-rate based stabilization tend to arrive later than one achieved via interest rate policy, especially if accompanied by an initial devaluation, as in the *Austral Plan* and Mexican *Pacto* (Reinhart and Végh 1994). This can buy time to implement other policies that may help reduce inertia.

Risks of exchange-rate pegs. The major drawback of implementing a nominal exchange-rate peg in a high inflation economy is that it tends to lead to a real appreciation in the currency (Dornbusch et al. 1990; Végh 1992; Reinhart and Végh 1994; Kiguel and Liviatan 1995; Frenkel and Rapetti 2010). With a fixed nominal exchange rate, then the real exchange rate will appreciate as long as inflation remains higher than abroad, which is likely if there is some inflation inertia. As evidenced by the 1994 Mexican crisis and 2001-02 Argentinian crisis, the eventual result of an overvalued currency with a fixed exchange rate is often a devastating currency crisis. Moreover, our analysis shows that in commodity-exporters, the fundamentals driving the exchange rate are liable to be subject to large swings. A sharp fall in commodity-export prices as occurred in Argentina from 1998, amplified by a tightening in financial conditions, may cause a previously sustainable peg to quickly become unsustainable.

Our model is also able to shed light on the optimal timing of an exchange-rate based disinflation for a commodity exporting economy. Since the key drawback is that the ensuing real appreciation may not be what is required by the fundamentals, the disinflation is best implemented when an appreciation is actually required. In our model, this is when there is a positive commodity price shock and

when financial conditions are loose. More flexible managed exchange rate regimes appear able to keep the real exchange rate better-aligned with fundamentals: compare Mexico's crawling peg to Argentina's fixed peg. But such a policy negates some of the credibility benefits of a clear commitment to a fixed nominal peg. Short of full dollarization, it may be that a currency peg is only ever a temporary solution, which "must give way to a more flexible rate regime that does not risk cumulative overvaluation" (Dornbusch et al. 1995). Since commodity price swings are exogenous to small commodity exporters, what should policymakers do if they are unable to build up the necessary credibility to switch to a floating regime? The case studies suggest that by slowing the real appreciation, policies to tackle inflation inertia may help.

Advantages of heterodox disinflation policies. Several of the case studies were, to some degree, heterodox programs that also included policies aimed at tackling intrinsic inflation inertia. Income policies of wage and price controls, while controversial among economists, helped to shift behaviors more rapidly toward a new equilibrium. Similarly, policies seeking consensus among different stakeholders were implemented alongside Argentina's Convertibility Plan. The agreements required union representatives to depart from their individually rational strategy of continuing to push for higher nominal wages. Collective agreement typically requires trust and successful communication. This can be hard to achieve, since the information sets and the preferences represented by union leaders can be very different to those officials negotiating with them. Negotiators who understand well the motivations of the other side may be more effective at avoiding breakdowns in communication and ultimately in trust.

Risks of heterodox policies. The biggest challenge for heterodox programs is that policies must be calibrated to be consistent with each other. First and foremost, there needs to be fiscal discipline—without which any plan is almost certain to fail. But the ultimate failure of some of the cases we discuss, despite fiscal discipline, suggests that this is a necessary condition not a sufficient one. Income policies may help as part of a policy package, but without a credible commitment to lower inflation, they are liable to lead only to

shortages, as with any price ceilings. The *Austral Plan* also highlights a related risk, once a disinflation is underway. If the plan involves a range of different policies, there may be uncertainty over which parts of the package are most important. This can increase the risk that policymakers backslide on the crucial but costly orthodox components of the plan: the need for fiscal and monetary discipline.

Summary

The model we propose in this paper is useful in disciplining our thoughts on the appropriate policy responses to commodity-price shocks. However, the practical experience of many commodity-driven economies, which may have histories or initial conditions of high inflation, may require a more nuanced approach. A variety of tools, including exchange-rate management, have benefits (and potential costs) outside the scope of our model recommendations. Our model also takes for granted that fiscal policy is on a sustainable path. The examples we provide suggest that this is a key necessary condition for success, but not sufficient. To attain credibility and reduce inertial inflation, authorities need to implement a coherent and consistent set of policies, but also to build consensus via a clear communication process that persuades people of the benefits of working together to achieve low inflation. We think research still has more to discover to inform the advice we offer policymakers in these circumstances.

VI. Conclusion

The growing contribution of commodity price shocks to business cycles, their role in relaxing borrowing constraints and the discussion around the financialization of commodity markets make it ever more important to think about the potentially special role of commodity trade in setting monetary policy. In this paper we have proposed a model in which the presence of a commodity sector triggers inefficient booms and busts. We highlight that these can be amplified when commodity prices drive financial conditions in the economy. The model implies that monetary policy, faced with a stabilization trade-off, fares relatively well with a domestic inflation target and a floating exchange rate. We have also pointed out crucial limitations of our framework. High inflation remains the primary challenge in many emerging and developing economies, requiring a long and uncertain transition

toward the low-inflation conditions where the model recommendations are of most relevance. More work on understanding the policies to achieve that transition should be a priority.

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Appendix A

Full Linearized Model

Relative price relations and resource constraint.

$$\hat{p}_t = \alpha \hat{p}_{f,t} + (1 - \alpha) \hat{p}_{h,t} \quad (54)$$

$$\hat{\tau}_t = \hat{p}_{f,t} - \hat{p}_{h,t} \quad (55)$$

$$\hat{s}_t = (1 - \alpha) \hat{\tau}_t \quad (56)$$

$$\hat{y}_{h,t} = s_{c,ss} \hat{c}_{h,t} + s_{m,ss} \hat{m}_{h,t} \quad (57)$$

Households.

$$\hat{c}_{h,t} = \alpha \hat{\tau}_t + \hat{c}_t \quad (58)$$

$$\hat{c}_{f,t} = (\alpha - 1) \hat{\tau}_t + \hat{c}_t \quad (59)$$

$$\phi \hat{n}_t + \hat{c}_t = \hat{w}_t - \hat{p}_t \quad (60)$$

$$= \widehat{mc}_t + \hat{a}_{h,t} - \alpha \hat{\tau}_t \quad (61)$$

$$\hat{c}_t = -(i_t - \mathbb{E}_t \hat{\pi}_{t+1}) + \mathbb{E}_t \hat{c}_{t+1} \quad (62)$$

$$\hat{c}_t = \hat{y}_t^* + (1 - \alpha) \hat{\tau}_t \quad (63)$$

Domestic goods sector.

$$\hat{y}_{h,t} = \hat{a}_{h,t} + \hat{n}_t \quad (64)$$

$$\hat{\pi}_{h,t} = \beta \mathbb{E}_t \hat{\pi}_{h,t+1} + \kappa \hat{mc}_t \quad (65)$$

$$\hat{mc}_t = \hat{w}_t - \hat{p}_{h,t} - \hat{a}_{h,t}. \quad (66)$$

Commodity sector. Production technology in the commodity sector is

$$\hat{y}_{c,t} = \hat{a}_{c,t} + \nu \hat{m}_{h,t}. \quad (67)$$

The demand for intermediate inputs from the commodity sector in the case where the working capital constraint binds (does not bind) is given by

$$(1 - \nu)\hat{m}_{h,t} = (1 + \chi)\hat{p}_{c,t}^* + \hat{\tau}_t + \hat{a}_{c,t} \tag{68}$$

$$(1 - \nu)\hat{m}_{h,t} = \hat{p}_{c,t}^* + \hat{\tau}_t + \hat{a}_{c,t} . \tag{69}$$

Derivation of efficient levels. We derive an expression for the efficient levels of domestic output and the trade balance in the log-linear system, $\hat{y}_{h,t}^e$ and $\hat{\tau}_t^e$, by log-linearizing (34) and eliminating $\hat{c}_{h,t}^e, \hat{m}_t^e$ and \hat{n}_t^e using household optimality conditions. This gives us an equation in $\hat{y}_{h,t}^e$ and $\hat{\tau}_t^e$ which we combine with the resource constraint to solve out for these variables as

$$\hat{y}_{h,t}^e = \frac{(1 + \phi)\mathcal{W}_{ss}\hat{a}_{h,t} + \left(\frac{\lambda_\tau}{\mathcal{W}_{ss}} - 1\right)s_{c,ss}\hat{y}_t^* - \frac{s_{c,ss}s_{m,ss}\nu}{\mathcal{W}_{ss}(1 - \nu)^2}(\hat{a}_{c,t} + (1 + \chi)\hat{p}_{c,t}^*)}{\frac{\lambda_\tau}{\mathcal{W}_{ss}} + \phi\mathcal{W}_{ss}} \tag{70}$$

$$\hat{\tau}_t^e = \frac{(1 + \phi)\mathcal{W}_{ss}\hat{a}_{h,t} - (1 + \phi\mathcal{W}_{ss})s_{c,ss}\hat{y}_t^* - \frac{s_{m,ss}}{1 - \nu}\left(\phi\mathcal{W}_{ss} + \frac{1}{1 - \nu}\right)(\hat{a}_{c,t} + (1 + \chi)\hat{p}_{c,t}^*)}{\phi\mathcal{W}_{ss}^2 + \lambda_\tau} . \tag{71}$$

Following FS, we have defined $\lambda_\tau = s_{c,ss} + \frac{s_{m,ss}}{(1 - \nu)^2}$ and note that

$$\lambda_\tau > \mathcal{W}_{ss} . \text{ For compactness of notations, we denote } \frac{\ln(P'_{c,t} / P'_{c,ss})}{\ln(P'_t / P'_{ss})} \text{ as } \hat{p}_{c,t}^*$$

so that $\hat{p}_{c,t}^*$ represents exogenous percentage variation in the dollar price of commodities. It is visible in (70) and (71) how the elasticity χ increases the sensitivity of the efficient allocations to variation in $\hat{p}_{c,t}^*$.

Derivation of natural levels. We derive the natural counterparts to these expressions above. These will differ (in deviations from steady state) from the efficient level due to the presence of the commodity sector. Using the log-linearized firm optimality condition in

the absence of price rigidities (where marginal costs are constant and thus $\hat{m}c_t = 0$), we obtain

$$\hat{y}_{h,t}^n = \frac{(1 + \phi)\mathcal{W}_{ss}\hat{a}_{h,t} + \frac{s_{m,ss}}{1 - \nu}(\hat{a}_{c,t} + (1 + \chi)\hat{p}_{c,t}^* - \hat{y}_t^*)}{1 + \phi\mathcal{W}_{ss}} \quad (72)$$

$$\hat{\tau}_t^n = (1 + \phi)\hat{a}_{h,t} - \hat{y}_t^* - \phi\hat{y}_{h,t}^n. \quad (73)$$

In line with the discussion in the main text, we can now see formally that $\hat{y}_{h,t}^n \neq \hat{y}_{h,t}^e$ and $\hat{\tau}_{h,t}^n \neq \hat{\tau}_{h,t}^e$ unless $s_{m,ss} = 0$ and thus $W_{ss} = \lambda_\tau = 1$.

Additional constraints. In addition to the NKPC and the IS curve, the set of constraints for the policymaker is completed by

$$\hat{\pi}_t = \hat{\pi}_{h,t} + \alpha(\hat{\tau}_t - \hat{\tau}_{t-1}) \quad (74)$$

$$\hat{\pi}_{h,t} = \mathcal{W}_{ss}(\hat{\tau}_t - \hat{\tau}_t^e) \quad (75)$$

$$\hat{c}_t^e = \frac{1 - \alpha}{\mathcal{W}_{ss}} \left[\frac{s_{m,ss}}{1 - \nu}(\hat{a}_{c,t} + (1 + \chi)\hat{p}_{c,t}^*) + \left(s_{c,ss} - \frac{\mathcal{W}_{ss}}{1 - \alpha} \right) \hat{y}_t^* \right]. \quad (76)$$

Derivation of the loss function. The key idea is to rewrite the utility function of the representative household using the aggregate production function as

$$\mathbb{W} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\ln C_t - \frac{[Y_{h,t} / A_{h,t}]^{1+\phi}}{1 + \phi} \Delta_t^{1+\phi} \right]. \quad (77)$$

It can be shown that a second order Taylor expansion of this expression around the zero inflation steady state (with the terms of trade normalized to unity), yields the expression

$$\mathbb{W} = \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \mathcal{L}_t \right\} + t.i.p. + \mathcal{O}^3 \quad (78)$$

with the period loss function given by

$$\mathcal{L}_t = -\frac{\Omega}{2} (\hat{\pi}_{h,t}^2 + \lambda_x \hat{x}_{h,t}^2), \quad (79)$$

and there *t.i.p* denotes “terms independent of policy” and \mathcal{O}^3 are all terms of order 3 or higher. The steps involved in this derivations are very similar to Ferrero and Seneca (2018) and we refer to Section 7 of their Online Appendix for the full details. See also the Appendix to Chapter 4 of Galí (2015) and the relevant chapters in Woodford (2003b).

Appendix B

Financial Autarky Version of the Model

This appendix sets out a version of our model featuring financial autarky, as discussed in Section IV of the main text. Under financial autarky, the setup of the domestic goods and commodity production sectors are unchanged from those presented in Section III. The only difference in the household optimization problem is that we assume that domestic households no longer have access to assets traded on world markets. They do, however, still have access to a full set domestically traded contingent securities, such that we have the same consumption Euler equation (13).

Balanced trade and household consumption. Under financial autarky, there is no longer international risk sharing, so condition (14) no longer holds to determine aggregate consumption. Instead, with no international trade in financial assets, the nominal value of consumption must always equal nominal value added production. We assume domestically-produced goods are not exported ($\alpha^* = 0$), so value added consists of home consumption goods, plus commodity production:

$$\begin{aligned} P_t C_t &= P_{h,t} (Y_{h,t} - M_{h,t}) + P_{c,t} Y_{c,t} \\ &= P_{h,t} C_{h,t} + P_{c,t} Y_{c,t}. \end{aligned} \tag{80}$$

Noting that the home consumption good demand curve (9) can be combined with imported good demand (10) to give

$$P_{h,t} C_{h,t} = P_t C_t - P_{f,t} C_{f,t}, \tag{81}$$

then substituting this into (80), and using the fact that the law of one price holds for foreign goods, highlights that the same condition can also be expressed as balanced trade:

$$\mathcal{E}_t P_{f,t}^* C_{f,t} = P_{c,t} Y_{c,t}. \tag{82}$$

To derive equations for home consumption of imported and domestically produced goods, and in aggregate, we first divide this equation through by P_t to give

$$\frac{\mathcal{E}_t P_{f,t}^*}{P_t} C_{f,t} = \frac{P_{c,t}}{P_t} Y_{c,t}. \quad (83)$$

We then use (19) to convert the relative price of commodities to international prices, and divide through by $\mathcal{T}^{1-\alpha}$ to give foreign (imported) good consumption as

$$C_{f,t} = \frac{P_{c,t}^*}{P_t^*} Y_{c,t}. \quad (84)$$

Given balanced trade, foreign good consumption is equal to commodity exports at world prices, deflated by world CPI. In stark contrast to the model under risk sharing, foreign consumption moves one-for-one with commodity income. Using this equation to substitute out, in turn, for $C_{f,t}$ in the relative demand for foreign goods (10) and for C_t in the relative demand for home goods (9) gives equivalent conditions for total and home good consumption:

$$C_t = \frac{P_{c,t}^*}{\alpha P_t^*} \mathcal{T}_t^{1-\alpha} Y_{c,t}, \quad (85)$$

$$C_{h,t} = \frac{(1-\alpha)P_{c,t}^*}{\alpha P_t^*} \mathcal{T}_t Y_{c,t}, \quad (86)$$

where

$$Y_{c,t} = A_{c,t} M_{h,t}^\nu = A_{c,t}^{\frac{1}{1-\nu}} \left(\bar{\chi} \left[\frac{P_{c,t}^*}{P_t^*} \right]^{1+\chi} \mathcal{T}_t \right)^{\frac{\nu}{1-\nu}}. \quad (87)$$

Despite the different asset market structure, consumption still depends positively on the terms of trade, i.e., a real depreciation boosts consumption. Under autarky, this occurs in part directly due to a substitution effect from foreign to domestic good consumption. It also occurs indirectly, via a wealth effect from increased commodity production ($Y_{c,t}$ depends positively on \mathcal{T}_t since the depreciation increases the profitability of commodity exports in terms of the CPI index).

Other than the terms of trade, consumption depends only on exogenous variables: the real price of commodities on global markets;

commodity sector productivity and the exogenous parameters determining the severity of the financial constraint.

Efficient and natural allocation. The market clearing conditions and equilibrium definition are as under risk sharing. The efficient allocation under financial autarky is the solution of the planner problem, which can be written, using (85) and (86), as

$$\max_{\mathcal{T}_t, N_t} \left\{ \ln \left(\frac{P_{c,t}^*}{\alpha P_t^*} \mathcal{T}_t^{1-\alpha} Y_{c,t} \right) - \frac{N_t^{1+\phi}}{1-\phi} \right\} \quad (88)$$

subject to

$$A_{h,t} N_t = \frac{(1-\alpha) P_{c,t}^*}{\alpha P_t^*} \mathcal{T}_t Y_{c,t} + M_{h,t}, \quad (89)$$

as well as the commodity producers' production function (18) and input demand (28). The solution to this problem is

$$\left(\frac{1}{1-\nu} - \alpha \right) Y_{h,t}^e = (N_t^e)^{1+\phi} \left[\frac{1}{1-\nu} C_{h,t}^e + \frac{1}{1-\nu} M_{h,t}^e \right], \quad (90)$$

which reduces to a constant efficient employment level satisfying

$$(N_t^e)^{1+\phi} = 1 - \alpha(1-\nu). \quad (91)$$

Comparing to the equivalent condition under perfect risk sharing, we can see that this result is obtained because under financial autarky, home consumption and commodity production both have the same elasticity with respect to the terms of trade of $\frac{1}{1-\nu}$. In turn, this arises due to our assumption of a unit elasticity of substitution, which ensures that there is no expenditure switching, and from balanced trade combined with perfect competition in the commodity sector. These assumptions mean that unlike under risk sharing, commodity sector expansions feed through fully into commodity sector revenues and, via increased household wealth, into consumption.

We can also derive the natural allocations that would obtain under flexible prices. We first substitute out the real wage in the household labor supply condition (12) using firms' labor demand under flexible

prices (the term inside the summation of equation (16)) as well as $P_{h,t} = P_t T_t^{-\alpha}$ from the definition of the terms of trade, to give

$$(1 + \zeta) \frac{\epsilon - 1}{\epsilon} A_{h,t} (\mathcal{T}_t^n)^{-\alpha} = C_t^n (N_t^n)^\phi \quad (92)$$

or equivalently

$$\frac{\epsilon}{(\epsilon - 1)(1 + \zeta)} (N_t^n)^{1+\phi} = \frac{(\mathcal{T}_t^n)^{-\alpha}}{\frac{C_t^n}{Y_{h,t}}} = \frac{1 - \alpha}{\frac{C_{h,t}^n}{Y_{h,t}}} \quad (93)$$

where the second equality comes from substituting out \mathcal{T}_t^n using the relative demand for home consumption goods (9). To calculate the efficient subsidy, we can further substitute (85) and the domestic good production function under flexible prices ($Y_{h,t}^n = A_{h,t} N_t^n$) into (93) to give

$$\frac{\epsilon}{(\epsilon - 1)(1 + \zeta)} (N_t^n)^\phi = \frac{\alpha A_{h,t}}{\frac{P_{c,t}^*}{P_t^*} Y_{c,t}^n \mathcal{T}_t^n} . \quad (94)$$

Next, noting from the commodity production function that $M_{h,t} = \frac{Y_{c,t} M_{h,t}^{1-\nu}}{A_{c,t}}$, we can rewrite the resource constraint under flexible prices as

$$N_t^n = \frac{C_{h,t}^n + \frac{Y_{c,t} M_{h,t}^{1-\nu}}{A_{c,t}}}{A_{h,t}} . \quad (95)$$

Substituting out for $C_{h,t}^n$ using (85) and $M_{h,t}^n$ using (28) implies that

$$\begin{aligned}
 N_t^n &= \frac{(1-\alpha)P_{c,t}^* \mathcal{T}_t^n Y_{c,t}^n + \bar{\chi} \left[\frac{P_{c,t}^*}{P_t^*} \right]^{1+\chi} \mathcal{T}_t^n Y_{c,t}^n}{A_{h,t}} \\
 &= \left(1 - \alpha + \alpha \bar{\chi} \left[\frac{P_{c,t}^*}{P_t^*} \right]^\chi \right) \frac{\frac{P_{c,t}^*}{P_t^*} \mathcal{T}_t^n Y_{c,t}^n}{\alpha A_{h,t}}.
 \end{aligned}
 \tag{96}$$

Finally, combining this with the previous equation gives

$$\frac{\epsilon}{(\epsilon-1)(1+\zeta)} (N_t^n)^{1+\phi} = 1 - \alpha + \alpha \bar{\chi} \left[\frac{P_{c,t}^*}{P_t^*} \right]^\chi. \tag{97}$$

If $\bar{\chi} \left[\frac{P_{c,t}^*}{P_t^*} \right]^\chi = \chi_t < v$ as we assume to ensure that the constraint binds in steady state, then the presence of the commodity sector means that the subsidy to correct monopolistic distortions will result in an inefficiently low level of steady state employment. A larger subsidy of $1+\zeta = \frac{\epsilon(1-\alpha(1-v))}{(\epsilon-1)(1-\alpha(1-\chi_t))}$ will be needed to ensure employment and output are at their efficient levels.

Interestingly, in the absence of the financial friction ($\chi = 0$), the flexible price level of output does not vary in response to shocks to commodity prices, so remains efficient given the subsidy. In contrast, the financial friction ($\chi > 0$) introduces a time-varying wedge between the natural and efficient rates of output and employment in response to commodity-price fluctuations. This difference arises because the friction amplifies the elasticity of commodity output with respect to prices. Commodity price fluctuations therefore cause inefficient reallocations between the domestic good and commodity sectors, exactly as in the risk-sharing model.

Log linearized model and loss function. The log linearized version of the model is almost as before, with the only change to the main model equations being the log linearized risk-sharing condition

(63), which can be replaced by the log linearized version of equation (85):

$$\hat{c}_t = \hat{p}_{c,t}^* + \hat{y}_{c,t} + (1 - \alpha)\hat{\tau}_t. \quad (98)$$

Since the efficient level of employment is a constant, we also have that $\hat{n}_t^e = 0$ and

$$\hat{y}_{h,t}^e = \hat{a}_{h,t}. \quad (99)$$

And we can substitute this into the resource constraint and solve for the efficient terms of trade:

$$\hat{\tau}_t^e = (1 - \nu)\hat{a}_{h,t} - \hat{a}_{c,t} - \left[1 + \chi(\nu + (1 - \nu)s_{m,ss})\right]\hat{p}_{c,t}^*. \quad (100)$$

Similarly, log linearizing (97) and substituting in the production function gives the natural level of output

$$\hat{y}_{h,t}^n = \hat{a}_{h,t} + \frac{\chi s_{m,ss}}{1 + \phi} \hat{p}_{c,t}^*, \quad (101)$$

with the natural terms of trade given by

$$\hat{\tau}_t^n = (1 - \nu)\hat{a}_{h,t} - \hat{a}_{c,t} - \left[1 + \chi\left(\nu + \frac{\phi(1 - \nu)s_{m,ss}}{1 + \phi}\right)\right]\hat{p}_{c,t}^*. \quad (102)$$

Again, this illustrates that if $\chi > 0$, $\hat{y}_{h,t}^n \neq \hat{y}_{h,t}^e$ and $\hat{\tau}_{h,t}^n \neq \hat{\tau}_{h,t}^e$, unless $s_{m,ss} = 0$. But differently from under risk sharing, the natural rates are also efficient if $\chi = 0$.

The steps to derive the second-order approximation to consumer welfare are similar to under risk sharing and in FS, and lead to a monetary policy loss function of the same form as (44) and (45), but with weights given instead by

$$\Omega = (1 - \alpha(1 - \nu))\frac{\epsilon}{\kappa} \quad (103)$$

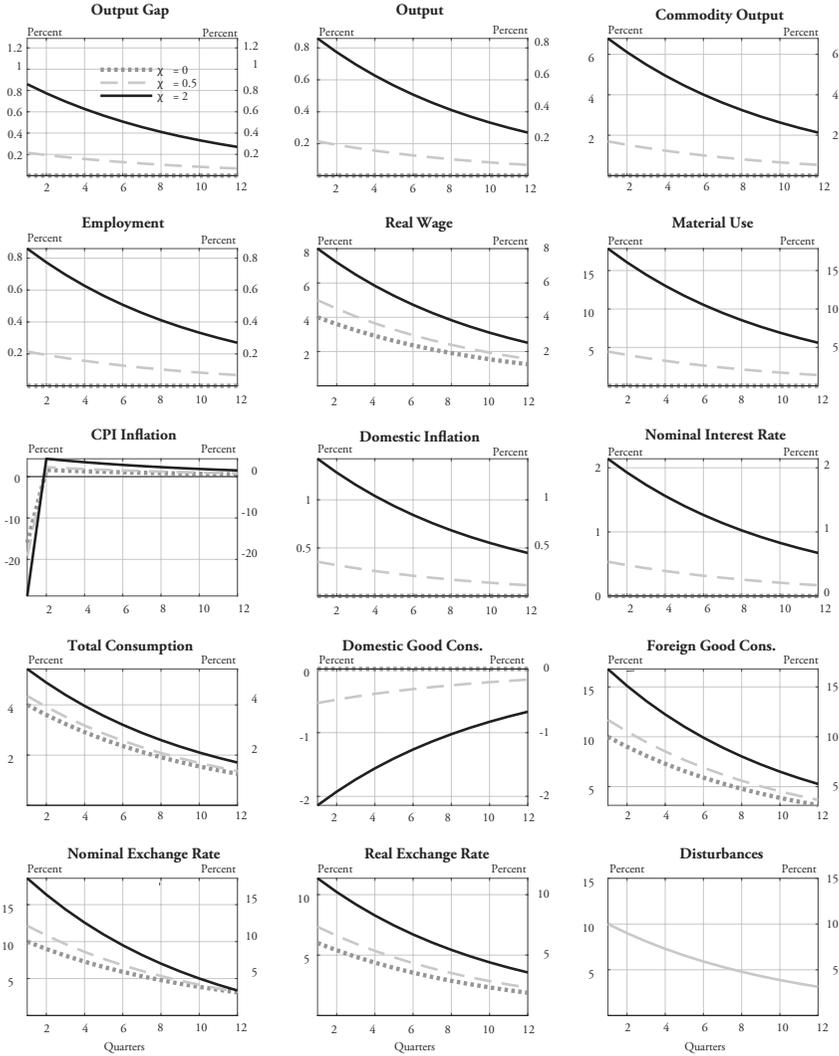
$$\lambda_x = \frac{\kappa}{\epsilon}(1 + \phi). \quad (104)$$

The weight placed on the output gap relative to inflation deviations, λ_x , is identical to that derived for a small open economy with no commodity sector in Galí and Monacelli (2005).

Results. The key differences in the transmission of the commodity price shock under financial autarky are discussed in Section IV of the main text. Charts B1 and B2 show the responses to a 10% commodity price rise respectively, under different strengths of the financial channel and under different policy rules.

As discussed above, with no financial friction, there is no inefficient boom in output under financial autarky. As a result, a domestic inflation targeting rule effectively stabilizes the economy entirely via an efficient appreciation of the exchange rate. The price increase feeds through only to a temporary fall in CPI inflation and rise in the real wage, which is spent on higher foreign consumption. Away from that nested case, the financial friction leads to an inefficient boom, and similar intuition as under risk sharing explains the qualitative responses of the key endogenous variables and of monetary policy.

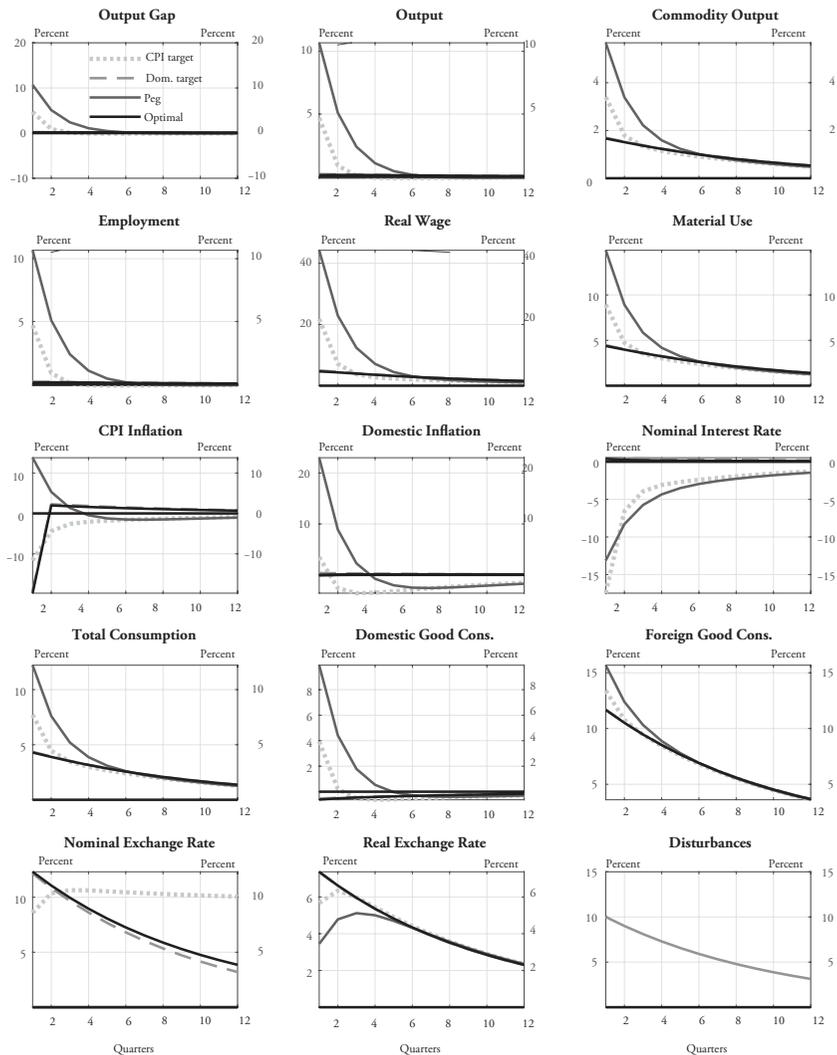
Chart B1
IRFs to Commodity Price Shock with Financial Autarky
for Varying Strength of the Financial Channel



Notes: IRFs to a 10% positive commodity price shock in the financial autarky version of the model described in Appendix B. The light dotted, medium dashed and dark solid lines show the responses of key variables for χ equal to 0, 0.5 and 2, respectively. The results are generated under the calibration shown in Table 1 with a domestic inflation targeting rule and $\varphi_b = 1.5$. Inflation and interest rates are shown in annualized percent. The nominal and real exchange rates are plotted as \hat{e}_t^{-1} and \hat{s}_t^{-1} so that an increase corresponds to an appreciation.

Chart B2

IRFs to Commodity Price Shock with Financial Autarky Under Different Policy Rules



Notes: IRFs to a 10% positive commodity price shock under alternative policy rules in the financial autarky version of the model described in Appendix B. The results are generated under the calibration shown in Table 1, setting $\chi = 0.5$. Inflation and interest rates are shown in annualized percent. The nominal and real exchange rates are plotted as \hat{e}_t^{-1} and \hat{s}_t^{-1} that an increase corresponds to an appreciation.

Endnotes

¹This result holds both in estimated structural macroeconomic models and in structural vector autoregressions (SVARs). While there has been disagreement over the level of these effects across estimation approaches (see Schmitt-Grohe and Uribe 2018), we point out that their increasing trend is a finding robust across methodologies.

²See in particular Bastourre et al. (2012), Shousha (2016), Fernandez et al. (2018) and Drechsel and Tenreyro (2018).

³These developments have been discussed extensively both in financial markets commentary and in the academic literature, as surveyed by Cheng and Xiong (2014).

⁴We use a New Keynesian small open economy (NK-SOE) model in the tradition of Galí and Monacelli (2005). To incorporate commodities, we draw extensively on the framework recently proposed by Ferrero and Seneca (2018).

⁵Building on the framework of Ferrero and Seneca (2018) has the advantage that the stabilization trade-off is present even in the unitary elasticity case studied by Galí and Monacelli (2005). The model does not feature the “divine coincidence” property, but consumer welfare can still be approximated using a second order expansion of utility around the steady state. This allows a tractable characterization of optimal policy.

⁶See Hevia and Nicolini (2013) for an important contribution studying monetary-fiscal policy coordination in an economy that uses traded commodities as an input in domestic production.

⁷See also Lombardo and Ravenna (2014) for a study on the determinants of openness and their implication for optimal policy. Leibovici and Santacreu (2016) focus on linking the Galí and Monacelli (2005) framework more explicitly to empirically observed international trade fluctuations. Wei and Xie (2019) incorporate global supply chains and Arellano et al. (2019) explore sovereign default. For a study on optimal monetary policy in the presence of a financial accelerator, but in a closed economy setting, see Leduc and Natal (2018).

⁸There is also a literature that focuses on monetary policy for commodity importers, especially in the case of oil imports. See for example Kormilitsina (2011) and Natal (2012).

⁹Recent examples include Aguiar and Gopinath (2007), García-Cicco et al. (2010), Chang and Fernandez (2013), Shousha (2016), Fernández et al. (2018), Kohn et al. (2018) and Drechsel and Tenreyro (2018). An important early contribution in this literature is Mendoza (1995).

¹⁰The findings in Schmitt-Grohé and Uribe (2018) suggest that terms of trade shocks only explain around a 10th of output variation in emerging economies. For a related study, see Aguirre (2011).

¹¹Note that in Drechsel and Tenreyro (2018), we also run an SVAR to guide the construction of our two sector open economy model, but we do not use the SVAR to study variance decompositions.

¹²The appendix to Drechsel and Tenreyro (2018) provides a formal illustration of the theoretical relation between interest-rate premia and access to borrowing. Min et al. (2003) document some more direct empirical evidence by showing that export earnings and better repayment capacity bring down yield spreads. In a model without commodities, Akinci (2017) generates a countercyclical country risk premium by introducing costly state verification frictions to the economy's firm sector.

¹³From 2006 the CFTC data can be broken down further with a separate category capturing "index traders" (or CITs). See for example Cheng and Xiong (2014) for a detailed discussion.

¹⁴A host of additional references are contained in the comprehensive survey of Cheng and Xiong (2014). While we do not provide review of existing work on the financialization of commodity markets beyond the discussion provided here, a few more important papers are worth pointing to. Acharya et al. (2013) also argue that financial investors' risk-bearing capacity may limit the degree of risk sharing differently over time. Sockin and Xiong (2015) show that futures prices are taken by producers as a signal of aggregate demand and adjust production accordingly. A lot of the important arguments are discussed in the literature that focuses on speculation in oil markets, e.g., Hamilton (2009), Kilian and Murphy (2014), Fattouh et al. (2012), Singleton (2014) or Juvenal and Petrella (2015). Inspired by the seminal work of Kilian (2009), a large literature has studied the sources of oil price shocks. Global demand shocks are generally found to be their key driver, with several studies highlighting the additional contribution financial speculation.

¹⁵In Section IV and in Appendix B we explore the implications of imperfect risk sharing in the model by examining the opposite extreme of financial autarky.

¹⁶See for example Rotemberg and Woodford (1999) or the discussion provided in Galí (2015). The employment subsidy equates the *natural* and the *efficient* level of output.

¹⁷Detailed discussion on this point is provided in the open economy NK literature, see for example Corsetti and Pesenti (2001) and Benigno and Benigno (2003).

¹⁸The more general case of the NK-SOE model is studied for example by De Paoli (2009).

¹⁹As we will show in more detail, the intuition is that while $\sigma = \eta = 1$ imply that domestic consumption demand responds 1-for-1 to changes in the terms of trade, the technological demand for resources coming from the commodity sector responds more than 1-for-1 to variation in the terms of trade.

²⁰Perfect risk sharing implies that the demand for foreign goods is a constant share of world output, while demand for domestic goods is a constant share of world output scaled by the real exchange rate. This can be seen from combining (9) and (10) with (14). This is particularly important to understand the consumption response in our model. More details will follow in the discussion of the results.

²¹For the details on the derivation of (16) see for example Woodford (2003b).

²²Since commodities are not consumed domestically, commodity prices do not have a direct effect on domestic inflation. See De Gregorio (2012) for a discussion of the rise in food and energy prices in the 2000s and the resulting repercussions on aggregate inflation measures.

²³For simplicity we assume that the loan is interest free and provided by foreigners. The working capital constraint can be thought of in the context of a within-period timing structure, by which at the beginning of the period, the expenditures necessary for production need to be financed with a loan which is repaid at the end of the period. The failure to repay allows lenders to seize commodity output. See also Jermann and Quadrini (2012) for a related discussion.

²⁴See also Shousha (2016) and Fernández, González, and Rodríguez (2018). DT have focused on the link between commodity prices and the intertemporal external debt position of the representative household. Here, we introduce an *intratemporal* working capital constraint in the commodity sector that is subject to a similar relation with international commodity prices. We make this choice to leave the intertemporal trade-off present in the GM framework unaltered. In light of our discussion on exchange rates, studying financial channels present in different margins of the NK-SOE framework is an important avenue for future research.

²⁵The appendix to DT provides a formal illustration of the theoretical relation between interest rate premia and access to borrowing. For the case of emerging-market bond spreads, Min et al. (2003) provide empirical evidence for such a channel, showing that export earnings and better repayment capacity bring down yield spreads. Their analysis includes corporate bond spreads.

²⁶FS emphasize that their model provides a benchmark mainly suitable for advanced commodity exporters such as Norway. We aim to enhance the framework's applicability to emerging and developing economies, where the transmission of commodity price shocks via borrowing conditions may be particularly important.

²⁷We recognize that there might be a tension between the assumption of perfect risk sharing in consumption across countries in the world economy and the presence of the working capital in the commodity sector. We choose to keep the risk-sharing assumption for tractability of the model and comparability with the results in GM and FS. In Section IV we also discuss the implications of relaxing the perfect risk sharing assumption and replacing it with financial autarky, which we do in Appendix B.

²⁸The difference between the binding and nonbinding case will be the effect of χ on the steady state magnitude of M_h and, importantly, on the strength of the effect of commodity price shocks on $M_{h,t}$. The conditions derived from the planner problem are otherwise unaffected.

²⁹In the absence of the commodity sector, when $s_{c,t}^e = 1$ and $s_{m,t}^e = 0$, the wedge collapses to 1.

³⁰It is of course conceivable that taxation is time-varying in a way that fiscal policy directly targets these inefficiencies. We explicitly investigate this in the discussion of our results in Section IV. Hevia and Nicolini (2013) provide a more detailed analysis in this direction.

³¹The normalization is satisfied by calibrating the steady state to ensure $T = 1$ satisfies (32).

³²If the borrowing constraint does not bind in steady state, the analogous expression for the efficient level of employment is given by

$$N_{ss}^e = \left(\frac{(1-\alpha)A_{h,ss}}{(1-\alpha)Y_{ss}^* + \frac{1}{1-\nu} \left(\nu \left[\frac{P_{c,ss}^*}{P_{ss}^*} \right] A_{c,ss} \right)^{\frac{1}{1-\nu}}} \right)^{\frac{1}{\phi}}$$

³³For compactness of notation in the log-linear model, we denote $\frac{\ln(P_{c,t}^* / P_{c,ss}^*)}{\ln(P_t^* / P_{ss}^*)}$ as $\hat{p}_{c,t}^*$ so that $\hat{p}_{c,t}^*$ represents exogenous percentage variation in the dollar price of commodities.

³⁴The calibration also involves the normalization some of some additional steady state values, such as the level of TFP in the two sectors.

³⁵Our environment would also allow studying TFP shocks in both sectors, that is, shocks to $\hat{a}_{c,t}$ and $\hat{a}_{p,t}$.

³⁶The model is solved with standard first-order perturbation techniques. When we vary χ further below, we adjust the model so that the steady state magnitudes remain unaffected.

³⁷Through the commodity sectors' effect on overproduction, the model captures in a stylized way the possibility of inefficient "Dutch disease" type reallocations (see the seminal contribution Corden and Neary 1982). In reality, reallocations toward the commodity sector can reduce investment in human capital and investment in research and innovation that could potentially lead to higher productivity growth in the industrial sector. A more recent literature also finds evidence that resource windfalls can lead to political instability and exacerbate the power of autocratic

regimes, which in turn lead to adverse economic consequences (see Caselli and Tesei (2016) and references therein).

³⁸The fact that the two inflation targets lie pretty close together in terms of the numerical welfare loss is in line with FS, who highlight that the relative performance of the CPI and the domestic inflation target is sensitive to the calibration of the parameter in the policy rule.

³⁹This also relates to the work of Eichenbaum et al. (2017) who study the predictability of inflation rates based on current exchange rates and highlight the importance of the monetary policy regime.

⁴⁰Leduc and Natal (2018) also study optimal monetary policy in a model with a financial channel. Their model contains an endogenous feedback loop between asset prices and borrowing conditions, but in a closed economy setting.

⁴¹Note that in practice the accumulation of reserves may reduce financial constraints and could thus be welfare improving. See Cabezas and De Gregorio (2019) for recent work on reserve accumulations.

⁴²This also means that consumption is not affected by the wealth effect coming from commodity profits. This is in line with the literature on the natural resource curse, which casts doubt on the premise that resource windfalls reach the general population, see Sachs and Warner (2001) and Caselli and Michaels (2013).

⁴³Financial autarky was previously explored in an important paper by Catao and Chang (2013), who also propose an NK-SOE model with commodities. Their framework incorporates imported intermediate inputs and implies that producer price index (PPI) targeting is the welfare dominant policy rule. This result is reinforced in the case of financial autarky relative to perfect risk sharing. See also Chang (2015) for a simplified version of this framework.

⁴⁴For a commodity price rise, the reallocation comes from a loosening in the borrowing constraint. This is inefficient because we also assume an employment subsidy to ensure an efficient steady state. Absent the subsidy, a relaxation in borrowing conditions would move the economy toward the social planner allocation. But if policymakers were to try systematically to offset inefficiently low average commodity output during booms, it would lead to undesirable increases in average inflation, analogous to the situation with the usual monopoly distortions.

⁴⁵In the general case studied in De Paoli (2009), lower exchange rate volatility is optimal when the substitutability between home and foreign goods is high. A rationalization purely based on the specification of preferences may still miss some of the potential trade-offs we allude to later.

⁴⁶A similar point has been made for example by Calvo and Reinhart (2002) and Cespedes et al. (2014). For a comprehensive classification of exchange rate regimes, see also Ilzetzi et al. (2017).

⁴⁷Note that this path of the subsidy can be calculated from efficient quantities and achieves full stabilization, so the results will look the same under any monetary policy rule.

⁴⁸See for example Cespedes and Velasco (2014) for a study on the pro-cyclicality of fiscal policy in commodity-driven economies.

⁴⁹Commodity prices appear to play a more prominent role in economic cycles in emerging economies than in advanced economies, while the financial friction that we incorporate captures a transmission channel via borrowing constraints that is particularly important for emerging and developing economies.

⁵⁰One specific definition is of annual inflation rates of at least 20% for five consecutive years (Harberger 1981). Hyperinflation, by contrast, was defined in the seminal paper by Cagan (1956) as price increases of more than 50% per month, or over 12,000% per year; or more conservatively, by Dornbusch et al. (1990) as an annualized rate of over 1,000% per year, persisting for several months.

⁵¹See Sargent (1983) for a discussion of the competing views.

⁵²See Gordon and King (1982), Ball (1994) and Fuhrer and Moore (1995) for empirical evidence of the costs of disinflations in advanced economies. For emerging economies, Reinhart and Végh (1994) find that GDP growth turns negative during a disinflation (although for exchange-rate based disinflations, this follows an initial increase in growth).

⁵³See, for example, Kozicki and Tinsley (2002), Sbordone (2007) and Whelan (2007) for recent discussions.

⁵⁴Others still have explored departures from rationality, which in some cases introduce more inertia into the inflation process (Gabaix 2016; García-Schmidt and Woodford 2019; Farhi and Werning 2019).

⁵⁵See Erceg and Levin (2003) for an example of a model where agents' rational learning about the true objective of an imperfectly credible monetary policymaker increases the output costs of a disinflation.

⁵⁶This insight is also in line with much of the recent literature on imperfect information in monetary models. In models of sticky information (Mankiw and Reis 2002) and imperfect common knowledge (Woodford 2003a; Nimark 2008), expectations are typically more inertial.

⁵⁷This point is highlighted by Sargent (1983) in the case of the U.K. and Goodfriend and King (2005) for the United States.

⁵⁸Sbordone (2007) highlights that some empirical estimates may fail to distinguish between intrinsic inflation persistence and changes in trend inflation, where the latter can be due to the policymaker's implicit or explicit inflation target.

⁵⁹See also Ascari et al. (2018) and Phaneuf et al. (2018) for recent applications.

⁶⁰For example, in the calibrated model presented in Ascari and Sbordone (2014), the maximum feasible rate of steady-state inflation is only 14.1%.

⁶¹See Kozicki and Tinsley (2002) for a discussion.

⁶²A recent study in the RBC-SOE literature that highlights the role of wage rigidities for exchange rate policies, but also does not explicitly focus on inflation inertia, is Schmitt-Grohé and Uribe (2016).

⁶³Detailed descriptions of this reform in the academic literature are provided by Heymann (1987), Canavese and Di Tella (1988) and Dornbusch and de Pablo (1990). See also Machinea (1990) for a retrospective.

⁶⁴A detailed description of the compact is given in Santaella and Vela (1996).

⁶⁵Edwards (1998) argues that the wider reform program had only limited success in terms of improving macroeconomic performance.

⁶⁶For a selection of the many competing analyses of the crisis, see Calvo and Mendoza (1996), Sachs et al. (1996) and Edwards and Savastano (1998).

⁶⁷See Morandé (2002), Schmidt-Hebbel and Werner (2002) and De Gregorio (2004) for detailed discussions of inflation targeting in Chile.

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